Effective Interaction Techniques in Information-Rich Virtual Environments

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Abstract

The goal of the proposed research is to examine an effective way of integrating symbolic data, such as text, video, audio, two-dimensional images, and other abstract data, into a virtual environment and to investigate the different interaction techniques. The resulting information-rich virtual environments may be ultimately more useful than traditional virtual environment. To reach our proposed goal, we must understand interaction techniques at a low level and standardize the measurement of performance. Two questions that we intend to answer are: (1) how to embed information in a virtual environment and (2) how to access information within a three-dimensional virtual world. We plan to develop guidelines on the basis of experimental results. Two controlled studies, in the areas of architectural walkthrough and biomedical training virtual environment will be performed. We hypothesize that these two applications will reflect principles and design guidelines for other general applications.

1. Two problem scenarios

Immersive virtual environments (VEs) have potential in many application areas, from architectural walkthrough, medical data visualization, to training and education. However, many systems exhibit usability and interaction problems as the environments become more complex. To illustrate these problems I have listed two problem scenarios.

1.1 An architectural walkthrough problem scenario

Problem scenario 1 (Figure 1): Mike is a professional designer in architecture. He views architecture in physical form – bricks, mortar, or price while selling and designing a house. In a virtual environment, he finds that the virtual world is not different from the physical world except that he can use a joystick or other navigation device to fly around. However, with such passive visualization, it is difficult for Mike to explain to his customers what the room looks like while customizing a room, for example, color and material change, price checking, etc.

This scenario describes Mike's experience as a professional designer in architecture. The virtual environment being used as a tool for simulation becomes reality for the user. However, we believe that the power of the virtual environment should not lay only in complete reality but be an extension of reality. A virtual environment should create a world, an information-rich virtual reality, that *enhances* the physical, cognitive, and perceptual capabilities of the user, allowing them to do things that are impossible in the real world [Bowman & Hodges 1999]. For example, we can offer an in-hand menu that allows Mike to investigate the current price of the house or check specific materials of the wall. We also like to see that virtual environment and information visualization are mutually supportive, which means that the virtual world will reflect the changes of the related symbolic information in real time.

1.2 A medical VE training scenario

Problem scenario 2 (Figure 2): Lisa is a first year medical school student who is taking an anatomy course. The professor presents a state-of-the-art virtual environment system for Visible Human dataset visualization and teaches the structure of the human body. Within such an environment, one can rotate the model, change the cutting plane, and move the position of the image with six degrees-of-freedom. The professor also gives a text document that describes the image shown in class. However, Lisa does not understand the correspondence between the given textual information and the image of the head model.

Figure 1 Architecture walkthrough - top view of a house structure used in the virtual reality of a construction project at Virginia Tech.

Notice that this environment does not provide any textual information about the building structure.

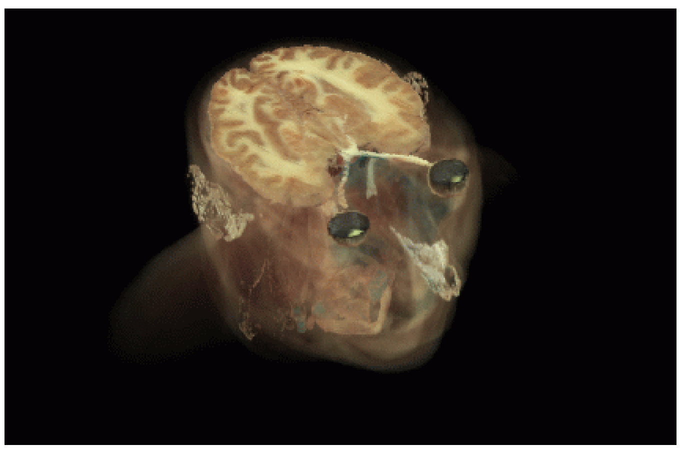

Figure 2 A human head build on SGI Onyx2 using OpenGL Volumizer™

Notice that in this VE, we don't have any additional information presented to help understand the names of the parts (e.g., brain, eyeball, nerve) of the head dataset.

This scenario describes Lisa's experience in her anatomy class. It is known that a volumetric virtual environment provides the ability to help people interact with volumetric Visible Human dataset. The three-dimensional (3-D) scene, built from a magnetic resonance image (MRI) enables a user to interact with the image in real time and explore the interior in a natural and intuitive way. However, going back to Lisa's experience, even with such a 3-D model, she still has a difficult time understanding the relation between the specific name in textual format and the 3-D environment. The difficulty can be partly attributed to the lack of the system to include textual information "inside" the virtual environment.

These illustrated examples present only two of many design scenarios in current VE research. Our solution to Mike and Lisa's problem is to build an information-rich virtual environment (IRVE) that integrates symbolic and scientific data into one-space. These environments consist of not only 3-D graphics and other spatial data but also related symbolic or abstract information. We can also help Lisa understand anatomy by providing textual information labeling the details of the anatomy structure.

The questions are: how and where to place information? What information should be displayed? How to access information? How are we going to architect the system? And how to display the accessed information within a 3-D space? We may also consider that IRVE might affect the user's sense of presence and other human factor issues. Finally, how must interaction change within an IRVE?

This proposal will address the development of guidelines to aid in building useful and usable IRVEs. Particularly, we investigate the interaction and interface issues that synthesize both existing and novel interaction techniques that fit the task of information gathering. The organization of this proposal is as follows. In this section, we have introduced the concept of the information-rich virtual environment, motivated by the need to solve two problem scenarios. Section 2, *Introduction*, presents a look at previous work that has influenced ours or provided background to our current research. Section 3, *Research objective*, emphasizes the scope of this proposed research area. Section 4, *Methodologies*, discusses the idea of our design with task analysis of the difference between IRVEs and traditional VEs. We then present the possible experiment setup. We conclude in Section 5, with milestones and the possible contributions of this work.

2. Introduction

Virtual environments (VEs) offer a new human-computer interaction paradigm in which users are no longer simply external observers of images on a computer screen, but are actively interacting with a computer-generated three-dimensional virtual world. We have crossed the stage when Bolter and co-authors [1995] stated that the main problem of integrating symbolic and perceptual information is due to hardware limitations. Today's state-of-the-art hardware components have become powerful enough to support dynamic rendering of 3-D scenes at a real-time refresh rate on high-resolution display systems. The evolution of effective software tools, such as those for graphic rendering, data preparing, lighting and shading, allows the developer to build an environment, which could be anything from 3-D objects to an abstract database. We have already seen that VEs are practically used in a broad range of fields from industrial design, data visualization, and training to educations.

In the physical world, an object is not only represented by "3-D models", but also by a type of symbolic information. Symbolic information, often relevant to the research area of information visualization, is concerned with abstract concepts such as prices, stress, baseball scores, materials, and so on. The data could be either numerical, ordinal (naturally ordered), or categorical (no order) format. Usually, abstract properties of data are mapped into perceptual qualities, such as size, shape, color, motion, and relationships between pieces of data that are represented spatially. The resulting 3-D visualization can reveal trends in the data due to patterns - such visual and spatial groupings that are not obvious from the original dataset.

To make a virtual environment more useful, we think that 3-D spatial model alone is not enough. Symbolic information is not only important, but will enhance the overall environment. Therefore, we propose developing information-rich virtual environment, where information is built "inside" the virtual world. Here, information could be any non-spatial information, including text, video, audio, two-dimensional images, and other abstract data. The ultimate goal of adding this information, thereby, is to make VE even more powerful as a tool to reproduce perceptual experience. Within an IRVE, users can interact not only with the spatial data, but also with the non-spatial data presented in various formats.

Only few virtual environments display symbolic information besides spatial information. One previous work in the context of building an IRVE is an application called the virtual venue [Bowman, Hodges, & Bolter 1998]. In this environment, users can navigate along a predefined path and obtain various types of information regarding the design and use of the venue and the sports of swimming and diving. Bowman and co-authors used a hand-menu and a 'pen and tablet' metaphors to interact with the IRVE. The usability study revealed that information visualization offers opportunities for effective information retrieval.

The authors then continued their research by comparing the information-rich virtual environment with traditional classroom teaching [Bowman et al. 1999]. In their virtual zoo exhibit, students can explore an accurate model of the gorilla habitat at Zoo Atlanta and access information related to the design of the exhibit. Although no statistically significant differences were found, the results indicated that students had higher test scores in a VE than those who only attended a lecture.

As a continued effort in this line of research, we investigate the interaction techniques of two other IRVEs presented in the first section: architectural walkthrough and biomedical training IRVEs. Most importantly, we intend to understand interaction techniques at a low level, derive guidelines, and standardize the measurement of performance.

IRVEs, comparing to traditional VEs, become increasingly more complex in visualizing vast arrays of data. Traditional VE has the mental overhead of having to remember the name of the objects within the world. On the other hand, IRVE reduces mental overhead, but may increase clutter in the virtual world due to the need to display symbolic data. We may risk the feeling of presence. The design of an IRVE requires an environment to be meaningful and understandable by users without losing usability. Therefore, a non-architectural approach to the organization of information in an IRVE can be a liability.

3. Research objective

The proposed work will answer only two questions, i.e., how to embed information and how to access information within an IRVE. Our experiments mainly focus on the investigation of navigation and manipulation and selection techniques within the context of two applications: an architectural walkthrough and a biomedical IRVE. We are interested in investigating how to make symbolic data visible and easy to manipulate, using an immersive VE as information space and how the user can easily and efficiently access the information while the abstract information is integrated into the environment. We also believe that the IRVE should create worlds that are simple for the user and natural to the task.

Based on previous experimentation and experience, we feel that development of a useful and usable environment requires optimization of three basic interactions: navigation, selection and manipulation, and system control. System control is usually implemented as selection, and we will talk about it with selection techniques. We will also examine the usability and user performance and aim at producing guideline for creating a mapping between an application's requirement and an information rich virtual environment. The purpose is to improve user task performance and system usability.

4. Methodology

4.1 Choosing applications

We will present two experiments as testbed, one is an architectural walkthrough project, and the other is biomedical data visualization. The experiments will cover at least techniques for the common VE tasks of general 3-D interactions. We expect that such specific design choices will show principles and further offer guidelines for general applications. We also predict there will be other specific applications that can be addressed by these design guidelines.

We take these two systems as testbed for two reasons. Firstly, we want to separate the research of the two interaction techniques: navigation, and selection and manipulation. The interaction within an architectural walkthrough experiment is mostly oriented for testing navigation since the space is in medium size. We tend to provide different views of the building and to facilitate heavy navigation. On the other hand, the visible Human dataset from the National Library of Medicine (NLM), as scientific data, forms an experiment for manipulation and selection tasks, because the data can be displayed in life-size and fits into the size of the VE displays. Navigation in this case is generally not required. Secondly, the author's advisor has been working on the construction data visualization for a long time; the author herself has experience in Visible Human Dataset Visualization. Although we focus on interaction in the context of these two applications, we do intend to develop interaction and interface components that will apply to other kinds of virtual models as well. Our goal is to present information in greater depth.

4.2 Analysis of navigation techniques

Navigation, as a way to move the user's viewpoint and body towards specific places in a virtual world, includes two subtasks: wayfinding and travel. Travel is harder in a VE than in a physical world because it has fewer constraints. For example, if we transit from one location to another in the physical (geographical) world, we may have to walk through doorways and gates to enter another room. A "neighbor" in this space is accessed as a function of distance. However, such constraints do not have to exist in a virtual environment. A user can fly to any point-of-interest. For example, user can point to any place on the mini-world and be there immediately in a map-type interaction technique.

Additionally, the peripheral information, in the physical world, also offers references, which reduces cognitive load. Without the constraints of the physical world, the user is left with few cues of how to explore and understand the virtual world. Therefore, wayfinding, the dynamic process of using our spatial ability and navigational awareness of an environment to reach a desired destination, gets harder within a VE during travel.

Such circumstances get even worse in an IRVE, where constraints are reduced even more. Users can navigate within an environment not only based on a geometrical map (we call this *spatial neighbor*), but also on the symbolic information presented (we call this *symbolic neighbor*). Within an IRVE, user may navigate towards the points of information (symbolic neighbor), which can be organized and structured as hierarchical, linear, radial, web-like, or clustered object, or a combination of these. For example, we can hyperlink to connect space, shown as textual information, and then fly around by pointing metaphor. Under such circumstances, users are most likely to get lost since more freedom is available.

We think the development of and reference to a cognitive map can partly solve this problem. A cognitive map is the means by which information about the relative location and attributes of one's environment is acquired, coded, stored, recalled, and decoded. So it is anticipated that a cognitive map or other format, which can show the spatial information, is particularly important while the environment is changing. We can also articulate the change besides visually presenting the change, e.g., using audio display.

4.3 Analysis of manipulation and selection and system control techniques

In the virtual world, we must have virtual 'touch' before selection and manipulation. In a traditional VE application, the user who is immersed within a VE has a natural inquisitive temptation to reach out and touch 3-D virtual objects. Including a virtual representation is a classic way to address this problem [Poupyrev, Tomokazu, & Weghorst 1998; Pierce, Stearns, & Pausch 1999]. The virtual representation is *spatially* registered with a physical input device which provides sensory feedback. System control, which is usually about selection, is useful for changing the state of the application and the mode of interaction or parameter. Menu interaction is a popular way to implement it.

In general, positioning an object in a virtual environment is difficult as six independent variables must be controlled: three for positioning and three for orientation. Metaphors are usually applied to minimize the user's cognitive load and improve task performance during VE exposure. Examples include virtual hand metaphor, go-go, silk cursor, flashing light, HOMER, put-that-there, WIM, virtual menu, etc. When implementing object selection, it is essential to incorporate adequate feedback. The manipulation has also been well addressed by the literature on 3-D desktop environment. Examples include cone-tree, perspective wall, themescapes, and point-of-interest navigation [Card, Mackinlay, & Shneiderman 1999] from the point of view of information visualization.

The difference for manipulation and selection and system control within an IRVE from a traditional VE is that 2-D selection might be needed more frequently. Since the menu system is also the most familiar 2-D computer interface that we know of, extending it in the IRVE might be beneficial. Almost all previous work uses the virtual menu or widget metaphor as a way to perform interaction. In IRVEs, the frequency of using 2-D menus is much higher than in traditional VE. We not only interact with 3-D spatial information, but interact with 2-D menus as well.

4.4 Design

We intend to design the environment (IRVE) based on single or the combination of existing interaction techniques, and then may come with new interaction techniques since IRVE presents a different interface from traditional VE. Our interface and interaction design would obey the phiolosphies of 3-D interaction design presented by Bowman and co-authors [2001]. After a literature review, we found that most existing systems use a menu or widgets as a way to present symbolic information.

Our design of the menu and widgets system will be mainly influenced by Feiner and his coauthor's works [Feiner et al. 1993]. They built 2-D windows for a 3-D augmented reality environment which provides a transparent window display relative to the user's head and body. This system provides three kinds of windows: object-fixed, view-fixed, and world-fixed. The object-fixed windows are attached at one or more virtual object in the world, and view-fixed windows are positioned at a fixed location relative to user. World-fixed windows are fixed locations or objects which are invokable by the user.

This design adds constraints to the virutal menus and limits the manipulation to a certain degrees of freedom. Therefore, it allows a user to perform any form of precise manipulation. We also think previous work about the menus and widgets can fit into this category although they might be presented in 1-D, 2-D, or 3-D and in other varieties.

For embeding information in our application, we use three types of displays: object-fixed, user-fixed, and world-fixed. But the meaning of these terms are slightly changed from Feiner's defination. Object-fixed display means the informaion is displayed at fixed location to an related object. User-fixed display is user-followed. User can activate or de-activate it at any time. World-fixed display refers to those that are displayed at a fixed position within the world.

For embedding symbolic information into a virtual world, our hypotheses are that:

(1) The symbolic information can be embedded into an IRVE as a world-fixed display, if the information controls the global state of the enviornment. For example, a navigation menu, which may include fly, move in X, move in Y, move in Z sub-menu;

(2) The symbolic information can be embeded into an IRVE as a user-fixed display, if the information controls or displays the local state of an object within the environment, and displaying the information will not block the user's view or affect interaction. For example, changing the clipping plane for the application of a specific position of the human body.

(3) The symbolic information can be embedded into an IRVE as a object-fixed display, if the information controls or displays the local state of an object within the environment, and dipslaying it will block the user's view or affect interaction. For example, the menu used in the architecutal walkthrough environment that controls wall material, color, size, price of a specific object in the 3-D world. This

variable provides details in the information visualization context.

We do notice that there are overlaps among such displays. Tradeoffs need to be considered while designing a virtual environment. We are also interested in embedding as much information as possible and keeping the interface useful and usable while avoiding clustering.

For accessing symbolic information related to navigation task, the possible hypotheses could be:

(1) If the application is spatially dominant, navigation should be based on spatial neighbors.

(2) On the contrary, if user's task is to investigate the symbolic data, the navigation should be based on symbolic neighbors.

4.5 Experiment

Evaluations of IRVE interactions will be performed by controlled experiments. We will define a series of tasks that could be used as a definitive guideline for conducting such studies. The controlled experiments for embedding information are set in two IRVEs. The task for the manipulation and selection testing, if a menu system is used, will be much more similar to the work by Kim and co-authors [2000], except for the fact that our environments are set up for particular applications. During the experiments, we expect to collect both quantitative data, such as the task completion time, accuracy, error rates, spatial orientation (during travel) and expressiveness of manipulation, and qualitative data, such as ease of use, ease of learning, etc., by using questionnaires. By analyzing this data, we hope to derive guidelines and principles for interaction design in an IRVE.

5. Milestones and Potential Contribution

The main milestones of this project would be:

(1) Form hypotheses that would include other media in an IRVE, besides text information.

(2) Build a prototype environment based on 3-D construction model and information, and then perform usability evaluations. Based on these evaluation results, we need to build two experiments.

(3) List the set of common tasks and form corresponding metrics to measure these tasks.

(4) Analyze and postulate general guidelines.

The main contribution of this project would be:

(1) The generation of a set of guidelines and principles based on the tasks to be performed which lends VEs a possibility of presenting more information that enhances the understanding of IRVEs. We believe that IRVEs have the potential to be applied to any area from education to design.

(2) The building of two experiments, construction walkthrough and Visible Human IRVEs, to be used for the experiment and hypotheses testing. They are among the main focuses of the current VE applications.

(3) The potential use of the guidelines and principles by other applications.

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