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Maxwell J. Wells

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Human Interface Technology Laboratory
University of Washington
FJ-15 Fluke Hall
Seattle, WA 98195

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The report documents the first year of work on a four-year project titled "Communicating Situation Awareness in Virtual Environments." Included in the report are references to the fifteen papers that were produced, and descriptions of eleven of the research projects that were started. In addition, there is a description of a workshop on virtual reality which was hosted at the University of Washington, and which was attended by 10 federal labs. Other work performed during the period and described in the report includes the conceptual and software development of a virtual world (the "Towering Inferno") for performing experimental manipulations, and the detailed design of a virtual reality testbed. As a part of the infrastructure for this line of research, a knowledge base was also developed. This knowledge base is structured to be compatible with ongoing efforts for electronic storage and retrieval of information. Ten objectives of the research effort are detailed. The report provides substantive evidence that the project is on schedule, and making effective use of the available facilities and support.

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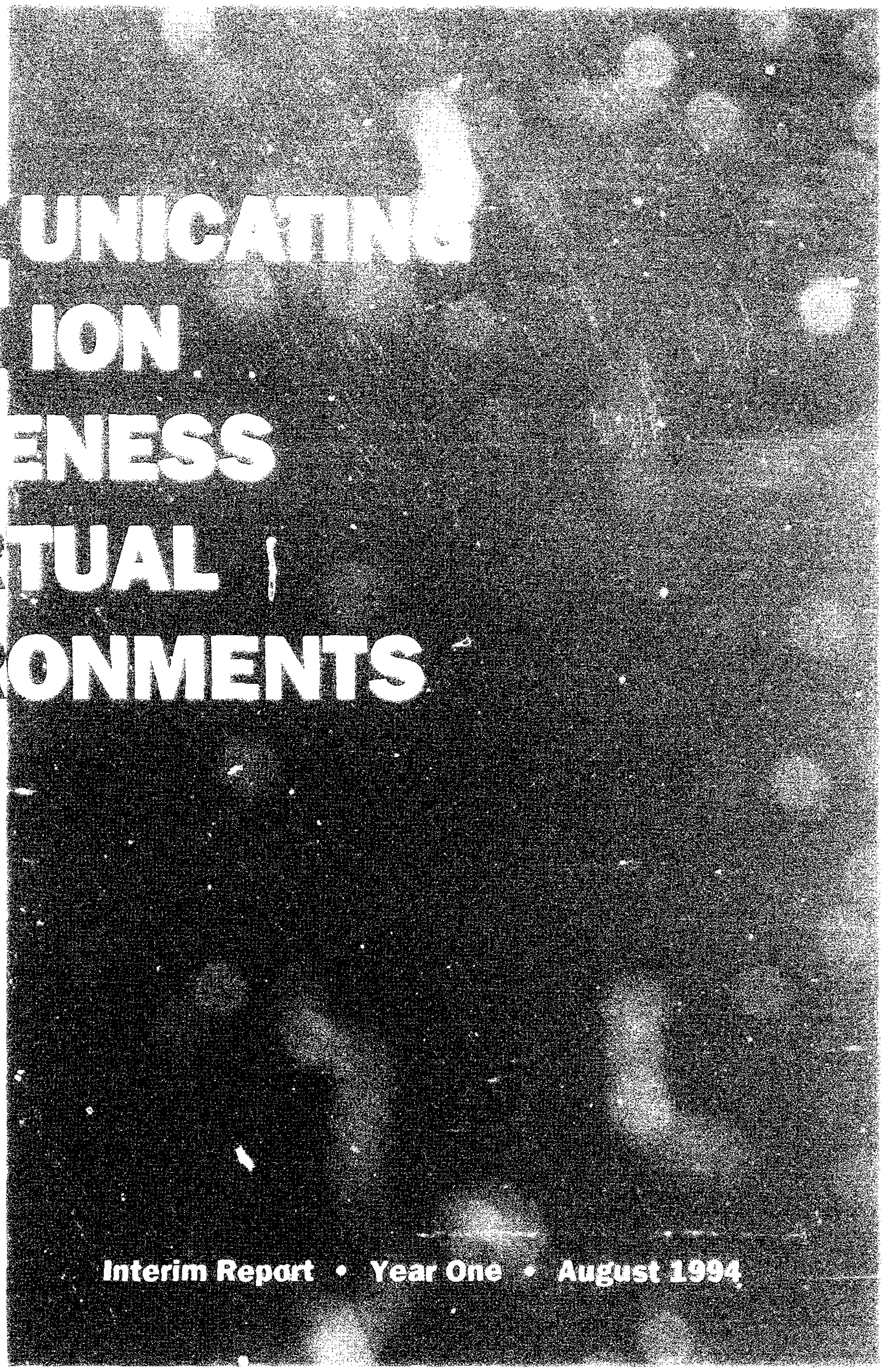
COMMUNICATING SITUATION AWARENESS IN VIRTUAL ENVIRONMENTS



Interim Report • Year One • August 1994

HUMAN INTERFACE
TECHNOLOGY LABORATORY
Washington Technology Center
University of Washington, FJ-15
Seattle, WA 98195
206.685.3215

COMMUNICATING SITUATION AWARENESS

IN

VIRTUAL ENVIRONMENTS

Year 1 interim report
for the period 5.15.93 to 5.14.94

Submitted to the AFOSR

by

Human Interface Technology Laboratory
Washington Technology Center
Fluke Hall, FJ-15
University of Washington
Seattle, WA 98195

Contents

Abstract

The report documents the first year of work on a four-year project titled "Communicating situation awareness in virtual environments." Included in the report are references to the fifteen papers that were produced, and descriptions of eleven of the research projects that were started. In addition, there is a description of a workshop on virtual reality which was hosted at the University of Washington, and which was attended by 10 federal labs. Other work performed during the period and described in the report includes the conceptual and software development of a virtual world (the "Towering Inferno") for performing experimental manipulations, and the detailed design of a virtual reality testbed. As a part of the infrastructure for this line of research, a knowledge base was also developed. This knowledge base is structured to be compatible with ongoing nationwide efforts for electronic storage and retrieval of information. Ten objectives of the research effort are detailed. The report provides substantive evidence that the project is on schedule, and making effective use of the available facilities and support.

1.0 List of objectives of the research effort

Over the period of the grant, it is our objective to address a number of questions which are fundamental to communicating situation awareness in virtual environments. These are listed below as bulleted items, and are treated in more detail in later paragraphs.

- How do we ensure the optimum coupling of the information medium to the human?
- Are there context and task impacts on perceptual requirements?
- How should we combine information elements into a "world" construct which rapidly communicates situation awareness?
- What are the combinatorial rules which optimize this communication?
- What is the relation between "presence" and display effectiveness?
- How do we measure situation awareness?
- What are the components of situation awareness?
- How do we measure spatial awareness?
- What is the use of mental models? Why compare them with real-time information input?
- Can we dynamically adapt the interface to match the user?

1.1 How do we ensure the optimum coupling of the information medium to the human?

It is necessary and important to make a distinction between the medium and the message. The medium refers to the virtual interface hardware which is used to convey appropriate visual and acoustic stimuli to the human to create a virtual environment. The message refers to organization of the information elements, and their embodiment into a world construct or archetype. One of our objectives is to insure that, at a signal level, we achieve optimum coupling of the information medium to the human. This will require investigating elements such as image quality, image stability, and the spatial and temporal coherency of multi-modal presentations, to determine both the minimum and optimum requirements for coupling.

1.2 Are there context and task impacts on perceptual requirements?

There are stories of pilots who, in the heat of battle, are impervious to a range of visual and auditory stimuli. This can have major detrimental effects on situation awareness and survivability. It remains to be investigated whether this type of perceptual gain control is context and task specific, and whether there are techniques for reopening the channel of communication under these conditions.

1.3 How should we combine information elements into a "world" construct which rapidly communicates situational awareness?

It is our contention that the formulation, by the operator, of a world construct or archetype, is essential for the development of situational awareness. Furthermore, it is our hypothesis that the manner in which these elements are combined and presented may affect the formulation of this archetype. We intend to test this hypothesis.

1.4 What are the combinatorial rules which optimize this communication?

By performing experimental investigations into the way in which information elements are combined, we propose to formulate design guidance for optimizing the effects of these combinations. It is planned that these combinatorial rules will provide guidance for multi-sensory inputs, as well as for combinations of elements in one modality.

1.5 What is the relation between "presence" and display effectiveness?

Presence maybe a product of the imagination. It is the experience of being there, or conversely, of something being here. The experience can be aided by suitable props, including displays, and other VR technology. The interest in presence stems from the contention that with it, there are certain performance enhancements. Therefore, a starting point for work in this area must be a test of this hypothesis. Other questions which will be addressed include: Can presence be operationally defined? What are the prerequisites for presence? How can presence be measured? What are the contributions of the medium and the message?

1.6 How do we measure situation awareness?

Situation awareness has been defined with minor variations by many authors, including Sarter and Woods (1991), Endsley (1988), Fracker (1991), Tolk and Keether (1982), McKinnon (1986), and Whitaker and Klein (1988). A consensus definition would be that situation awareness refers to an understanding of the current state of the subject's environment, together with an ability to predict changes to the environment.

Techniques for measuring it include having subjects respond to questions about the state of their environment (Endsley, 1987, 1988a), and looking at responses to specific events (Fracker, 1991). Other authors have explored the use of a techniques which assess the dynamic aspects of situational awareness (Sarter and Woods, 1991). We intend to use a combination of the techniques, and others, to address the issue.

Endsley,M.R. "Design and Evaluation for Situation Awareness Enhancement", *Proceedings of the Human Factors Society* -- 32nd Annual Meeting -- 1988.

Endsley, M.R. "SAGAT: A Methodology for the Measurement of Situation Awareness," *Northrop Technical Report:* NOR DOC 87-83, August 1987.

Endsley, M.R. "The Functioning and Evaluation of Pilot Situation Awareness," *Northrop Technical Report:* NOR DOC 88-30, April 1988a.

Fracker, M.L. Measures of Situation Awareness: An Experimental Evaluation (U)", AL-TR-1991-0127.

Tolk, J.D., and Keether, G.A. (1982). Advanced medium-range air-to-air missile (AMRAAM) operational evaluation (OUE) final report (U). Air Force Test and Evaluation Center, Kirtland Air Force Base, NM.

McKinnon, F.B. (ed.). (1986). Final report of the intraflight command, control, and communications symposium (U). 57th Fighter Weapons Wing, Nellis Air Force Base, NV.

Sarter, N.B., and Woods, D.D., (1991). Situation awareness: A critical but ill-defined phenomenon. *The International Journal of Aviation Psychology, 1(1),* 45-57.

Whitaker, L.A., and Klein, G.A. (1988). Situation awareness in the virtual world: Situation assessment report. *Proceedings of the 11th Symposium of Psychology in the Department of Defense*, April.

1.7 What are the components of situation awareness?

In our proposal to the AFOSR we proposed a model of situation awareness which included the components of: spatial awareness factors (geometry), state awareness factors (status), and situation awareness factors (problem solving). It is our intention to refine this model further and to explore some of the components, and their relative contributions to situation awareness.

1.8 How do we measure spatial awareness?

Spatial Awareness is a major component of Situational Awareness. Therefore, any interface which strives to communicate situational awareness, must also communicate spatial awareness (Endsley, 1988). Spatial awareness is manifested as the ability to move through an environment efficiently and locate items or areas. Attaining spatial awareness allows one to make transformations on mental representations of an area so as to view and recognize it from different perspectives. The components involved in spatial awareness are spatial orientation, spatial visualization and understanding spatial relationships (Lohman, 1979). Spatial orientation also allows mental manipulation of an object using oneself for reference. Spatial visualization goes further in that the person can manipulate the relationships within an object (Newcombe, 1982). The third component involves understanding the spatial relationships between oneself and the environment, and between two objects. The perceptions are influenced by displays of the world, field of view and the amount of experience in the environment (Andre, Wickens, Moorman & Boschelli, 1991). Experience can be of an egocentric and/or exocentric manner.

There are a number of methods for measuring spatial awareness. These include target replacement metrics (Wells, Venturino & Osgood, 1988), cued target position discrimination (Palmer, 1990), distance estimation (Euclidean and shortest path) between two landmarks, and directional pointing (Sholl, 1987). Also, there are metrics from the domain of ecological psychology which may be of benefit. We intend to explore these metrics, and develop our own.

References:

Andre, A.D., Wickens, C.D., Moorman, L., & Boschelli, M.M. (1991). Display formatting techniques for improving situation awareness in the aircraft cockpit. *International Journal of Aviation Psychology.*

Endsley, M.R., (1988). Design and evaluation for situation awareness enhancement. *Proceedings of the Human Factors Society --32nd Annual Meeting.*

Lohman, D.F. (1979). Spatial Ability: Review and re-analysis of the correlational literature. Stanford University Technical Report 8. Cited in Infield, S.E. (1991). An investigation into the relationship between navigation skill and spatial abilities. *Doctoral Dissertation.* University of Washington.

Newcombe, N. (1982). Sex-related differences in spatial ability: Problems and gaps in current approaches. In Potega, M. (Ed.) Spatial Abilities Development and Physiological Foundations. 223-250. New York: Academic Press.

Palmer, J. (1990). Attentional limits on the perception and memory of visual information. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 332-350.

Sholl, M.J. (1987). Cognitive maps as orienting schemata. *Cognition, 4,* 615-628.

Wells, M.J., Venturino, M., & Osgood, R.K. (1989). The effect of field-of-view size on performance at a simple simulator air-to-air mission. *Proceedings of SPIE, Helmet-Mounted Display., 1116* , 126-137.

1.9 What is the use of mental models? Why compare them with real-time information input?

A mental model is the organization of knowledge about the environment, a specific system, or other things with which people interact (Norman, 1988). It forms the basis for understanding a system and predicting its future behavior (Wickens,1992). People form mental models through experiences, training, or instructions.

Mental models are not always correct representations of systems or environments. However, when they are correct, mental models can contribute to complex problem solving. It has been found that a person who learns a system operation with the use of a mental model is able to solve a novel problem, whereas those who learned with procedural instructions are not able to do so (Wickens, 1992). An accurate mental model of a system can be beneficial because it provides the user with knowledge that is useful when other leaned procedures fail. We are interested in investigating mental models because of their impact on situation awareness.

In using virtual reality technology to improve situation awareness, it is necessary to consider the relationship between mental models and information inputs. Real-time information represents the dynamic state of some parts of the system. There are three representations which must be considered when an interface is designed (Wickens, 1992):

1) The physical system
2) The internal representation
3) The interface between the above two

It is important to maintain a high degree of compatibility among these three representations so that information inputs can be compatible with the operator's information processing needs, or mental models of the system. Without such compatibility, longer information processing is required, or in the worst case, errors result. In a complex and dynamic environment, it is especially crucial to have compatibility between information inputs and mental models to allow accurate and quick responses from users.

Norman, D.A. (1988). *The Psychology of Everyday Things.* New York: Harper & Row.

Wickens, C.D. (1992). *Engineering Psychology and Human Performance* (2nd Ed.). Harper Collins Publishers.

1.10 Can we dynamically adapt the interface to match the user?

One of the attributes of an ideal interface would be the ability to dynamically adapt to the user. Such an interface may make it possible, for example, to provide the optimum clustering of state and spatial information during a mission segment which required the user to switch from an offensive to a defensive mode of operation. In order for this to occur, it is necessary to measure the user's requirements, unobtrusively if possible, as well know what to do with this information. We intend to investigate techniques for measuring user state. In combination with the knowledge gained from our explorations into display effectiveness, and coupling of the human to the medium, we intend to develop methods of matching the interface to the user.

2.0 Status of the research effort.

2.1 Research efforts underway

The AFOSR funding is currently being used to support 11 research studies. The titles of these efforts are listed below, and descriptions of the goals and research plans are included in subsequent sections.

2.1.1 List of research efforts

- Relationship Between Presence and Attentional Resources in Virtual Environments.
- Increasing Spatial Awareness in Exocentric Displays
- Effect of a Virtual Body on Spatial Awareness
- Effects of Spatialized Sound on Presence and Performance Within Virtual Environments
- Facial Expression Exhibition in Human Computer Interaction
- Subjective Measures of Presence
- Memory for virtual experiences
- Virtual Reality Monitoring
- Measuring Presence in Terms of Subjective Reference Frames
- Navigation and Wayfinding in VR: Finding the Proper Navigational Tools and Cues to Build Navigational Awareness
- Effective Information Presentation to Facilitate Decision Making Under Uncertainty

2.1.2 Relationship Between Presence and Attentional Resources in Virtual Environments.

Ove L. Bjorneseth (supervised by Woody Barfield)

The purpose of the research is to discover how combinations of different sensory modalities compete for attentional resources within the real world and virtual environments and how presence is influenced by the allocation of attentional resources.

It is well known that people have difficulties in performing multiple tasks at the same time. This arises from the fact that people have a limited amount of attentional resources. In other words, people can pay attention to only so much information at the same time. The concept of workload is well investigated and closely tied to attentional resources. It is reasonable to assume that a similar relationship exists between workload and presence. That is, as attentional resources are allocated more-and-more to virtual stimuli, presence for virtual stimuli should increase.

Independent variables in this research will focus on different types of sensory information (visual, auditory, tactile and kinesthetic), together with display variables (FOV, resolution and frame rate). Dependent variables are task performances and subjective questionnaires in addition to physical measures (EEG, pulse, blood pressure and skin conductivity).

Currently, a total immersive testbed is under development in the Laboratory for Interactive Computer Graphics and Human Factors that will make it possible to move stimuli between the real and the virtual environment.

2.1.3 Increasing Spatial Awareness in Exocentric Displays
Gina B. Crvarich (supervised by Suzanne Weghorst)

Introduction
Spatial awareness is a key component of situation awareness. Within virtual environments, it is generally argued that as the fidelity of the sensory input to a participant increases, the sense of presence and possibly of situation awareness will also increase. This project will evaluate how virtual environments can increase one's spatial and thus situation awareness.

Goal: Maximize the perceptual fidelity of 3D spatial displays by manipulating a range of computer generated depth cues.

From an Exocentric Point of View
A controller is an outside participant in a specific mission who needs to rapidly assess a critical situation and then communicate information to an inside participant. It has been reported that an exocentric display (god's-eye-view frame of reference) is superior to an egocentric display for developing an accurate mental model of a flight environment formed during a mission. This project will use an exocentric display to facilitate a controller's spatial understanding of a mission environment.

Computer Graphics Displays
In the real world, we use a variety of depth cues to recognize and visualize relative spatial locations of objects. Real world depth cues can be artificially created via specific characteristics of computer graphic displays. The following is a partial list of depth cues and how they are recreated within computer graphic systems:

Real World Cue	**Computer Graphics Cue**
Monocular Cues	
linear perspective	perspective projection
texture gradient	varying texture maps
motion parallax	motion tracking
Kinetic Depth Effect	rotational displays
Binocular Cues	
stereopsis	stereoscopic displays

The effective use of computer graphic display technology is needed in order to create useful exocentric displays. The creation of each depth cue is computationally expensive, thus only depth cues essential to increased spatial awareness should be used. Parameters of an effective exocentric display will be determined by varying the computer graphic cues listed above.

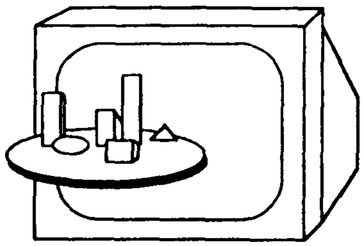
Experimental Tasks
The actual experimental tasks to measure a controller's spatial awareness are under development. An area currently under consideration is:

"What Do They See?" Task

Goal: Evaluate the controller's ability to understand the spatial viewpoint of an inside participant as well as the controller's understanding of the mission environment.

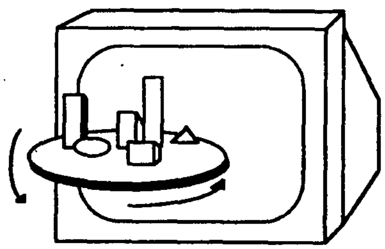
Measure: Given an exocentric display which includes an inside participant with a specific viewing direction, the controller will judge what the inside participant would actually be seeing.

Display Options



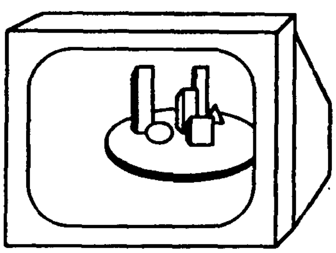
Stereoscopic Viewing

- Evaluate performance with monoscopic vs. stereoscopic viewing



Rotation

- Evaluate performance with rotation around multiple axes
- Evaluate performance with monoscopic vs. stereoscopic viewing
- Observe rotation strategies



Head-Motion Tracking

- Evaluate performance with and without rotation
- Evaluate performance with monoscopic vs. stereoscopic viewing
- Observe head-motion strategies

2.1.4 Effect of a Virtual Body on Spatial Awareness
Mark H. Draper (supervised by Max Wells)

Introduction

VR offers many freedoms regarding self-representation as a 'virtual body (VB)':

- Size
- Shape
- Level of Realism
- Body Configuration (from no VB to a full body part representation)

The representation of self is fundamental to virtual interface design. The tremendous flexibility described above needs to be harnessed by performance metrics to determine what VB configuration is appropriate for a defined task.

Design Question

"Include a VB?"

"YES"

- Increases level of Presence
- Self-expression/identity in virtual commons

"NO"

- Hardware/Software costs
- Cumbersome body interface devices
- Performance benefits ill-defined

Thesis Question:

Given:

- AFOSR Contract focuses on transmitting Situation Awareness in VR, and Spatial awareness is assumed to be a subset of Situation Awareness,

Does the existence of a VB in a virtual environment enhance one's spatial awareness? If so, what virtual body elements contribute to this effect?

Definitions:

- VB: The representation of one's own body (or subset of it) that can be self viewed in a virtual world.
- Spatial Awareness: An awareness of the relative locations of objects in the environment in relation to the participant.

Research Ideas:

- Pilot Study: A quick look to see if humans use their own body as a contextual aid in absolute distance estimation tasks in the real world.
- Main Study: A carryover of the pilot study into VR, where subjects will perform spatial awareness tasks and the VB can be manipulated freely. Again the emphasis will be on observing any spatial awareness enhancements that can be associated with the existence of a VB.

Potential VB Configurations:

- Arms Only
- Full VB
- No VB
- Static/Limited Dynamics
- Other?

2.1.5 Effects of Spatialized Sound on Presence and Performance Within Virtual Environments

Robert G. Futamura (supervised by Max Wells)

In many cases, the presentation of spatialized auditory cues in addition to visual cues may increase performance measures on certain tasks. In addition, the sense of presence may be desired in order to facilitate some performances within a virtual environment. The veridical (re)construction of sounds within a virtual environment may increase the likelihood of conveying a sense of presence, or being within the virtual environment.

Presence is commonly defined to result from the match of input and output channels of both the human operator and the virtual interface. With the addition of a realistic 3D auditory channel to the existing virtual interface, it is expected that levels of performance and presence would increase.

Several factors to manipulate include:
- spatial vs. non-spatial vs. no sound sources
- static vs. dynamic sound sources
- interactive vs. non-interactive sources
- number of sound sources

2.1.6 Subjective Measures of Presence

Claudia Hendrix (supervised by Woody Barfield)

Claudia's research effort is twofold: (1) the development of metrics for the evaluation of presence and performance within virtual environments, and (2) an investigation of the resolution of computer-generated sensory input necessary for a person to "get a feeling" of presence within a virtual environment. Factors which she is investigating include the visual field of view, update rate, stereopsis, headtracking and degradation of the sensory input (i.e., resolution) in terms of presence and performance of navigation tasks and spatial discrimination. The investigation will be conducted by evaluating the performance of subjects in a computer-generated environment where both the visual resolution, field of view, and frame update rate, etc. will be varied. The approach taken for the development of metrics is a standardized subjective questionnaire which will relate variables used to generate virtual environments with presence. Currently a literature search is being conducted on hardware and software variables which may influence presence and also on metrics to measure presence and performance within virtual environments. Exploratory studies on the sense of presence within visual and auditory virtual environments as well as in spatial discrimination have been conducted.

2.1.7 Memory for virtual experiences
Hunter G. Hoffman

Abstract

We investigated whether subjects could separate memories of events experienced in virtual reality from real and imagined events: Virtual-reality monitoring. Subjects studied 8 separate spatial configurations of real geometric objects arranged on a life-sized chessboard, 8 configurations in virtual reality (an immersive, computer-simulated world), and imagined objects in 8 other configurations. On a later identification of origin memory test, subjects were generally able to correctly identify the sources of the events. Results are interpreted within the Johnson-Raye (1981) theoretical framework.

According to a number of researchers (e.g., Barfield, Slater, Zeltzer, and Sheridan, in press), researchers presently lack a theoretical framework within which to study virtual reality, and lack an objective measure of "presence", the feeling that one is "in a place" when immersed in a virtual environment. The goal of our research is to develop a theoretical framework to guide research on virtual reality, and to develop a measure of presence.

Reality monitoring is the decision process by which memories of real and imagined events are distinguished. According to Johnson and colleagues (see Johnson, Hastroudi, & Lindsay, 1993, for a review), differences between real and imagined events as originally experienced are preserved in memory and can later serve as cues to where the memory originated. That is, memory source is inferred by the subject at the time of retrieval, based on cues associated with the target memory. Reality monitoring decisions take advantage of differences in qualitative characteristics of memories from different sources. Examples of reality monitoring decisions in the real world include separating memories of what one actually witnessed in a crime from imagined "elaborations"; separating fact from fantasy with respect to childhood sexual encounters; and unconscious plagiarism (unwittingly identifying the origin of an idea as original when in fact someone else told you the idea).

In research just completed, we investigated whether subjects could discriminate memories of events experienced in virtual reality from real and imagined events. Subjects studied the spatial locations of geometric objects located on a life-sized chessboard. The objects were either real, imagined, or virtual (presented in a computer simulated reality). Subjects later took a memory test requiring them to identify the source of each spatial configuration. They were shown a number of 2-d diagrams of spatial configurations of geometric objects they had seen in the study phase (and distracters). For each test item, they were to choose whether they had seen it in the real world, had imagined the objects based on instructions, had seen that configuration of objects in virtual reality, or if it was new (not in the study phase). Following the logic used by Johnson and colleagues, we predicted that some of the differences in the qualities of the experiences as originally experienced would get stored in association with the target memories, and would allow subjects to infer the sources of their memories on a later memory test. More specifically, we predicted that cues associated with memories of virtual events would allow the virtual source of these memories to be identified. As predicted, we found that subjects were generally able to discriminate memories of virtual events from memories of real and imagined events, establishing the reality monitoring paradigm as a theoretical framework in which to study similarities and differences between real, virtual and imagined experiences.

Keith Hullfish and I are now investigating whether reality monitoring confessions can serve as an objective measure of presence. Perhaps virtual-reality monitoring can be used as a metric for assessing how closely virtual events simulate real events, a sort of Turing test for quantifying the fidelity of virtual technologies. The more convincing the virtual world, the more "present" subjects will feel. Increasing the feeling of presence and the quality of the virtual experience will increase the similarity between the virtual and real experiences, making subjects more likely to get memories of virtual and real events confused.

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Barfield, W., Slater, M., Zeltzer, D., & Sheridan, T. (in press). Presence and performance within virtual environments. In W. Barfield & T. Furness (Eds.) Virtual Environments and Advanced Interface Design. London: Oxford University Press.

Johnson, M.K., and Raye, C.L. (1981). Reality monitoring. Psychological Review, 88, 67-85.

Johnson, M.K., Hastroudi, S., & Lindsay, D.S. (1993). Source monitoring. Psychological Bulletin, 114, 3-28.

Zeltzer, D. (1991). Autonomy, interaction, and presence. Presence: Teleoperators and Virtual Realities, 1, 127-132.

2.1.8 Virtual Reality Monitoring
Keith C. Hullfish (supervised by Max Wells)

The current research effort includes adapting a paradigm from cognitive psychology, Source Monitoring (Johnson, Hashtroudi, & Lindsay; 1993), within which to study Virtual Reality. Virtual Reality Monitoring is the decision process by which people distinguish between real, virtual, and imagined origins of memories (i.e., sources). Historically, this paradigm has been used to examine the differences between external (real, virtual) and internal (imaginary) sources of information in memory. Evidence of differences between source events, as originally experienced, are preserved in memory and can later serve as cues to where the memory originated. Monitoring decisions are based on the qualitative differences between the memories. Source of a memory is inferred based on the average differences of memory characteristics, in combination with judgment processes. These memory characteristics are: sensory/perceptual information, contextual information (spatial and temporal), semantic detail, affective information, and cognitive operations. Qualities typically associated with a real event include more sensory/perceptual and contextual information whereas imaginary events reflect mental effort.

The research effort is developing the concept as it applies to Virtual Reality and, thus, will examine the similarities and differences of virtual experiences with both real and imaginary experiences. It is proposed that the limitations that the technology impose on the senses, prevent a person from fully contextualizing information at acquisition, which could reduce encoding of potentially relevant external source information. In addition to degrading the sensory/perceptual and contextual information available to a participant, additional mental effort could be required. According to the theoretical framework, these characteristics could increase source monitoring confusions between external (virtual) and internal (imaginary) events than otherwise would have resulted if the technology simulated the real world perfectly. These characteristics could also serve as a cue to a virtual source, and thus distinguish a virtual event from real and imagined events.

An initial study was conducted (Hoffman, Hullfish, and Houston; in preparation) to establish the validity of adopting this paradigm. Subjects were able to distinguish between real, virtual, and imagined events, indicating that virtual experiences have unique memory characteristics. Efforts are underway to refine the experimental procedure and developing the concept of Virtual Reality Monitoring confusion scores as a metric for presence in virtual environments.

2.1.9 Facial Expression Exhibition in Human Computer Interaction

William J. King (supervised by Suzanne J. Weghorst)

Within the context of the evolution of the human-computer interface, detection of non-verbal behavior of the user may afford more proactive systems. In particular, facial behavior may convey information about the user's cognitive state, which can be used to adapt system configuration and response. Facial indicators of situation awareness (or its absence) may be useful metrics, both in the laboratory and in deployed man-machine systems.

In this study, facial expressions were recorded during subjects' interactions with a maze traversal game based upon the towering inferno scenario. Subjects were tasked with moving an icon through a plan view of a building (in one condition), or navigating through an "Adventure"-style text scenario (in a second condition). Subjects were selected from a large undergraduate subject pool for a criterion level of computer experience using the ACM SIGCHI computer user abilities test. Each of the 18 subjects completed two four-minute trials, with condition order counterbalanced across subjects.

Prior to each move, subjects were required to request state information about the adjacent room ("live" video footage, "live" audio, smoke levels, temperature, or concentration of toxins). Information was redundant across information modalities but all room states were randomly re-determined with each icon move. Subject annoyance with system response delay was also manipulated by randomly varying the wait time for room state information after each request. In the maximal delay condition the state information was declared "Unavailable" after a wait of 30 seconds. The conditions of the game were such that it was not possible to "win" within the time frame allowed. Subjects were shown an on-screen count-down clock throughout the task and a final (non-contingent) score was flashed at the end of the trial.

A telecommunications-style head-up display (reflecting a beam-split image of a 13-inch color computer monitor) provided a means for unobtrusive video (and audio) recording of the subject's head and upper body throughout the trials. All keyboard responses and game parameters were continuously recorded, along with time tags, for later micro-interactive analysis and for correlation with subjects' non-verbal behaviors. Facial expressions were derived from the acquired video sequences using the facial Action Unit coding methods of Ekman's Facial Action Coding System (FACS).

Initial results show significantly more facial expressions exhibited in the plan view condition than in the text-based condition. An unexpected number of asymmetric facial expressions was also observed. Additional analyses are underway. In particular, we will attempt to distinguish between perplexity due to room state unpredictability and annoyance due to system delays.

2.1.10 Measuring Presence in Terms of Subjective Reference Frames

Jerrold D. Prothero (supervised by Donald Parker and Thomas Furness)

Introduction

• Does presence in a virtual environment reflect a switch from using the external world to define one's sense of position, orientation, and motion (one's "rest frame") to using cues provided by a virtual environment?

• This model can be tested quantitatively by setting up an experiment in which physical and virtual orientation cues conflict, and observing which cues subjects tend to rely on, and whether the tendency to rely on cues coming from the virtual environment correlates with measures of presence.

• Whether the "subjective rest frame" theory is shown to be true or false, we will have learned something important about the nature of presence.

• If it is shown to be true, the experimental paradigm described in the methods section may be useful for quantitatively measuring the sense of presence in particular environments.

Method

• Our apparatus will consist of a platform which the subject will lie on and which can be rotated around the Y-axis running left-to-right through the subject's body at the center of mass. The subject will be wearing an HMD, and will have a pointer mounted on the platform near his or her waist which can be used to indicate the subjective impression of which direction is up.

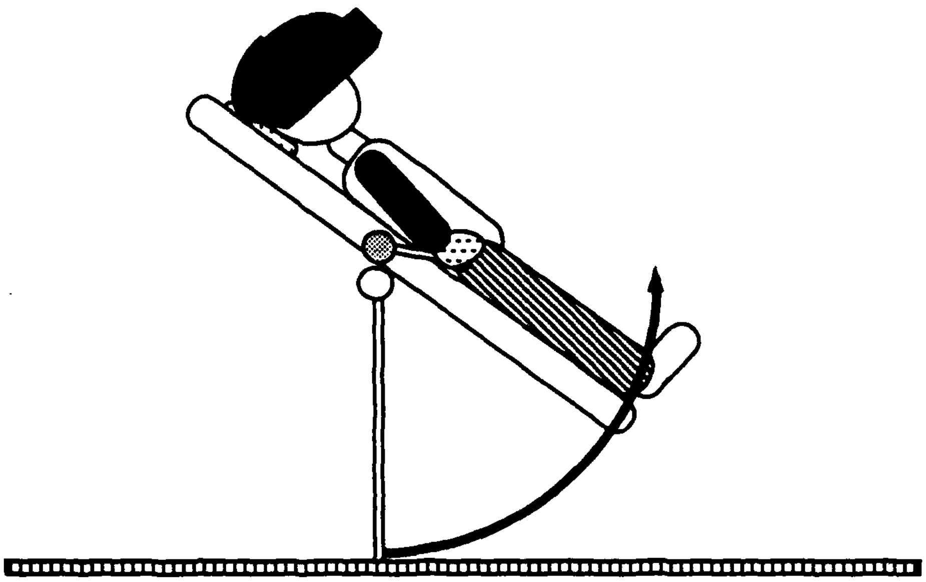
• The experimental stimulus will consist of images presented in the HMD, which may be used to provide a "visual polarity" (indications about which direction is up) different from that of external physical gravity.

• Possible independent variables:
  - Scenes with and without visual polarity
  - Rotating the scene around the visual polarity or gravity axes
  - Varying the field-of-view
  - Subject's tilt around the Y-axis

• Possible dependent variables:
  - The "up" angle indicated by the subject
  - Subjective measures of presence
  - A performance measure of presence

• Vection:
  - Latency
  - Saturation

Tilt Machine



Expected Results

• If the rest frame theory is correct, we expect that the tendency of the subject to identify "up" with the cues provided by the virtual environment will correlate with measures of presence.

• Increasing the field-of-view, which increases the sense of presence, should also increase the subject's tendency to identify "up" with the virtual cues.

• We suspect that rotating the scene will increase presence, and will tend to cause subjects to indicate an "up" direction aligned with the axis of rotation.

Conclusion

• The experiment will test the simplest theory of what presence could be. If the theory is shown to be false, we will have a sound basis for proposing more complex theories.

• If the theory is shown to be true, then we will have a quantitative method for measuring presence, in terms of the extent to which we can get subjects to identify "up" with the visual polarity of the virtual scene, rather than with the physical gravitational cues. This would allow us to investigate quantitatively the importance of factors such as field-of-view and resolution to presence.

2.1.11 Navigation and Wayfinding in VR: Finding the Proper Navigational Tools and Cues to Build Navigational Awareness

Glenna A. Satalich (supervised by Max Wells)

Introduction

Virtual Reality allows the participant to experience data and environments in a 3-D and egocentric manner. This gives the participant multiple viewpoints in seeing the environment and interacting with it.

Question : Given a perfect VR system, would the user have problems navigating through a VR world to reach a particular area? The literature on human behavior in navigation and wayfinding in the real world say Yes.

Goal : *To find the proper navigational tools and cues to build navigational awareness efficiently.*

Task : An informed search and rescue task in a virtual towering inferno environment. The goal location will be known but the path or paths will not be given. The time and errors of navigators using differing tools, cues and display mediums will be compared.

Navigational Awareness: The ability to relate one's ego-centered reference frame with the world-centered reference frame. The five sequential steps for navigational awareness are:

1. landmark recognition: choosing stable and directional landmarks
2. routes or links: paths that connect landmarks together
3. survey knowledge: knowledge of Euclidean distances between landmarks and recognition of alternate paths.
4. chunking of the environment: creating small areas from a large environment.
5. nesting and transitioning: nesting smaller areas under larger ones - multiple representations of the same space.

Wayfinding: The process used to orient and navigate. The overall goal of wayfinding is to accurately relocate from one place to another in a large scale space. The four basic requirements for successful wayfinding are

- knowing one's orientation
- choosing an appropriate route
- being able to monitor the route for confirmation of being on the correct route
- destination recognition

The Tools and Cues: Real world and virtual tools and cues will be incorporated into the environment to enhance each navigational step. The tools and cues available are extensive and a selection of likely candidates will be made. The following are a subset of tools and cues that can be used.

- Architectural cues: differentiation, visual access and complexity
- Real world tools: sun or moon, compass, maps, signs, verbal directions, video tour
- Virtual tools: Visual or Audio breadcrumbs, agents (static and mobile), teleportation, contour and gridlines

The Metrics: The most crucial step in this research is understanding when a navigator has reached a particular navigational awareness step. The following metrics have been used in previous navigation and wayfinding studies in the real world. They will be modified for usage in a virtual world. Additional metrics are being researched.

- Landmark observation test: The goal is to have the navigator choose stable and directional landmarks as opposed to transient landmarks.
- Route recognition: The navigator should recognize a path traveled between landmarks and be able to give correct directions.
- Landmark distances: For procedural knowledge the distance given should be length of the path. For survey knowledge the distance should be Euclidean. For chunking peculiar biases will be noticed depending on whether the landmark is in the same small area or in a differing one.
- Path inference testing: For survey knowledge the navigator should infer alternative paths if a common path is blocked.
- Directional pointing: This test can be used for procedural, survey, and nest transitioning.

2.1.12 Effective Information Presentation to Facilitate Decision Making Under Uncertainty
Ryoko K. Williamson (supervised by Max Wells)

Introduction

Effective decision-making (DM) processes in a complex situation require the maintenance of situation awareness to obtain satisfactory outcomes. Decision-making could be affected by uncertainties due to the nature of the world which is dynamic and complex. It has been found that the Traditional DM theory which is based on mathematical models does not reflect the human DM processes (naturalistic DM).

Research Questions:

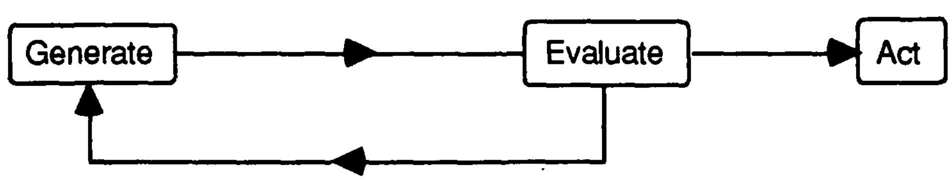
- What types of errors would we expect from the use of different types and forms of presenting information in a virtual environment?
- What is the difference in making decisions between experts and novices given uncertain information?
- In what situations, do options of alternative actions help to make decisions?

Goal: Identify types and forms of information that would facilitate *naturalistic decision making* under uncertainty and develop an interface using that knowledge.

Decision Making

Naturalistic DM

- Sequential Processes: generates and evaluates a single option at a time -> Decision Cycle

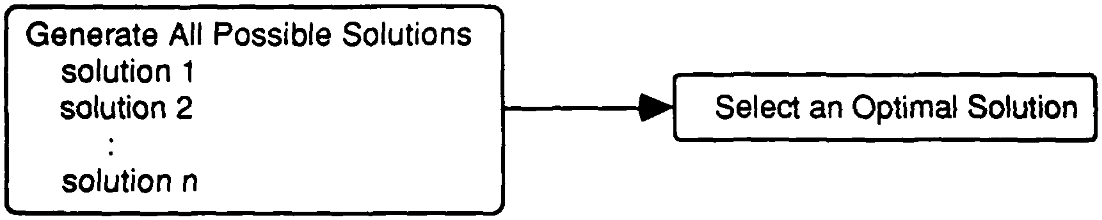


Naturalistic Decision Cycle

- Strategy: "satisficing"(good enough)
- Schema-Driven reasoning guided by the knowledge of the decision maker.
- Difference between experts and novices is their ability to assess situations, not their reasoning skills.

Traditional DM

Consequential Processes: generate all possible alternatives and select an "optimal" solution.



Uncertainty

Uncertainty affects real-world decision making by interrupting ongoing action, delaying intended action, and guiding the development of new alternatives.

Uncertainties include:

1) the meaning of information
2) the value of consequences
3) act-event or event-event sequences
4) the appropriate decision process
5) the ability to affect future events

Interesting Finding: It is suggested that some uncertainty is essential to good decision making, because it motivates decision makers to shift from automatic to reflective action, and guides their search for better solutions.

Research Ideas

Uncertainties could be introduced by getting information from:

- Sensors (limited update rate, malfunction)
  This consequentially introduces the *time* factor.
- Other participants (unpredictability of their action)

Task: Assess the situation and navigate oneself by making appropriate decisions to accomplish a search and rescue task successfully.

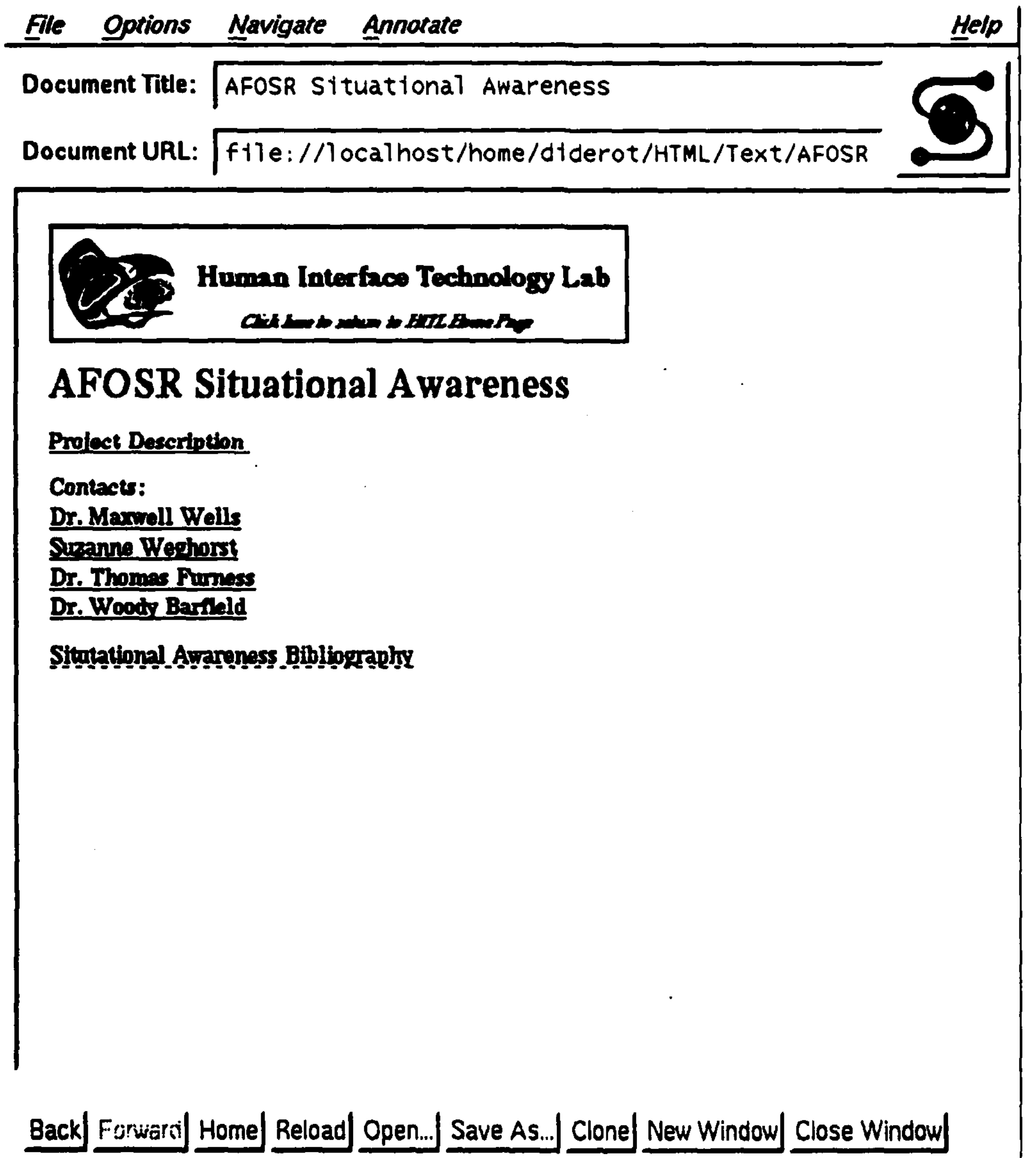
Independent Variables:
- Forms of Information : probability vs. descriptive
- Types of Additional Information :
  a. List of Options
  b. Video Camera View of Queried Location

Proposed Metrics:
- Performance Time
- Decision Errors
- Subjective Situational & Decision Strategy Assessment Test (e.g. think aloud or retrospective self-report)

2.2 Creation of a knowledge base

The HITL Knowledge Base is a collection of electronic information available online, as well as papers, books and other reference materials used to support research in advanced human interfaces.

• The AFOSR portion of the Knowledge Base is devoted specifically to materials relating to Situational Awareness and Presence in Virtual Environments. It was started in 1992 and contains over 529 journal articles, conference papers and technical reports. The bibliography was developed and is maintained using the ProCite bibliographic database. It is also available in various electronic formats, including an HTML (Hypertext Mark-up Language) document, access to which is available for the AFOSR Project group using the Mosaic interface.



How the AFOSR Knowledge Base was constructed

• The first step was to interview professionals in the field to identify key concepts, researchers, conference proceedings, and journals.

• Among the databases searched for relevant material were INSPEC, COMPENDEX, NTIS and PSYCLit.

• Relevant citations were identified and documents were retrieved and indexed into ProCite. The documents were filed alphabetically by first author.

• Many of the articles in the AFOSR Knowledge Base were also found as the result of student research projects.

• In addition to the formal identifiers provided by the commercial databases, such as INSPEC, the AFOSR Knowledge Base is also indexed informally according to specific student interests. Each HITL student identified three phrases relevant to their research area of interest. The eight HITL students reviewed and classified all of the articles in terms of these key words. The results of this classification exercise are also available as part of the AFOSR Bibliography. This process was also helpful in removing articles that were not directly relevant to the AFOSR literature review.

• The bibliography is available online to HITL Staff and students through the information browser developed at NCSA, Mosaic.

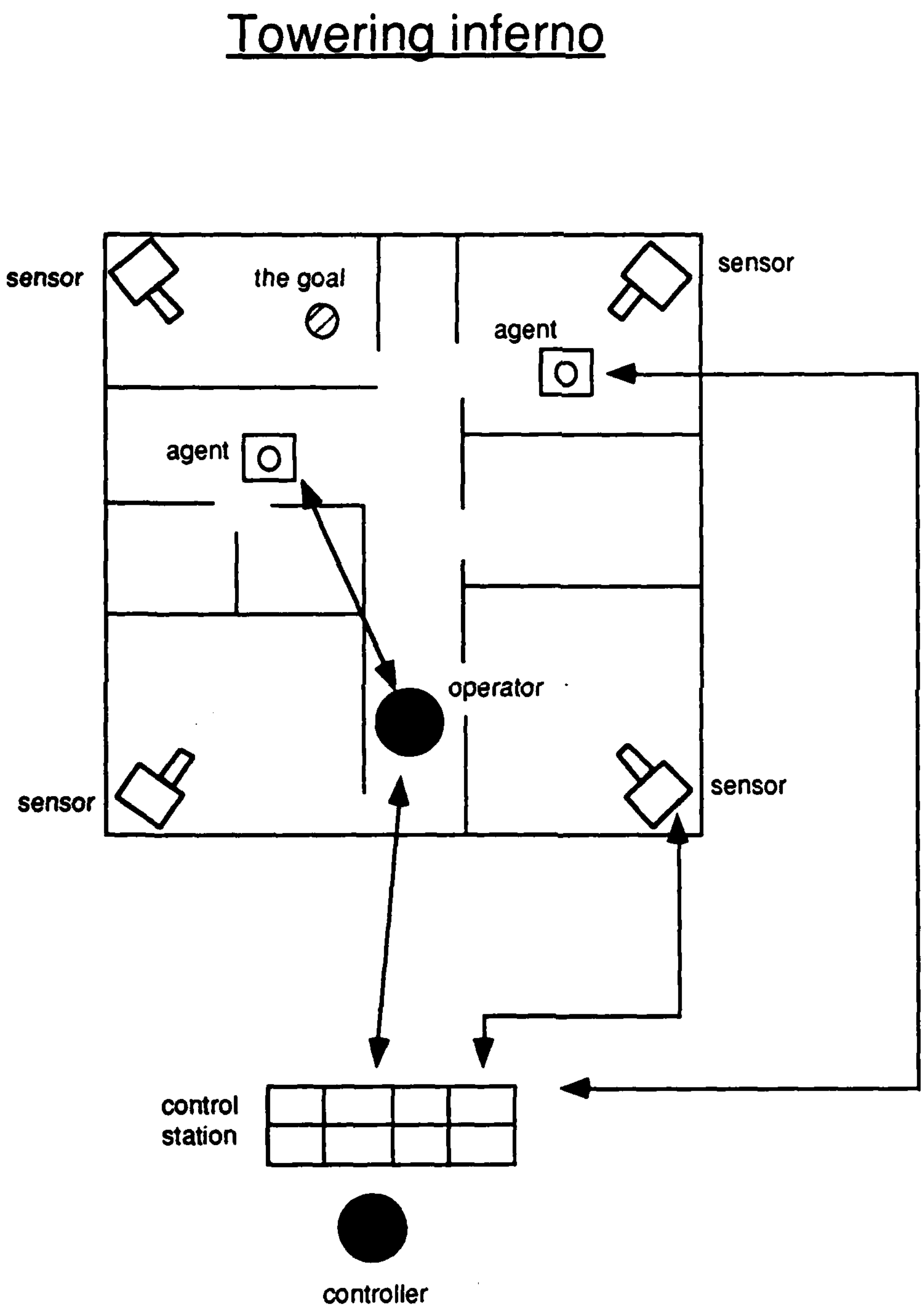
The keywords for these articles provided by databases such as INSPEC are also available online with abstracts, so articles on particular documents can be identified quickly.

• The HITL Knowledge Base staff continues to monitor the literature for new resources.

2.3 Development of an experimental paradigm

One of the goals of the research effort is an investigation of situation awareness. In order to do so, it is necessary to create an environment in which to manipulate variables, collect data and test hypotheses. The operational environment in which the Air Force is interested involves a complex interplay of multiple elements in an air-to-air engagement, or some other command and control situation. Simulating such an environment in virtual reality has been accomplished by various labs, and several of the principle investigators on this project have experience both developing and working with such scenarios. However, one drawback with such an environment is the need to use highly skilled operators to collect meaningful data. Also, the results of such work would be context specific, whereas the aim of this research project is to generate data and provide guidelines which will be relevant across a number of different contexts.

In order to address the needs of the project and the constraints of our subject pool, a more generic scenario was developed, termed the "Towering Inferno."



The "Towering Inferno" consists of a number of generic elements, illustrated in the figure. The basic scenario is that of a multi-story building, only one story of which is illustrated. Each story consists of several rooms, some of which may be on fire. There is an operator, whose task it is to perform a search and rescue task (reach the objective). The operator may be aided or hindered by agents. The agents may be computer-controlled, or manned. Some of the agents may be in direct communication with the operator or may be in contact via a controller stationed outside the building. The controller may also collect information from sensors positioned throughout the building. The channels of communication can be selectively manipulated (e.g. degraded or delayed) by the experimenter. Also, the state of the fire in each room may be controlled by the experimenter. By imposing time stresses and competition, the experimenter can create fairly demanding experimental situations.

The "Towering Inferno" provides participants with complex task-demands. It is capable of being used by people with varying skill levels. It can be used by multiple participants, and provides a range of complex scenarios with which to explore issues such as situation awareness, training, communication, spatial awareness, command and control, and decision making.

2.4 Hardware

An integral part of the proposal to the AFOSR was the purchase of a SGI Onyx/2 RE2 computer for the development of complex virtual environments. The machine was ordered in late May and received in late June. It has been integrated into the HIT lab's computing infrastructure. A complete list of the HIT lab's facilities is shown in Appendix A, along with a description of the lab. The facilities being used by the AFOSR project include those of the Interactive Computer Graphics and Human Factors Lab, headed by Dr. Woodrow Barfield. A description of that lab, and it's facilities, is included in Appendix B.

Another recent purchase, which will enhance the HIT lab's research capabilities, was a light-weight helmet-mounted display, the VR4 from Virtual Research Systems Inc. The VR4 is an active Matrix LCD-based HMD with 742x230 pixels per eye and a 60-67 degree diagonal field of view. Interpupillary distance (IPD) is adjustable between 52mm and 74mm. Eye relief is adjustable between 10 and 30 mm. Overlap is user settable between 85% and 100%. The device will take stereoscopic and monoscopic image sources, switched at a control box. It has input connectors for RS-170A (RGB) and S-VHS video formats. The helmet comes with built-in Sennheiser HD440 headphones.

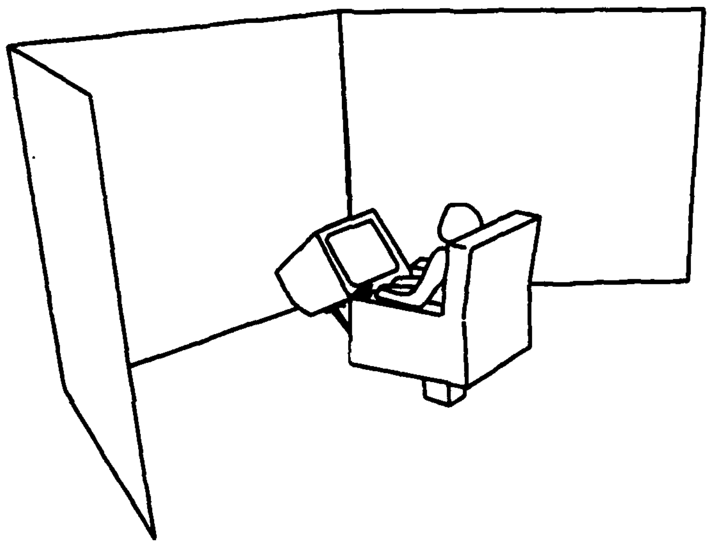
In order to increase the realism and inter activity of the virtual environments which are planned for this project, and to expand on the lab's capabilities, a proposal was written by the HIT lab to the DoD (U.S. Army Research Office, Attn: AMXRO-IP, DURIP proposal Topic #11) for funding to develop a virtual reality test bed. The specifications for this device are shown in Section 2.4.1.

The Neurosciences Laboratory at Johnson Space Center has agreed to provide a 90 foot-pound servo-controlled rotator (Contravas) to the HITL on long-term loan. The rotator permits mounting of various restraint systems and locomotion-simulation apparatus. It includes a chair that provides simple on-axis yaw rotation. We anticipate that the rotator will be used to examine effects of combined visual and inertial cues on various dependent variables including self-motion perception, measures of "presence," spatial memory and compensatory tracking. A second rotator-driven apparatus -- The Pitch and Roll Device, PARD -- may be acquired from Johnson Space Center at a later date.

2.4.1 Planned developments

HIT Lab Testbed

In order to develop more effective approaches for communicating situation awareness in virtual environments, we will be constructing a testbed for exploring the sensory, perceptual, and cognitive factors which contribute to this transfer of information. The HIT Lab testbed will feature a virtual environment display involving the projection of computer generated stereoscopic imagery onto one or more screens which surround a participant wearing shutterglasses. This system will provide us with an opportunity to investigate a wide range of egocentric display concepts. In addition, a separate non-projection monitor will be included to provide an exocentric display.



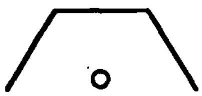
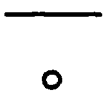
HIT Lab Testbed: three flat screen configuration, with exocentric display.

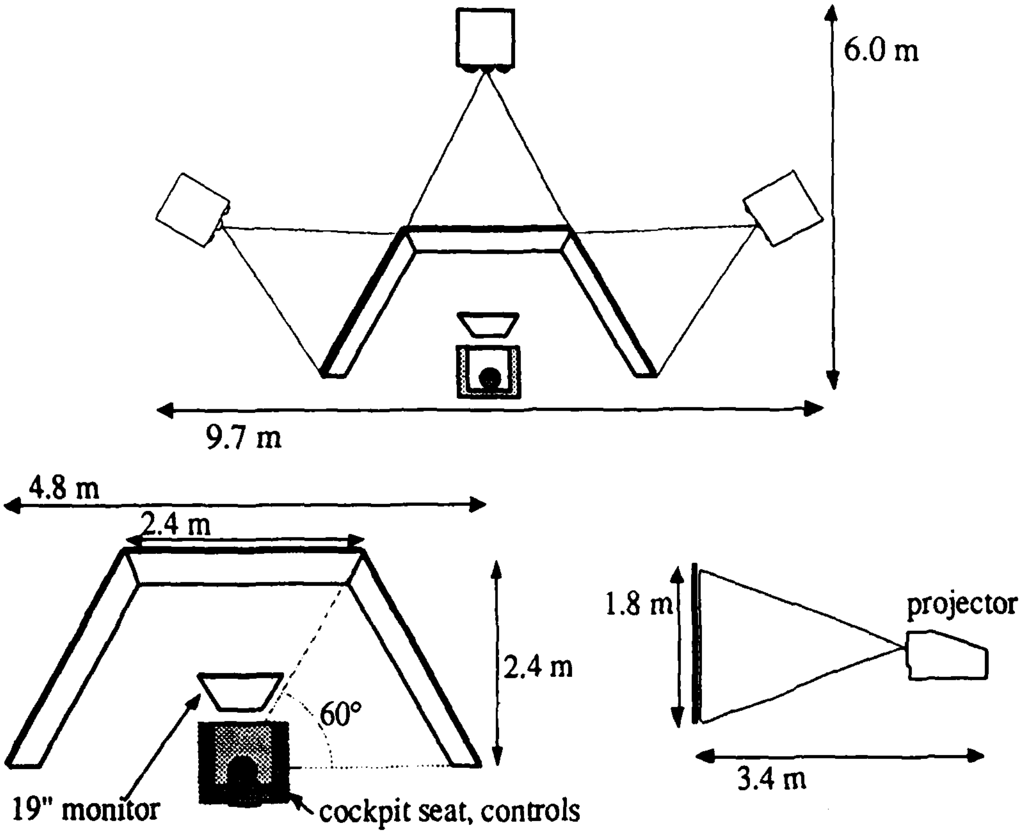
Goals

- **Field of View:** Vary instantaneous FOV through 180° and beyond.
- **Visual Acuity:** Support a wide range of resolutions, (ideally) approaching human visual acuity of about 1 min. of arc.

- **Latency:** Study effects of eliminating rotational latency while retaining stereoscopic latency.
- **Simulated HMD:** Electronically blank portions of display, based on head orientation.

Proposed Implementations

Layout	Projection	Graphics
3 flat screens rear projection *- large room size (30'x20')*  180°	**3 projectors stereo** 3 high-end CRT projectors: $20K x 3 = [$60K] *- requires active eyeware (105° IFOV)*	**3 RE2s** upgrade Onyx [~$250K] 3 stereo outputs, each 1025x768 96 Hz (48Hz/eye) *+ total resolution 3075x768: 3.5 min of arc pixels*
	6 projectors stereo 6 low-end CRT projectors: 6 x ~$10K = [~$60K] 2 projectors/screen *+ supports passive eyeware (180° IFOV)* *+ brighter* *- additional alignment complexity*	**MCO** already have [$0] 6 outputs, each 640x480 60Hz (60Hz/eye) *- total resolution 1920x480: 5.5 min of arc pixels* *- slower update rate with 1 RE2 than with 3 RE2s*
	3 projectors mono 3 low-end CRT projectors: 3 x ~$10K = [~$30K] *+ supports passive eyeware (180° IFOV)* *- not stereo*	**MCO** already have [$0] 3 outputs, each 960x680 60Hz *+ total resolution 2880x680: 4 min of arc pixels*
1 flat screen rear projection *+ upgradable to 3 screens* *+ smaller room size (8'x20')* *- small field of regard*  60°	**1 projector stereo** high-end CRT projector: [$20K] *- requires active eyeware (105° IFOV)*	**1 RE2** already have [$0] 1 stereo output 1025x768 96 Hz (48Hz/eye) *+ total resolution 1025x768: 3.5 min of arc pixels*
	2 projectors stereo 2 high-end CRT projectors: 2 x ~$20K = [~$40K] *+ supports passive eyeware (180° IFOV)* *+ brighter* *- additional alignment complexity*	**MCO** already have [$0] 2 outputs, each 1280x1024 60Hz (60Hz/eye) *+ total resolution 1280x1024: 2.8 min of arc pixels* *- MCO: cannot upgrade to 3 screens at 1280x1024*
	2 projectors stereo 2 low-end CRT projectors: 2 x ~$10K = [~$20K] *+ supports passive eyeware (180° IFOV)* *+ brighter* *- additional alignment complexity*	**MCO** already have [$0] 2 outputs, each 640x480 60Hz (60Hz/eye) *- total resolution 640x480: 5.5 min of arc pixels*
curved screen front projection *- large room size (16'x20')*  180°	**1 projector stereo** Hughes-JVC Light Amplifier projector: 310E: 2000 lumens [$60K] -or- 320S: 2300 lumens [$70K] -or- 335S: 3500 lumens [$115K] optics for curved screen [$?] *+ MUCH brighter than CRT projectors* *- 16.7ms response time probably insufficient for stereo* *- requires active eyeware (105° IFOV)*	**1 RE2** already have [$0] 1 stereo output 1025x768 96 Hz (48Hz/eye) *- total resolution 1025x768: 10.5 min of arc pixels* *- curved screen: graphics computation slower*
	1 projector mono Hughes-JVC Light Amplifier projector: same as above: [$60K, $70K, or $115K] *+ MUCH brighter than CRT projectors* *- not stereo* *- requires active eyeware (105° IFOV)*	**1 RE2** already have [$0] 1 output 1280x1024 60Hz *- total resolution 1280x1024: 8.5 min of arc pixels* *- curved screen: graphics computation slower*



Details of three flat rear-projection screen design with additional exocentric display.

Equipment

- **Graphics computer**: The HIT Lab currently has a Silicon Graphics Deskside Onyx RE2, with 2 processors, 1 Reality Engine 2 (RE2) graphics board with 4 raster managers (RMs), and a Multi-Channel Option Board (MCO). This system could potentially be upgraded to a three RE2 rack-mounted system for the planned three screen, three projector stereo testbed configuration.
- **Projectors:** A variety of projectors are being considered for inclusion in the system. These vary in price and performance. The final decision will be based on a price, performance and upgradability trade-off.

2.5 Development of software

The development of virtual environments is a complex task, requiring a unique integration of hardware and software skills. Often, these skills are held by more than one person, and so the challenge becomes one of both technical and managerial integration. In the past, building the various components of a virtual world was the domain of a few highly specialized individuals. To a certain extent this is still the case, however a number of vendors have been producing products which address some of the needs of newcomers to the VR business. In particular, there are toolkits which help in the building of virtual worlds.

In the virtual worlds which we wish to use for our experiments (the "Towering Inferno"), there is a need for complex scenarios such as live video, augmented reality, and multiple viewports. These cannot all be done with commercially available software, and so there is a need to develop our own. On the other hand, in order to maximally utilize the talents of the students who are conducting much of the research, there is a need for well documented, well supported, easy-to-use software. Also, in our role as an educational establishment, we need to ensure that the software skills that the students acquire during their time in the lab are portable to the outside world. The trade-off between ease-of-use and functionality is one which will continue to be made during the research project. However, for the time being, we have chosen to use dVISE, made by Division, for our world development. We are also considering the use of World Toolkit, by Sense8, as another authoring package.

Prior to our decision to use commercial software, we produced a proof of concept demonstration of the "Towering Inferno" using in-house software. This was developed on DEC machines with Kubota graphics board. The demonstration was successful, achieving a 20 Hz update rate, live video, and multiple viewports. Work also started on an experimenter's control station. Subsequently, the graphics boards went out of production and were no longer supported. Some of that software is currently being ported to SGI machines.

3.0 Cumulative, chronological list of written publications (including in press and in preparation)

Barfield, W., Bjorneseth, O. and Hendrix, C. Spatial performance with stereoscopic displays as a function of computer graphics eyepoint elevation and geometric field of view, *submitted to : Applied Ergonomics*, June 1994.

Barfield, W., Hendrix, C., Bjorneseth, O., Lotens, W., and Kazaramac, K. Comparison of human sensory capabilities with technical specification of virtual environment equipment, *submitted to : Presence Journal*, July 1994.

Barfield. W. and Hendrix, C. Exploratory studies on the sense of presence within stereoscopic virtual environments, *submitted to : Presence Journal*, July 1994

Barfield, W., and Weghorst, S. The sense of presence within virtual environments: A conceptual framework, 5th International Conference on Human-Computer Interaction, Orlando, Florida, 1993.

Barfield, W., and Danas, E. Comments on the use of olfactory displays for virtual environments, *will be submitted to : Presence Journal*, August 1994

Hendrix, C. and Barfield, W. Spatial discrimination in three-dimensional displays as a function of eyepoint elevation, *In press : Human Factors Journal.*

Hendrix, C. and Barfield, W. Relationship between monocular and binocular depth cues for judgments of spatial information and spatial instrument design, *submitted to: Displays Journal*, April 1994.

Hendrix, C. and Barfield, W. Exploratory studies on the sense of presence within auditory virtual environments, *will be submitted to : Presence Journal*, September 1994

Hendrix, C. and Barfield, W. Exploratory studies on presence and spatial discrimination in virtual displays as a function of geometric field of view, headtracking, and stereopsis, *will be submitted to : Presence Journal*, September 1994

Hoffman, H.G., Hullfish, K., and Houston, S. (in preparation). Virtual-reality Monitoring. *Paper to be submitted for publication.*

Hollander, Ari J. (1994). Master's Thesis: "An Exploration of Virtual Auditory Shape Perception."

Hollander, Ari J., and Furness, Thomas A. "Perception of Virtual Auditory Shapes". International Conference on Auditory Display. Santa Fe, NM. Nov. 1994. *In press*

King, William J. (1993) "Investigation of the Exhibition of Facial Expressions within Human Computer Interaction," in Proceedings of the 2nd IEEE International Workshop on Robot and Human Communication, 1993, 182-187.

King, William J. (1994) "Defining Phenomena for an Emotion State Model in the Human Interface," in Proceedings of the 3rd IEEE International Workshop on Robot and Human Communication , 1993, 191-195.

King, William J. (submitted) "The Representation of Agents," in Proceedings of the 1995 ACM/SIGCHI Conference on Human Factors in Computing Systems , 1995.

4.0 Professional personnel associated with the research effort

Staff

Woodrow Barfield (Director, Interactive Computer Graphics and Human Factors Lab)
B.A. Experimental and Engineering Psychology, 1976, UCLA.
Ph.D. Industrial Engineering, 1986, Purdue University.

William Bricken (on leave without pay since March 1994)
B.A. Psychology, 1967, University of California at Los Angeles.
M.A. (candidate), 1968, Social Psychology, Ohio State University, OH.
Dip. Ed. 1972, Monash Teachers College, Melbourne, Australia.
M.Ed (candidate) 1975, La Trobe University, Melbourne, Australia.
M.S. Statistics, 1984, Stanford University, CA.
Ph.D. Education, 1987, Stanford University, CA, "Analyzing errors in elementary mathematics.

Toni C. Emerson (Research Staff, HIT Lab)
B.A. Spanish; B.A. Drama, 1973, University of Washington, Seattle.
M.L.S. (Masters of Library and Information Science), 1993, University of Washington, Seattle.

Thomas A Furness III (Director, HIT Lab)
B.A. Electrical Engineering, 1966, Duke University.
Ph.D. Engineering and Applied Science, 1981, University of Southampton, England.

Donald E. Parker (Adjunct Professor, Dept of Otolaryngology, UW)
B.A. Psychology/Economics (1958), DePauw University, IN
Ph.D. Experimental Psychology (1961), Princeton University, NJ, "Vertical organization of the auditory cortex in the cat."

Hunter Hoffman (Research Staff, HITL)
B.S. Psychology, 1985, The University of Tulsa, OK.
M.S. and Ph.D. 1992, Cognition and Perception, minoring in Physiological Psychology, University of Washington, Seattle, "Reality monitoring: the process by which people separate memories of real events (fact) from imagined events (fantasy)."

Suzanne J. Weghorst (Director of Human Factors and Interface Development, HIT Lab)
B.S. Psychology, 1972, Seattle University.
M.A. Psychology, 1975, University of California, Riverside.
Ph.D. (candidate), Psychology, 1977, University of California, Riverside, "A Sociobiological Approach to Human Jealousy."
M.S., Computer Science, 1989, University of Washington, "Exploring Graph Perception with an Automated User Interface Research Tool"

Maxwell J. Wells (Associate Director, HIT Lab)
B.Sc. (Honors) Biology and Psychology, 1978, University of Stirling, Scotland.
Ph.D. Engineering and Applied Science, 1983, University of Southampton, England, "Vibration-induced eye movements and reading performance with the helmet-mounted display."
CPE (Certified Professional Ergonomist) 1993.

Students

Ove L. Bjorneseth (Research Assistant, Laboratory for Interactive Computer Graphics and Human Factors)
B.S. Electrical Engineering, 1985, Gjovik College of Technology, Norway.
B.S. Industrial Engineering, 1992, University of Washington, Seattle.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

Gina B. Crvarich (Research Assistant, HIT Lab)
B.Sc. Information and Computer Science, 1985, University of California, Irvine.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

Mark H. Draper (Captain, USAF)
B.S.E. (Magna Cum Laude) Human Factors Engineering, 1989, Wright State University, Dayton, Ohio.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

Robert G. Futamura (Research Assistant, HIT Lab)
B.A. Physics and Psychology, 1992, Miami University, Oxford, Ohio.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

Claudia Hendrix, (Research Associate, Laboratory for Interactive Computer Graphics and Human Factors)
B.S. Industrial Engineering and Management, 1986, North Dakota State University, Fargo.
M.S.I.E, 1994, University of Washington, Seattle. "Evaluation of Presence in Virtual Environments as a Function of Visual and Auditory Cues".
Ph.D. Industrial Engineering and Human Factors, In Progress, University of Washington, Seattle.

Ari Hollander, (Research Assistant, graduated, HIT Lab, currently HIT Lab staff)
A.B. Astrophysics, 1991, University of California.
M.S.I.E. (Virtual Environments and Advanced Interface Technology), 1994, University of Washington, Seattle, "An Exploration of Virtual Auditory Shape Perception."

Keith C. Hullfish (Research Assistant, HIT Lab)
B.A. Mathematics, Physics concentration, 1987, Franklin and Marshall College, Lancaster, Pennsylvania.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

William J. King (Research Associate, Psychology)
B.A. (Honors), 1993, Experimental Psychology and Computer Science, Southwestern University (Georgetown, Texas)
Ph.D. Cognitive Psychology, In Progress, University of Washington, Seattle.

Jerrold D. Prothero (Research Associate, HIT Lab)
B.S. (Honors) Physics and Computer Science, 1986, University of Washington, Seattle.
M.S.E. Interdisciplinary Engineering, 1993, University of Washington, Seattle, "The Treatment of Akinesia Using Virtual Images."
Ph.D. M.E., In Progress, University of Washington, Seattle.

Geoffrey M. Silverton (Research Assistant, HIT Lab)
Sc.B. (Honors) Electrical Engineering, 1991, Brown University, Providence, RI.
M.S.E.E., 1993, University of Michigan, Ann Arbor.
Ph.D. E.E., In Progress, University of Washington, Seattle.

Glenna A. Satalich (Research Assistant, HIT Lab)
B.A. Experimental Psychology, 1982, University of California, San Diego.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

Ryoko K. Williamson (Research Assistant, HIT Lab)
B.S. (Honors) Cognitive Science, 1993, University of Washington, Seattle.
M.S.E. Human Factors, In Progress, University of Washington, Seattle.

5.0 Interactions

5.1 Papers presented at meetings

Hendrix, C. and Barfield, W. Perceptual biases in spatial judgments as a function of eyepoint elevation angle and geometric field of view. *The 5 th European Symposium on Space Environmental Control Systems*, Friedrichshafer, Germany, June 20-23, 1994.

Hoffman, H., Hullfish, K., and Houston, S. (July. 1994). Confusions between memories of real, virtual and imagined events. Paper presented at AFOSR workshop, HITL, Seattle WA.

5.2 AFOSR workshop

On July 14-15, 1994, the Human Interface Technology Laboratory (HIT Lab) at the University of Washington hosted a workshop to share research ideas and agendas, and to promote cooperation between virtual reality research programs sponsored by the Air Force. Representatives from various Air Force organizations and researchers from the University of Washington attended. The following people attended the workshop:

Name	***Organization***	***E-mail***
Tom Furness	UW / HITL	tfurness@u.washington.edu
John Tangney	SAF / AQT	(703) 746-8900
Bob Eggleston	AL / CFHP	teggleston@falcon.
Bill Reedy	SM-ALC / FMD (2)	reedybi@smdi501.mcclellan.af.mil
Richard Thurman	AL / HRA	thurman@hrlban1.aircrew.asu.edu
Dan Repperger	AL / CFBS	d.repperger@ieee.org
Paul V. Whalen	AL / CFBA	p.whalen@ieee.org
Art Kerr	HITL	adkerr@hitl.washington.edu
Dick Slavinski	RL / C3BA	slavinskir@lonex.rl.af.mil
Long Yu	NAWCWPNS / P237	yul@mugu.navy.mil
Suzanne Weghorst	UW / HITL	weghorst@u.washington.edu
Jim Fleming	AL / HRTI	fleming@alr+d.af.mil
Bill Berry	AFOSR / NL	berry@afosr.af.mil
Maxwell Wells	UW / HITL	mwells@hitl.washington.edu
Wayne L. Waag	AL / HRA	waag@hrlban1.aircrew.asu.edu
Glenna A. Satalich	UW / HITL	geesat@hitl.washington.edu
Ryoko Williamson	UW / HITL	ryokow@hitl.washington.edu
Gina Crvarich	UW / HITL	crvarich@hitl.washington.edu
Robert G. Futamura	UW / HITL	futamura@u.washington.edu
Jerry Prothero	UW / HITL	prothero@hitl.washington.edu
Geoffrey Silverton	UW / HITL	geoffs@hitl.washington.edu

Claudia Hendrix	UW / Human Factors Lab	hendrix@u.washington.edu
Capt. Keith A. Shomper	AFIT / ENG	kshomper@afit.af.mil
Ove Bjorneseth	UW / Human Factors Lab	ovebj@u.washington.edu
Keith C. Hullfish	UW / HITL	eagle@hitl.washington.edu
Woody Barfield	UW / Human Factors Lab	barfield@u.washington.edu
Stacey J. Houston	UW / HITL	stacey-houston@uwtc.washington.edu
Capt. Mark Draper	UW	drapermh@u.washington.edu
Hunter Hoffman	UW / HITL	hunter@hitl.washington.edu

The workshop consisted of presentations by each of the Air Force representatives as well as a description of activities at the University of Washington being supported by the AFOSR grant. Items discussed appear on the following agenda.

USAF/U of WASHINGTON WORKSHOP ON VIRTUAL REALITY

Thursday 14 July

0800	CONTINENTAL BREAKFAST (1st Floor Conference Room, Fluke Hall)	
0830	Welcome and Opening Remarks	Waag AL/HRA
0840	Overview of the HIT Lab	Furness UW
0900	Virtual Reality as a Performance Interface and a Training Tool: Empirical Results	Regian AL/HRT
0920	Virtual Environments and Distributed Interactive Simulation: Aircrew Training Research at Armstrong Laboratory	Thurman Al/HRA
0940	Overview of VR at AFIT	Shomper AFIT
1000	BREAK	
1020	Assessment of Human Performance with VR Systems	Eggleston AL/CFHB
1040	Air Force Research in Human Sensor Feedback for Telepresence	Whalen AL/CFBA
1100	Overview of VR at Sacramento Air Logistics Center	Reedy SM ALC/FMDD
1120	Overview of VR at CFBS	Repperger AL/CFBS

1140	Advanced Display and Intelligent Interfaces	Slavinski RL/C3AB
1200	LUNCH (Faculty Club)	
1300	AFOSR research agenda	Wells UW
1320	Demonstrations in the HIT Lab	
1440	Education and training activities at HITL	Winn UW
1500	BREAK	
1520	Force displays	Hannaford UW
1540	Development of subjective measures of presence / Research in the Lab for Interactive Computer Graphics and Human Factors	Hendrix Barfield UW
1600	Using facial expressions as a metric of cognitive function	Weghorst UW
1620	Virtual Reality Monitoring	Hoffman Hullfish Houston UW
1640	Visit to the Laboratory for Interactive Computer Graphics and Human Factors	Barfield UW

Friday 15 July

0800	CONTINENTAL BREAKFAST (1st Floor Conference Room, Fluke Hall)	
0830	Review of Future Directions	All
0930	Identify Possible Areas of Collaboration	All
1000	BREAK	
1020	Final Discussions	All
1130	Adjourn	

Graduate students working on the grant also held a poster session which described their thesis work and shared ideas with the Air Force representatives. Attendees also had the opportunity to view demonstrations of other lab projects.

POSTER PRESENTATIONS

Gina Cvarich	Essential characteristics of a graphical display needed to communicate spatial awareness
Mark Draper	The influence of a virtual body on spatial awareness
Toni Emerson et al	Transforming information into knowledge
Bob Futamura	Effects of spatialized sound on presence

Keith Hullfish Hunter Hoffman Stacey Houston	Virtual Reality monitoring
Jerry Prothero	Is presence a switch in rest frame?
Glenna Satalich	Navigating and wayfinding in VR
Geoff Silverton	HITLab Testbed specifications
Ryoko Williamson	Exploring the effect of information representation for decision making in uncertain situations.

HIT Lab DEMONSTRATIONS

Greenspace	Paul Danset
Towering inferno	Geoff Silverton
Sun demo	Wendy Sommerset
VRD	Rich Johnston
Polyshop	Peter Oppenheimer
Virtual Vision	Mark Billinghurst
Virtual Lab	Dace Campbell
Under sea visualization	Mark Cygnus
Ship fly through	Mark Cygnus
Vestibular simulator	Jerry Prothero
Knowledge base	Toni Emerson

The workshop accomplished several things. First, attendees acquired a survey of the current research projects at each organization. This gave researchers the opportunity to establish communications with others who had related interests. Moreover, formative discussions led to the identification of needs for future research and collaboration. It was generally agreed that there was a need for benchmark tasks in experiments whose results could transfer to real world Air Force scenarios. Such tasks should reflect new models and metrics of human performance in VR that also need to be developed. Lastly, the workshop provided a forum in which to identify possible collaborations. Participants had the opportunity to share their hardware and software needs which could be satisfied by loans from other organizations.

6.0 Additional statements

A one year hiatus in the HIT Lab, during which there were no graduate students, meant that we were unable to commence research as soon as funding was received. We took on new graduate students at the start of the contract. They spent their first year being trained. As is evident from the number of research efforts currently underway, they are now becoming maximally productive. We do not expect this to have a significant effect on our fulfillment of the contract.

Other significant events include changes in personnel. William Bricken stopped working on the project in February 1994. Maxwell Wells joined the HIT Lab as the Associate Director in April 1994 and was delegated responsibility for management of the AFOSR project. Dr. Wells previously worked at Wright Patterson Air Force Base where he served as a senior scientist on projects related to the use of VR technology in high-performance aircraft.

<u>APPENDIX A</u>

Description of the Human Interface Technology Laboratory (HIT Lab)

Lab Description

Brief History

he HIT Lab was established in October 1989 by the Washington Technology Center to transform virtual world concepts and research into practical, economically viable technology products. The Washington Technology Center allocated $250K of seed funding to the HIT Lab for the 89-91 biennium. The lab has since grown and currently has an operating budget of $7.3 million for the 93-95 biennium.

Mission

The HIT Lab's mission is to conduct research and development in human-machine interface technologies that will empower humans by creating better ways of interacting with advanced computers and other systems.

These interface technologies will:

- accelerate learning
- enhance creative abilities
- extend communication
- assist rapid information assimilation
- recapture "lost" world citizens

Personnel - Summary

The lab currently employs 61 people whose positions fall into the following categories.

21 HIT Lab Staff
7 Faculty Associates
22 Graduate student Asst./Assoc.
3 Student Aides
6 Summer Interns
11 Graduates
4 Visiting Scholars
2 Industrial Fellows
2 Consultants
----
61 TOTAL

The Virtual Worlds Consortium

Organized in September of 1990, the consortium serves as a nexus for coordinating the birth of a new global industry. The HIT Lab serves as a bridge between academia and industry, facilitating the flow of ideas, students, intellectual property, and patents between academia and industry. Consortium members provide resources to the HIT Lab to develop infrastructure and crucial technologies, and also provide a focus and driving problems for the lab's activities.

Current Projects

Virtual Retinal Display. The Virtual Retinal Display (VRD) will render existing head-mounted virtual reality systems and state-of-the-art HD TV obsolete. Rather than wearing a bulky helmet display or sitting in front of a flat, two-dimensional screen, the user will put on a pair of conventional eyeglasses and will view images projected directly onto the retina of each eye. The VRD can be used to produce a circumambient environment-a portable IMAX theater for the eyes.

Recent progress on the VRD project includes putting the project infrastructure in place, successfully demonstrating the first phase prototype, and the development and disclosure of the mechanical resonance scanner.

Micro Vision Inc. has recently financed the commercial development of VRD by the multidisciplinary HIT Lab VRD team. The company expects commercial products from VRD technology to start appearing within two years, and full development of the VRD technology to be completed by 1998. Imaging applications of the VRD will benefit science, medicine, education, telecommunications and visual entertainment.

Dynamics Toolkit. A Dynamics toolkit is being created to allow users and world builders to incorporate physical dynamics into VR applications. Dynamical simulation is important in many application areas where physical realism is desired and/or necessary. This software will allow untrained users to generate physical systems capable of performing complex motions. A menu of various joints and bodies will be presented to the user, from which the user can construct his/her physical system.

Spatial Sound Server. The Spatial Sound Server takes the next logical step in virtual audio display implementations. Current systems use dedicated hardware at each participant's VR workstation. The Spatial Sound Server will produce the same results without the requirement of multiple dedicated audio hardware.

Education. The HIT Lab and the U.W. College of Education joined resources to establish the Learning Center as a nexus for VR related research. This exploration process ranges from introducing VR into school curriculum to assessing innovative strategies that promote learning. The Learning Center is a place where teachers, students, and research faculty come together to build virtual worlds that are relevant to school curriculum and to test their effectiveness in the classrooms. Beginning this Fall, the Center will act as a distribution hub from which the hardware and software for world development will be sent out to schools around the country (the VRRV Program).

The Virtual Reality Roving Vehicles (VRRV) Program. The VRRV is a mobile experiential learning laboratory which uses virtual reality to immerse students within interactive 3-D VR learning environments. The primary objective of the VRRV program is to create the ultimate experiential learning environment. This environment will be widely accessible to teachers and students and will be a place where children learn by exploring and sharing virtual "worlds". Students will construct such worlds as part of their K-12 school curricula.

In the tradition of the "bookmobile", the VRRV will transport the virtual reality technology and worlds to the communities and school settings across a wide region, ensuring that a more diverse population of students and teachers are involved. Over the next 3 years, four VRRVs will be deployed in four states. Gradually, the schools will be linked with wide bandwidth cables and will be able to communicate with one another.

The knowledge gained from the VRRV program will help provide direction to HIT Lab's Learning Center for future school-based VR projects, leading toward the eventual use of VR in the nation's schools to improve education.

TreeTown. Complex virtual environments require powerful construction techniques. The goal of the Treetown project is to develop algorithm-based construction tools for building virtual worlds. Treetown is the HIT Lab's contribution to the Polyshop project being developed at the University of South Florida. Treetown provides rapid modeling capabilities that bridge the gap between photographic images and solid modeling with polygons.

Parkinson's & Virtual Images. HIT Lab researchers have helped to develop a radical new approach to the treatment of certain common movement disorders. Many people with Parkinson's Disease experience progressively greater difficulty initiating and sustaining walking, a condition known as akinesia. Using Virtual Vision Sport eyewear co-invented by Tom Furness, near-normal walking can be elicited by presenting virtual objects and abstract visual cues moving through the patient's field of view at speeds that emulate normal walking.

Telemedicine Interfaces. Developments in medical imaging and telecommunications over the past few years are making real-time delivery of health care over long distances a viable option (e.g., long distance transmission of digitized radiology images or video conferencing among doctors). Spurred on by the new ARPA program in remote battlefield trauma care, HIT Lab researchers have been exploring the possibilities of merging virtual interface technology with other enabling telemedicine technologies. Members of the HIT

Lab have been instrumental in assembling an interdisciplinary team of medical researchers from the U.W. Medical Center, the U.W. College of Engineering as well as medical and technical collaborators outside the University. Several research proposals have been submitted for funding.

GreenSpace. The goals of this project are to develop and demonstrate an immersive communication medium where distant participants feel a sense of presence in a shared virtual environment, a "virtual common". Ultimately, the project aims to promote collaboration-at-a-distance among 100 or more participants over broadband networks such as SONET/ATM, immersed in an environment rich in visual, aural, and tactile cues.

This fall the lab will demonstrate a preliminary testbed in which two to four people, in Tokyo and Seattle, will perform a a cooperative task in a real-time 3-D visual space.

VR-Architecture. The CEDeS lab (Cascadia Community and Environment Design and Simulation Laboratory) is a design and simulation laboratory being put together by the HIT Lab and the U.W. Architecture Department. It will integrate traditional 3-D design skills with virtual reality technology to allow immersive simulations of planned buildings and proposed urban developments such as the Seattle Commons project. (A plan to renovate a large piece of waterfront property). Graduate students from the HIT Lab and the U.W. Architecture Department have prepared a virtual representation of what downtown Seattle will look like if the Seattle Commons proposal is approved. This CEDeS lab proof of concept demonstration will be presented to the public this Autumn. The Virtual Commons is indicative of the kind of design and representation that will become commonplace with the integration of VR and architectural design. Eventually, broadband communication links will allow VR demonstrations in the Architecture building using reality machines based in the HIT Lab.

VR in Manufacturing. In collaboration with the HIT Lab, members of the Industrial Engineering department at the University of Washington, applied for and received seed funding to investigate the use of VR in manufacturing.

HIT Lab Facilities

VR system

1 Division Provision 200

VR transducers

3 6D Joystick

1 BioMuse : bioelectronic signal processor to use nervous system signals for the control of digital interface devices

1 Konami Laserscope : voice command optical targeting headset

4 Logitech 6D mouse and tracking system
1 Nintendo PowerGlove
3 Polhemus 3-Space Isotrak
3 Polhemus 3-Space Fastrak with 4 sensors
1 Spaceball 6D
1 VPL DataGlove

VR output devices
2 Crystal River Engineering Convolvotron 3D sound systems
1 Gehring Focal Point 3D sound card
2 StereoGraphics CrystalEyes 3D glasses
1 Virtual Research VR4 Head-Mounted Display
1 Virtual Research Flight Helmet Head-Mounted Display
1 VPL Eyephones Head-Mounted Display

Network servers
1 DECstation 3000 alpha : primary file server
1 DECstation 3000 alpha : network and e-mail gateway
1 DECstation 5000/240 : X terminal server
1 Sun SparcStation 2 : WWW server
Ethernet network devices

Lab computer systems

Computers
1 *Silicon Graphics 100 MHz R4400 Onyx/2 Reality Engine2*
1 Silicon Graphics 150MHz R4400 Indigo2
1 Silicon Graphics 4D 320 VGX
1 Silicon Graphics R4600 Indy
2 Sun SparcStation 10
1 Sun SparcStation 2
6 Sun SparcClassic
5 Sun 4/110
6 DEC 3000 (4 with Kubota video board, 1 with 6300 board samples speech/video)
5 DEC VT1300
1 DECpc 560 ST
2 DECpc 433
1 DECpc 333 portable
1 DECpc 320 SX notebook
5 PC 486
1 NeXT workstation
2 Apple Macintosh Quadra 840 AV
1 Apple Macintosh Quadra 660 AV
1 Apple Macintosh Quadra 650
5 Apple Macintosh Quadra 610
1 Apple Macintosh Centris 650
4 Apple Macintosh Centris 610
3 Apple Macintosh IIfx

1 Apple Macintosh Duo Powerbook
1 Apple Macintosh Powerbook 540C
1 Apple Macintosh Powerbook 520C
7 Apple Macintosh Plus
1 Commodore Amiga 3000

Printers
1 Apple LaserWriter II printer
1 Apple printer
1 DEC Laser 3250 printer
1 DEC Laser 3200 printer
1 DEC PrintServer 20
1 Hewlett Packard DeskJet 650C plotter
1 Hewlett Packard DeskJet 520
1 Hewlett Packard Thinkjet
1 NeXT laser printer
1 Tektronix color printer

External hard disks
1 Apple 80SC expansion
4 Digital storage expansions
6 Ehman external hard disks
2 Sun disks storage

External drives
2 44MB Syquest drives
1 88MB Syquest drive
1 Ocean V256 external 3.5" drive
3 CD-ROM drives

Scanner
1 Digital MD 30C scanner
1 ScanPlus Color 3000 scanner

Software
Development
Borland C++ (PC)
C compiler (DEC)
Hypercard (Mac)

Graphics
Modeling, rendering
Sense8 WorldToolKit (SGI) : C libraries for building virtual environments with texture maps
dVISE (PC, SGI) : set of high-level customizable inclusive tools for building virtual environments
Alias (SGI) : 3D modeling and animation package
3D studio (PC) : CAD 3D modeling, rendering and animation

AutoCAD for Windows (PC) : CAD drawing and 3D modeling
Design Workshop (Mac) : 3D modeling for conceptual design and design development
Sketch : 3D illustration and design
Swivel Pro (Mac) : 3D modeling and rendering for building virtual environments
Body Electric (Mac) : Data flow language

Others

Animator Pro (PC) : 2D image and animation editing
Microsoft Graph (Mac) : graphs building tool
Mac Paint (Mac) : bitmap drawing
Mac Draw (Mac) : object oriented drawing
TypeStyler (Mac)
VEOS: In-house developed Virtual Environment Operating System

Simulation

Performer (SGI) : High performance simulation environment
Inventor (SGI) : 3D object oriented toolkit
dVS (PC, SGI) : runtime software for virtual environments built with dVISE
Virtual Environment Navigator (PC) : low and garage VR package
Rend 386 (PC) : garage VR package
VR 386 (PC) : garage VR package

Scientific visualization

StatView (Mac) : statistical analysis
Mathematica (Mac) : mathematics package

Audio/Video

FusionRecorder (Mac) : video frame grab to Quicktime
Audio Pointer (Mac) : demonstration
Midi 3D (Mac)
PatchBay (Mac) : MIDI environment
AudioMedia (Mac) : signal processing
BioMuse software (PC)
MAX (Mac) : object oriented MIDI development

Audio/Video equipment

Video

Memorex 3.5" portable B&W TV
Mitsubishi 27" color TV
Panasonic HiFi VHS player
Panasonic VHS player
Panasonic video camera
Sony SSM-121 B&W monitor
Sony video 8mm video player

Sony video 8mm camera
Virtual Vision Sport Personal projection TV and camcorder
Phillips CD-I System

Audio

- DEC Audio system
- DECTalk
- Stereo computer speaker system
- MacFace Sonus midi interface used with Mac IIfx
- Realistic stereo mixing console
- Tascam MM-I keyboard mixer
- Sony AM/FM receiver
- Yamaha stereo receiver
- Headphones with microphone (3)
- Headphones (2)

Spatial orientation manipulation equipment

- HITL Tilt Device
- Contravas : servo-controlled whole-body rotator

Electronic test equipment

Optical equipment

Fabrication equipment

APPENDIX B

Description of the Laboratory for Interactive Computer Graphics and Human Factors (Human Factors Lab)

Lab Description

The main goals of this laboratory are twofold: (1) to develop innovative techniques for presenting visual, auditory, and tactile information to users of complex systems and, (2) to perform empirical studies to test alternative methods for designing graphical user interfaces. In addition to the basic research orientation, we also design and build prototypes of visual and auditory interfaces for virtual environment displays.

Presence Within Virtual Environments

The degree of presence that someone feels in a virtual environment is of major interest to researchers and designers of virtual worlds. The basic systems we use for creating stereoscopic virtual environments and to study presence includes Silicon Graphics (SGI) workstations to model and render images, a 6 ft by 8 ft rear projection system to view the images, and a medium resolution head-mounted display for full immersion. With the large rear-lit screen viewing system, we use Stereographics shutter glasses to view the stereo images rather than a head-mounted display (HMD). Using this system, we achieve a high spatial resolution (1024 x 1280) but at the expense of a 360 degree viewing environment. The participants within our virtual worlds interact with the virtual objects by using a data glove, or other 6 degree of freedom input devices such as the Ascension Bird, the Polhemus Fastrak, or by using a 3 degree of freedom space control stick. Furthermore, we are exploring less expensive commercially available products such as the Mattel power glove, the Logitech Cyberman, and MIDI keyboards with pitch wheels, data sliders, and foot pedals, as alternative low cost input devices to manipulate virtual objects. Limited tactile feedback is provided by a Mondotronics Tactor and limited vibration feedback by the Cyberman.

Based on a joint effort with the Human Interface Technology Laboratory, we have established a comprehensive research program to investigate the relationship between presence, situational awareness, and performance within virtual environments. Questions that we are addressing include among others: How do we measure the level of presence experienced by a participant within a virtual environment? What is the relationship between variables such as frame update rate, display resolution, field of view, and presence? Under what conditions might presence be a detriment or benefit to performance?

We are not limiting our studies to fully immersive virtual environments, but are also investigating presence for augmented reality applications and for real environments. Thus far, the greatest emphasis has been on the development of subjective metrics, such as questionnaires to determine the degree of presence one experiences when working in real, augmented, or virtual environments, and the development of performance measures to evaluate tasks performed within virtual environments such as manual tracking, or spatial navigation. Our work on presence will lead to a validated set of metrics which can be used to evaluate presence as a function of the characteristics of the virtual environment.

Spatialized Sound Research

Generally, our work with spatialized sound focuses on determining how best to integrate sound into the virtual environment. Sound has two properties that differ from light. Sound is intrusive and all-encompassing, meaning that it can't easily be shut out and it can be sensed from any direction. We hope to increase the feeling of presence in a virtual world by augmenting the visual objects in the world with specific sounds emanating from the same apparent location in the three-dimensional environment. The use of nonspeech sound has the potential to add a great deal to the functionality of computer interfaces. Sound should be used in computers as it is in the world, where it conveys information about the nature of sound-producing events. Such a strategy leads to enhancements to interfaces such as auditory icons, which are everyday sounds meant to convey information about computer events by analogy with everyday events. Auditory icons are an intuitively accessible way to use sound to provide multidimensional, organized information to users.

We currently have the capability to produce "virtual" three-dimensional sound (or spatialized sound) using three different types of auditory display hardware. The first type of hardware is the Focal Point card produced by Bo Gehring. The card has the capability to spatialize two sound sources simultaneously and independently. The card has two monophonic inputs and one stereoscopic output. Sounds can be spatialized in real-time in terms of azimuth, elevation, and gain. A second card we use to spatialize sound is made by Advanced Gravis Computer Technology. The Gravis Ultrasound card can preprocess a monophonic sound source and play back the spatialized sound in real-time. The Gravis Ultrasound card can also manipulate azimuth, elevation, and gain. Finally, the third card we use to spatialize sound is the Beachtron card made by Crystal River Engineering. Unlike the Focal Point card or the Gravis Ultrasound card, this card has the capability to accept alternate head related transfer functions (HRTF) besides the single HRTF that comes with the card. In addition, the Beachtron card has the capability to spatialize two monophonic sound sources in real-time by manipulating azimuth, elevation, and gain.

For spatialized sound, one topic of investigation concerns the accuracy with which a listener can judge the position of a sound source in three-dimensions. To investigate this topic, we recently completed a study in which we compared the ability of subjects to locate objects in 3-space using either the visual or auditory modalities. In general, the results indicated, not surprisingly, that performance using the visual modality was twice as accurate (overall about 7 degrees) for spatializing stimuli than the auditory modality (overall about 14 degrees). However, the auditory stimulus was found to be an excellent "pointer for the eyes" when the objects were located outside the subject's visual field of view. In another study, Jeff Brandt is investigating the human's ability to localize sound sources in a three-dimensional acoustic environment created using HRTFs played over headphones while a person is moving within that three-dimensional environment. A Polhemus Fastrak is used to track a person's location and head orientation. This information is then fed to a sound card (Beachtron, Focal Point, or Gravis) that imparts the localization information (similar to how your head and pinnae perform the same process) on the sound before it reaches your ear canals. The result is that objects or locations in a three-dimensional virtual world can be endowed with a characteristic voice or sound. It is hoped that this will add realism, aid in localization and identification, and increase the overall feeling of presence in virtual worlds.

Augmented Reality

Currently, most designers of virtual worlds start with a visual void, then laboriously model scenes with polygons, and eventually present computer-generated stereoscopic imagery of the scenes through opaque head-mounted displays. A problem with this approach is that most current workstations do not have sufficient computing power to render the number of polygons necessary to create a complex scene at a high enough frame rate. This often leads to low fidelity virtual environments in which it is difficult for the user to suspend disbelief. In addition, there are many situations in which we would like to interact with the surrounding real word. An augmented reality display can make this possible by presenting imagery that enriches rather than replaces the real world.

Numerous examples of monoscopic real world imagery integrated into graphics environments. However, the real world has a wealth of depth information that it not available using just a monoscopic display. Our approach recognizes this dimensionality, therefore over the last year we have developed a stereoscopic augmented reality system, which is capable of integrating stereoscopic real-time video with stereoscopic computer-generated imagery for use in human computer interfaces.

The prototype system in use in our laboratory was built by Dav Lion and Craig Rosenberg and can be broken down into three main parts; video capture, computer graphics rendering, and signal integration. A brief overview of how the system works follows. The video capture of the left eye/right eye view (both necessary for creating a stereo image) is done using two consumer grade S-VHS cameras. The next step is to digitize the two images using two live motion video capture boards. The computer graphics is generated using Silicon Graphics workstations. Finally, the video images and computer-generated graphics are merged in a video keyer before the combined image is displayed through StereoGraphics hardware on either a 19 inch monitor, a 6 foot by 8 foot rear projection screen, or an HMD. A participant within an augmented reality world is viewing a stereoscopic video image of himself overlaid with stereoscopic computer-generated imagery in the form of stars circling his head. A sensor (Polhemus) is mounted on the users hat to track head position and is yoked to the position of the computer-generated imagery. Note that two video cameras are used to capture the real environment necessary to create a stereo image. The image on the SGI monitor appears double unless viewed using StereoGraphics shutter glasses. Current and future work will be concentrated on improving the quality of both the real-time video images and the computer-generated imagery, together with exploring new possible application areas like; computer aided instruction, equipment maintenance and repair, architectural visualization, and telerobotics.

Furthermore, it should be noted that there are significant technical problems, both hardware and software, which must be solved before augmented reality systems are more widely used. One of the significant problems is the placing of the virtual image exactly where it should be in the real world scene. For applications in medicine, for example, this will be critical. However, for some applications, say entertainment, exact positioning of the virtual object within the scene may not be necessary. For purposes of demonstrating the feasibility of our system, we solved this problem essentially by trial-and-error by first placing the transmitter at a fixed location and then adjusting the software values representing the position of the virtual object until the ring of stars correctly "floated" around the person's head. For our system, we also had to solve the problem of correctly yoking the movement of the computer-generated objects (i.e., stars) to the movement of the user's head. This was accomplished by using a head positioning sensor and by placing a clipping plane through the user's head so that stars which floated behind the person's head were no longer visible.

Stereoscopic Display Design

A general issue in the design of spatial displays is how parameters of perspective, such as geometric field of view (like zoom in film) and station point distance (like dollying in film) influence perceptual and spatial performance using these displays. Manipulations of the geometric field of view magnify or minify the image, while manipulations of the station point distance result in compression of the depth dimension of the scene.

Presenting three-dimensional information using traditional two-dimensional displays requires mental reconstruction of the missing dimension. Three-dimensional displays are considered a more intuitive means in which to present three-dimensional spatial information. However, three-dimensional displays such as perspective and stereoscopic, still required a certain amount of mental reconstruction due to the perspective distortions which are inherently part of perspective displays. The degree to which distortion influences human performance is dependent on the perspective parameters used to design the display. Therefore, it is critical that engineers and designers incorporate appropriate design parameters when creating spatial displays to minimize the effect of perceptual biases on spatial judgments.

Claudia Hendrix and Ove Bjorneseth, have conducted several studies to determine what display conditions, or parameters of perspective, used in designing a perspective display will minimize human errors in spatial judgments. Some of the design parameters they have investigated include the effect of geometric field of view, eyepoint elevation angle, viewing vector angle, target location in the vertical and horizontal dimensions, stereoscopic versus monoscopic display conditions, and the interaction of these factors with three-dimensional sound on human performance in spatial judgments.

A study in progress is designed to investigate the effect of the presence or absence of depth cues on judgments of spatial information. The experimental set-up for a typical study generally involves a subject, wearing time multiplexed shutter glasses from Stereographics, viewing a stereoscopic perspective display on a screen. The subject uses a screen to the right to record a response. This study will allow us to determine the importance of individual depth cues, the effect of their interaction, as well as the degree to which they influence the magnitude of error in spatial judgments. The accumulation of information generated by the perspective display studies has resulted in human factors guidelines that can be used to design perspective displays so as to maximize human performance in spatial judgments.

Facilities

Hardware

Computer Systems
- 2 Silicon Graphics Indigo2 Extreme Computer Graphics Workstation
- Silicon Graphics IRIS 4D 70/GT Computer Graphics Workstation
- HP 340 Computer Graphics Workstation
- 4 IBM AT Compatible PC (386/486)
- Texas Instruments Microexplorer
- Introl Hard Drive
- 3 Macintosh Computers
- Laser Writer II Printer
- Okidata Printer, other PC printers

Displays
- GE Imager 610 Back-lit 6'x8' Screen Projection System
- 3 SGI 19" High Resolution Stereo Capable Monitors
- Eye-Gen 3 Head-Mounted Display
- Sony PVM 2030 NTSC Video Monitor
- Virtual Vision
- Stereographics CrystalEyes 3D Glasses

Tranducers
- Ascension Bird, a 6df position and orientation tracking device
- Polhemus Fastrak, a 6df position and orientation tracking device
- Logitech Cyberman, 6df vibrotactile mouse
- Tactor, a tactile output device
- Power Glove, 4df finger positional sensing input device
- Flight Stick

Audio
- 3 MIDI Interfaces (Mac, PC, UNIX)
- Roland Tone Generator
- Ensoniq Digital Sampling System
- 12 Channel Mackie Audio Mixer
- 4 Channel Realistic Audio Mixer
- Stereo Amplifier
- Focal Point 3D audio card
- Crystal River Beachtron 3D audio card
- Gravis 3D audio card
- Infinity Speakers
- Roland MIDI Keyboard

Video
- Two 8mm Video Cameras for Stereo Images, with Stereo Mount (RICOH)
- 1 Canon Camcorder
- 2 Miniature CCD Cameras
- Two Industrial SVHS Video Tape Recorders (Panasonic 7500A)
- Two Video Capture Cards (New Media)
- Video Editing Equipment (Videonics)

- Victor NTSC to RGB Converter
- Mediator VGA to NTSC/SVHS Converter
- Videologic Scan Converter
- Lyon Lamb Minivas Animation Controller
- ENC VII NTSC Encoder/Sync Generator
- Kitchen Sink, time based corrector
- Laird Video Keyer
- Video Titler
- Pentax 35mm Camera with Tripod and Filters
- 35mm Slide Projector

Simulator
- Automobile Simulator, full scale, fully instrumented

Software

- Alias : Software for modeling, rendering, and animating images
- I3DM : Software for modeling, rendering, and animating images
- Precept : Virtual environment development software, developed in-house
- Open Inventor (SGI)
- Performer (SGI)