White Paper

The Benefits of Immersive Visualization in the University

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Introduction

SGI™ Reality Center™ facilities are a seamless integration of hardware and software technologies used for immersive, collaborative visualization, also known as virtual reality (VR). These facilities enable the creation and use of interactive, multisensory, three-dimensional worlds, or environments and models. Immersive visualization configurations are historically recent. The viewer-centered perspective of immersive visualization can be traced to Ivan Sutherland's 1968 "Headmounted Virtual Reality" prototype. The first public demonstration of an immersive visualization system designed to accommodate groups of people was the University of Illinois Electronic Visualization Lab's CAVE exhibit at SIGGRAPH in 1992.

The integration of SGI Reality Center configurations into the university context has taken place very quickly since that first CAVE debuted. It is the purpose of this white paper to describe the quantitative and qualitative return on investment benefits that SGI™ immersive visualization configurations are already providing.

The findings herein are based on interviews conducted via an inductive case study approach with a methodology of describing, explaining, and understanding. A selected group of Reality Center customers who are directors of university research programs were interviewed and their responses recorded and categorized.

1.0 The Modern University

1.1 Traditional Responsibilities

A modern university must possess the facilities and faculty to engage in work far beyond the introductory level and is characterized by a commitment to excellence. While Reality Center technologies are still relatively rare in university laboratories, the research using these systems has been so effective to date, showing increased efficiencies and expanded comprehension, that Reality Center platforms will soon become a key platform for research in numerous disciplines and industry-based projects.

Academia is highly competitive in the pursuit of new research findings, and Reality Center capabilities strengthen both the research process and findings. According to all case study interviewees for this study, both government and industry funding sources recognize the worth of Reality Center configured research. Every interviewee stressed that the presence of Reality Center configurations gives their research projects an edge in funding competition.

Today's university maintains much of the symbolic legacies of the academy from ages past, although the strain of newer demands are apparent-especially in terms of financing and infrastructure. The university's traditional values and roles are threefold: 1) research, 2) teaching, and 3) service. The modern university administration's data management infrastructure is a fourth institutional responsibility and one that is now largely computerized across campuses.

1.1.1 Research

The research mission of the university carries the ancient scholarly tradition of "vita contemplativa" —the importance of reflection, contemplation, and mature evaluation of ideas. Immersive visualization research was found to be broken into five major categories at the conclusion of the 1990s:

1.1.1.1 Basic research and development deals with the capabilities of virtual reality hardware and software. The hardware and software development under way at Iowa State University's Virtual Reality Applications Center (VRAC) falls into this type of basic R&D research category. Says VRAC's Carolina Cruz-Neira about her software project, "We built VR Juggler to accommodate whatever hardware input device is most appropriate for the application." (Note: VRAC has numerous research projects under way, and not all are R&D efforts.)

Software research and development has already proven to be beneficial for VRAC. VR Juggler lets the developer concentrate on the application without spending a great deal of up-front time with technical or rendering details. Preliminary findings from VRAC indicate that immersive visualization approaches may accelerate research findings overall. Cruz-Neira reported findings for one particular project in which engineers using VRAC's 12-foot by 12-foot C2 immersive configuration were 50% more efficient when finding critical elements within immersive data as compared to traditional nonimmersive methodology for that same project.

1.1.1.2 Applied research is the direct use of the configurations in such fields as astrophysics, fluid dynamics, computational chemistry, economics, architecture, education, and training. The University of Houston's Virtual Environments Research Institute (VERI) is an excellent example of how applied immersive visualization research moves from laboratory research conducted by a collaborative, multidisciplinary team to a concrete application that is used in the real world. The applications that originated in VERI's Reality Center configurations are now being used for actual training of NASA astronauts. The economic ROI for applied research is realized in the field after the research becomes operationalized. In the example of VERI, NASA's shuttle missions now routinely train astronauts in VR environments based in part on VERI's research. NASA's cost-benefit returns are realized because VR environments are more cost-efficient for training astronauts than the water tank training environments previously used.

1.1.1.3 Multidisciplinary research projects are becoming more numerous on all university campuses and overlapping to some extent with applied research efforts. Numerous applied research projects being conducted with Reality Center configurations are becoming multidisciplinary in nature with team members drawn from numerous disciplines collaborating to solve real-world problems. Grant formulas from government agencies such as the National Science Foundation as well as from corporate agencies are becoming weighted in favor of multidisciplinary collaborative research on projects that are complex and drawn from the real world.

William Jepson, computing director of UCLA's Architecture and Urban Design Department, commented that "research devoted toward one discipline is hypothetical in nature, but a multidisciplinary research team reflects the complexity and interaction of the actual world and concrete situations." Reality Center visualizations provide the most powerful depiction of the complex natural world and in so doing provide strong computer and metaphorical environments in which these multidisciplinary research teams can analyze complex situations.

UCLA's "Visualization Portal" was not yet in operation at the time of the case study interviews. But Margo Reveil, coordinator of the "Portal" that is scheduled to open in 2000, explained that UCLA's new immersive visualization facility is designed to support multidisciplinary cross-campus research for UCLA's widely distributed campus. Reveil further commented that both government and private sector grants are now requiring multidisciplinary teams. UCLA already has a strong history in supercomputer visualization and multidisciplinary teams; the Laboratory of Neuroimaging at the UCLA Division of Brain Mapping's project was the first ever to combine advanced neuroscience and advanced computer graphics technology.

1.1.1.4 Human-centered research focuses on the effects of immersive visualization technologies on humans physically or cognitively. The M.I.N.D. Lab at Michigan State University is perhaps the first university in the world to concentrate on the interaction of mind and the immersive visualization medium.

Human-centered research will undoubtedly create new knowledge about human cognition, cognitive diversity, and multidisciplinary science related to immersive motor channels, to name just a few. The "soft sciences" are under more and more examination from international businesses. Psychosocial characteristics are becoming considered as competitive advantages in the international business arena. For example, a recent statement from global telecommunications leaders stressed that "diversity is a competitive advantage. Different people approach similar problems in different ways." Coincidentally, several interviewees for this white paper commented on immersive visualization's ability to "attract diversity," and Don Stredney of Ohio State University emphasized the technology's ability to "nurture cognitive diversity." The industrial clients of future Reality Center applications also support the need for human-centered research. Victor Schmitt, exploration editor of OffShore Magazine, expressed concern at the lack of human-centered research when he wrote about VR's use by the oil industry in May 1999: "All VR sessions are a form of active undocumented experimentation at this point . . . there are currently no research projects focused on the psychophysical effects of VR systems on interpreters." Those psychophysical research teams may be forming even now as this report is prepared. The University of Houston's Bowen Loftin concurred with the importance of the soft sciences such as communication when he discussed the collaborative communication capabilities of networked Reality Center facilities. Loftin believes the collaborative interactions that will be possible within future Reality Center installations will become the secret to success for economic globalization. The research returns in this category are yet to come, but the ROI opportunities are becoming better defined as businesses better understand their need for psychological characteristics such as the diversity example discussed above. In terms of hardware, human-centered research will benefit teleimmersion interfaces and the overall quality of communication mediated electronically.

1.1.1.5 Technology transfer is research devoted to the long-term development of commercial products. The Australian National University's Collaborative Virtual Environments (COVE) Project is one of the first university-based immersive visualization research efforts to transfer a marketable product from the university laboratory to the marketplace. The COVE project developed the haptic ReachIn device that is now being marketed by ReachIn Technologies in Sweden. More and more, the traditional research university will be encouraged to extend its traditional research mission into the arena of commercial development. No ReachIn commercialization figures were available for this effort, but the economic ROI benefits of technology transfer can be directly accounted. Royalties and gross license income received are already tabulated and ranked for universities. For example, the University of California system had gross license income of $67 million in 1997 from technology transfer projects. A percentage of future Reality Center research will produce technology transfer moneys.

Immersive visualization not only extends existing lines of research in established areas within computer science or engineering, but also promises fertile new research domains as well. It's estimated that knowledge doubles every five to ten years and undoubtedly the Reality Center projects will be part of that proliferation. As an example of new research interests, University of Houston's Bowen Loftin pointed out the "complete absence of a theory of a multisensory representation," and he predicted that many discoveries will be made as computer scientists turn their attention to multisensory representations generated by immersive visualization configurations. These technologies will open new arenas of research and commercial development for multisensory computing as well.

1.1.2 Teaching

Teaching is the second mission of the university, and it may be the function most affected by technology. At the time of this white paper, the teaching process had not been affected significantly yet by immersive visualization technologies. As Roy Kalawsky of the UK's Loughborough University Advanced VR Research Centre commented, "We don't have readily available content yet nor have we adequately researched pedagogical models to use with these systems to date." But he forecast that both content and pedagogical theory and teaching methodology will evolve to best utilize the technical capabilities of Reality Center facilities for learning environments.

Meanwhile, the majority of interviewees for this white paper predicted that Internet2's broad bandwidth will bring immersive visualization based on cubicle-like desks into common collaborative usage within the next 10-20 years. The student will sit at a desk in the middle of a complex networked, collaborative learning space. Other students and professors from disparate locations will be brought together into these virtual learning spaces within Reality Center environments.

With respect to benefits gained in Reality Center facility-based learning environments, preliminary results are tantalizing. Return-on-investment for Reality Center training applications can be estimated by reviewing flight simulator efficiencies and the successes of early VR training studies, such as the 1995 Motorola headmount-based assembly assessment. (This study was conducted at Motorola University. In Motorola's controlled study of VR's effectiveness, 21 trainees from three factories were trained for the same assembly tasks in three manners: 1) standard, on-the-job training; 2) computer-based curriculum using a mouse for input; and 3) HMD technology and specially designed software depicting the factory process and assembly tasks. The trainees who were trained in the virtual manufacturing environment performed as well as and better than the other two control groups. An additional benefit is that neither the VR-trained group nor the computer curriculum-trained group incurred costly errors.)

While not statistically significant, early findings indicate that VR's ability to provide an individual trainee with a virtual factory can be of great economic benefit in the corporate training field.

In terms of situated learning, interviewees for the case studies tell of "understanding" the visualized data instantly, of "seeing it better and putting the information together more intuitively." Reality Center style visualizations capitalize upon the human brain's powerful biological visual processing capabilities. For example, early applications of Reality Center within the oil industry have enabled geophysical scientists to make accurate decisions in a very time-efficient manner that saves the parent companies literally millions of dollars.

Those same benefits will lead to equally positive return on investment for future learning curricula.

The accelerating technological innovation will transform all aspects of university-level teaching and learning in ways that are outside the parameters of this study. There seems little doubt that immersive visualization configurations will be in the literal and metaphorical center of that teaching-learning transformation-with tomorrow's professors and classes literally standing or sitting in the middle of Reality Center spaces.

1.1.3 Service

Professional service includes all professional activities that enrich the greater community of the academy. Land-grant universities in the United States have an additional need to serve the geographical society in which they are based. For most individual researchers, service includes publishing (particularly in refereed journals), presenting at professional meetings, volunteering in some kind of capacity with professional organizations, and serving on university committees as an elected officer or a volunteer.

Immersive visualization professionals are quite active in the professional service arena with IEEE VR, SIGGRAPH, and ACM conferences, related to computer-human interface. Additional research findings expand the potential for additional service activities, even for new publications and special interest groups (SIGs) within professional associations.

1.2 Challenges

The overarching challenge to universities today is that of funding. Major university programs can't operate without outside sources of funding. Examples abound in which universities receive half their total budgets from government and private research grants. Reality Center projects are showing the way to the future in terms of funding patterns on university campuses. Reality Center efforts are even now more closely aligned with sources of outside funding than has been the norm for the academy. The presence of cutting-edge technologies places universities in a strong competitive position for both government grants and industry funding, particularly for multidisciplinary research. The lineup of funding institutions for current Reality Center research is a stellar list of the worlds' most prestigious granting agencies.

2.0 Immersive Visualization Configurations

2.1 Overview

Reality Center facilities are a seamless integration of hardware and software technologies used for immersive, collaborative visualization, also known as virtual reality. These facilities enable the creation and use of interactive, multisensory, three-dimensional "worlds," or environments and models. The name "Reality Center" initially described only SGI's theater-type environments; the first of these opened in July 1994 at SGI's UK headquarters in Theale, Berkshire. That installation is a room designed to accommodate up to 35 people. One wall is occupied by a wide, curved projection screen and the rest of the wall, ceiling, and floor surfaces are matte-black. The screen shape is a section of a sphere with a 12-foot radius, providing the occupants of the theater with a 150° horizontal x 40° vertical field of view, sufficient to immerse them visually in the images being displayed.

Today, the Reality Center nomenclature has been expanded to include all SGI configurations that provide an immersive, collaborative computing environment to support workgroups handling multiple processes, from engineering and data analysis to training and presentation. Present-day configurations include Reality Center walls, Reality Center desks, and Reality Center rooms, all of which will be discussed later in this section.

2.2 History

Reality Center configurations are the evolutionary melding of virtual reality technologies and concepts with projection-based display technologies and techniques. The concept of an interactive, multisensory, three-dimensional, computer-generated world originated with Ivan Sutherland in 1965, when he proposed the "Ultimate Display": a display connected to a digital computer that gives us a chance to gain familiarity with concepts not realizable in the physical world. Sutherland's first virtual reality prototype in 1968 combined position tracking, a stereo headmounted display, and a graphics engine that synthesized and displayed a virtual environment to the user.

This area of Sutherland's work blossomed into the headmounted display (HMD) and the virtual reality field as we know it today. The standard virtual reality HMD is a set of goggles or a helmet with tiny monitors that generate 3D images in front of each eye. Often the HMD is combined with a head tracker so the images displayed in the HMD will change as the head moves. HMDs isolate the viewer from the ordinary world and provide a viewer-centered perspective on the computer-generated world. Other hallmark features that have come to be regarded as characteristic of a VR experience include navigation, immersion, engagement, presence, and interaction.

Projection-based displays are the second important precursor of today's immersive visualization family tree. Flight simulators, often housed in domes, have used projection-based technology since the early 1970s. Earlier vehicle simulators had functional instrument panels built inside plywood boxes mounted on motion platforms. Images were supplied by video cameras suspended over scale models of airports and the motion controlled by the actions of the trainees seated inside the simulated cockpit. In the late 1960s, Sutherland realized that computer-generated images could be used for flight simulators, and he and David Evans formed a company named Evans and Sutherland that manufactured and produced interactive computer graphics engines for flight simulators.

These types of systems have proven to be extremely effective for training pilots due in part to their wide field of view that exploits human situational and spatial awareness. The perspective maintained in a sphere is naturally a wide angle and a natural imaging paradigm comes into play when images are projected onto a hemisphere or dome. The eye naturally points to the center of a sphere and the perspective tends to be maintained at a wide angle. However, the drawbacks of flight simulators include these points: 1) the focus of attention for a pilot in a flight simulator is a vehicle-centered perspective, and 2) the system does not allow for social interaction, group decision-making, or collaboration.

In the early 1990s, researchers began to pull together the various theories and components of display systems to produce immersive visualization configurations that are more than the sum of the parts of virtual reality and flight simulators. History was made in 1992 when the power of viewer-centered headmount technology was coupled with the strengths of projection systems at SIGGRAPH 92. The University of Chicago's Electronic Visualization Lab developed its first CAVE (Computer Assisted Virtual Environment) and displayed the configuration at the Chicago SIGGRAPH. The CAVE virtual reality environment is a projection-based VR system that not only overcomes many of the limitations of other systems, but also offers a new approach to VR design.

The CAVE concept has evolved and been commercialized, and a number of vendors today are building virtual reality "rooms" rooted in the original CAVE's design. Modern virtual reality rooms vary, but still have the advantages of the original CAVE structure. Carolina Cruz-Neira, the designer of the original 1992 CAVE, identifies these advantages for configurations now commercially available:

- High resolution: projection system's resolution is determined by the image generator capabilities
- Large field of view (FOV): projection planes surround the viewer, providing a large FOV and a panoramic view
- Noninvasive display: participants wear shuttered or polarized glasses and do not require any heavier headgear
- Easy to share: multiple participants can share the experience by simply stepping inside the projected area
- No isolation from the real world
- No need to recreate real objects
- Real and virtual objects can be mixed in the environment

- Participants can tolerate slower rendering adjustments in the stereo projectors

In the CAVE confluence between VR and projector systems, SGI saw the potential significance of large-scale, immersive, interactive, real-time graphics visualization technology to industrial, scientific, medical, and entertainment systems. The first curved-screen Reality Center facility was built in the UK in 1994.

2.3 Types of Reality Center Configurations

In the years since the 1996 opening of the front-projected, curved-screen Reality Center at SGI corporate headquarters in Mountain View, California, over 22,000 people have experienced the SGI Reality Center theater-type setting. Many rear-projected, immersive visualization facilities from outside vendors are also thriving. SGI Reality Center walls and rooms typically call for an up-front investment in the range of U.S. $300,000-$500,000. Stereoscopic desks (also called workbenches) are available at a lower cost. As of this writing (early 2000), approximately 300 desks, walls, and rooms have been installed around the world.

Today, SGI Reality Center configurations typically feature a fully integrated system with powerful visualization display of 3D and 2D graphics, high-performance computing architecture, and video applications support. Varied display and control configurations support diverse functions, group sizes, and software applications. A Reality Center facility immerses the participants in the data, so they can move around and perceive the data much as they perceive the physical world. A flat or curved screen may comprise one wall or more fully surround the audience. The images may be viewed in stereo. The control of the visualization may involve a keyboard or a handheld tracking device.

An overview of each of the configurations is provided below.

2.3.1 Reality Center Walls

These are large, flat, or curved screens that may be front-projected or rear-projected; two, three, or more projectors are typically arranged in a linear array to create a single, wide, seamless, high-resolution image. Reality Center walls may or may not use stereoscopy and/or tracked input devices.

2.3.2 Reality Center Desks

Desk-style configurations are powerful solutions for scale models and environments. The desk uses folded optics to project bright, high-resolution images in two dimensions or stereoscopic views onto an intuitive, table-like work surface. The design supports collaborative workgroups and easy access to any part of a computer model. A stereoscopic desk with tracking devices supports extremely natural interaction with 3D imagery. Images viewed with tracked, active stereoscopic eyeware appear to float above the table and can be viewed from all angles like a physical object.

2.3.3 Reality Center Rooms

The room-sized visualization systems combine high-resolution, front- and rear-projected display of 3D graphics onto rectilinear screens to create the illusion of complete immersion in a virtual environment for one or more participants. These "rooms" maintain high-resolution over a wide field of view by using arrayed projection techniques developed for training simulators. Multiple video outputs are tiled or soft-edge-blended over the screen surface to create a continuous, geometrically correct image when properly rendered. The participant walks right into the middle of the room for a complete "you are here" experience.

2.4 The Power and the Promise

Research is being conducted throughout the world with Reality Center configurations today. These kinds of display systems can greatly amplify the productivity and creativity of workgroups. The ability to present a high-resolution, spatially immersive environment to a group of people can greatly enhance their understanding and communication of complex situations, processes, and data sets.

3.0 Return on Investment Benefits Offered by Reality Center Systems

3.1 Quantitative Return on Investment

Although specific industrial research tasks have been evaluated and found to be conducted more efficiently by using immersive visualization systems, researchers hesitated to have those specific numerical results reported and informally generalized to all efforts. The research paradigms and statistical sampling of sizes of the case studies included in this white paper were not originally designed to provide data that could be extrapolated and ethically interpreted to represent all immersive visualization efforts. There was also concern that the projects have not had time to produce quantitative findings of statistical significance yet.

Nevertheless, within these interpretative cautions, the hard quantitative returns have all been positive for the individual studies performed. Broadly, the quantitative findings thus far have been significantly more accurate and significantly quicker than the same processes undertaken without a Reality Center configuration. Further, the general sense is that the quantitative benefits of the Reality Center approach are not specific to a particular project nor even to an individual discipline.

Quantitative return on investment findings:

- The presence of an immersive visualization configuration on-site attracts significant research dollars from both private and government sources
- Industry is ever more interested in immersive visualization as a business tool and supportive of both basic and applied research in the university setting for the purpose of developing specialized business tools
- Immersive visualization research enables processes that are cost- and time-efficient for industry
- Immersive visualization reduces transfer costs in learning, education, and training scenarios
- Immersive visualization makes the multidisciplinary research process more efficient because the virtual scenarios enable scientists from various disciplines to understand each other's culture and orientation more quickly and with greater accuracy

Furthermore, it is generally understood that collaborative, networked environments afforded by Reality Center systems will make globalized business operations less expensive and more effective since far-flung work teams will be able to easily and economically communicate.

3.2 Qualitative Return on Investment

Qualitative benefits were by nature more subjective and often were calculated in "softer" or emotional terms. There are no standardized criteria against which to rate "better quality of student and faculty," but each interviewee stated that the presence of Reality Center configurations attracts high-quality staff.

While it is difficult to measure the emotional impact of a larger-screen immersive experience, this effect must not be overlooked. Universally, first-time participants tend to react to a Reality Center demo with one word: "Wow!" Every respondent cited the emotional impact as a solid financial benefit to these case-study universities. The visceral, positive, emotional response was seen as a tool that leveraged sponsors and financial backing overall.

Qualitative return on investment findings:

- Immersive visualization studies generate important new knowledge
- Immersive visualization supports and extends upon existing discipline areas of expertise on a campus, thereby strengthening existing research as well as originating new inquiry
- The visceral, overwhelming positive response to immersive visualization demonstrations is a powerful good-will tool for building coalitions with university administrators and possible outside funding agencies
- A better quality of graduate student is attracted to research projects having immersive visualization capabilities
- Cognitive diversity is promoted with Reality Center research and development
- Immersive visualization is an attractor of faculty and student diversity
- Professional service opportunities for publishing and presenting new research findings will increase as immersive visualization matures as a discipline of study

3.3 Summary

Throughout the course of the interviews for this paper, it was found that the immersive visualization projects had been integrated into the existing university infrastructure in such a way that traditional university responsibilities of research, teaching, and service are being well served by the technologies. Therefore, the traditional academic triad of responsibilities is receiving return in the academic definition of ROI. At the same time, more industrially oriented ROI can be seen in terms of efficiency and effectiveness for problem solving with the use of Reality Center configurations.

It was also found, albeit unexpectedly, that the early adopters of Reality Center technologies are also providing glimpses of newer patterns of operation within the university infrastructure. This is an unanticipated ROI that is emerging ethnographically out of the collaborative nature of Reality Center research itself. Reality Center media are shaping researchers into tighter, more collaborative research groups around the world than has been common to date. Case study respondents indicated that their larger immersive visualization community is collaborative and tight-knit, global in orientation, multidisciplinary in thought rather than adherent to a single discipline, and more closely aligned with sources of outside funding than has been the norm for the academy in decades past.

Researchers contacted for this white paper stressed their allegiance to traditional research ideals. They also emphasized that academia is highly competitive and expenditures are evaluated to determine whether moneys have produced front-runner status. There is a great deal of pressure on universities to maintain first-level funding and concomitant research. Sociologist Woody Powell from the University of Arizona spoke of the need for return on investment assessments: “There are huge costs of being left behind in the academic setting. Universities no longer in the vanguard will find themselves poorer, losing out in competition for new facilities, and losing up-and-coming faculty, promising graduate students, and research funding.”

4.0 Case Study: Comprehensive Descriptions

The Chicago School’s inductive case study approach was the research methodology used for this white paper; a complete description of the methodology can be found in the Appendix, 6.2. The premise of this effort was that immersive visualization configurations provide quantitative and qualitative ROI benefits within the university setting. Case study interviews that are recorded here are with:

4.1 Dr. Frank Biocca, Media Interface and Network Design Labs, Michigan State University, East Lansing, Michigan, and Ohio State University, Columbus, Ohio;

4.2 Dr. Carolina Cruz-Neira, Virtual Reality Applications Center, Iowa State University, Ames, Iowa;

4.3 Dr. Peter Ebbesmeyer, Heinx Nixdorf Institute, University of Paderborn, Paderborn, Germany;

4.4 Dr. R. Bowen Loftin, Virtual Environments Research Institute, University of Houston and NASA/Johnson Space Center, Houston, Texas;

4.5 Dr. Don Stredney, Biomedical Applications Research Initiative, Ohio State University, Columbus, Ohio;

4.6 Dr. Glen Wheless, Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia.

4.1 Michigan State University, and Ohio State University

M.I.N.D. Lab
www.mindlab.org
Interviewee: Dr. Frank Biocca, Ameritech Professor of Telecommunication

The Media Interface and Network Design (M.I.N.D.) Labs are composed of a network of research facilities. Currently the M.I.N.D. Lab has facilities at Michigan State University and Ohio State University. Others labs, including overseas facilities, are in negotiation or under development. The M.I.N.D. Labs are dedicated to research on how telecommunication technology can augment human ability. The labs subscribe to the principle that minds linked via intelligent virtual environments can work better than minds alone. The M.I.N.D. Lab conducts research on human-computer interaction, the interaction of mind and medium. The research produces designs for virtual reality, VRML, social presence, and communication applications of virtual environments. It has one of the largest research teams in the world concentrating on human communication research in immersive visualization configurations.

Lab Director Biocca stressed that the M.I.N.D. Lab is especially interested in the various ways the body will be connected to immersive visualization interfaces in the future. Interface design for teleimmersion is an emphasis at this lab. Biocca explains, “The body is the primordial means of communication, and greater immersion of sensory and motor channels will be inevitable in the future of virtual environments.”

CONFIGURATIONS ON-SITE

Systems

The M.I.N.D. Lab has two sets of virtual reality configurations. The first is a stereoscopic, large screen visualization configuration, an ImmersaDesk from Fakespace Systems (also sold by SGI) driven by a Silicon Graphics® Onyx® InfiniteReality® workstation from SGI. The second configuration is an immersive-VR headmount system using Fakespace Pinch gloves and also driven by an Onyx InfiniteReality workstation.

Rationale for Systems Chosen

The two systems serve different purposes. The ImmersaDesk is used for R&D of applications that involve multiple scientists interacting within visualization/simulation data. There are powerful arguments for the ImmersaDesk system—it's relatively easy to use and it's less expensive than full immersive configurations. Its drawback is that the configuration is not presently networked, although it can be.

The HMD configuration is used to do research on immersive systems that include higher levels of embodiment that involves greater immersion of the senses and motor systems. One such endeavor is to determine whether virtual environments facilitate learning or interaction. But a major research interest with the HMD system is in the exploration of cognition, manipulation, and memory for the information space around the body. The M.I.N.D. Lab believes that the interface is the driving force rather than the applications. Immersive VR configurations are therefore used for research on spatial cognition, i.e., whether being immersed makes natural spatial memory more or less effective.

RETURN ON INVESTMENT BENEFITS

Quantitative Return

Biocca explained that immersive visualization configurations enable the M.I.N.D. Lab to attract research projects and funding. "Grant funding is intellectually driven and new knowledge is the goal."

The promise of breakthrough new knowledge is implicit in psychosocial research with Reality Center configurations. The entire field is new, and the major findings are yet to be made. The first M.I.N.D. Lab officially opened January 1999 at Michigan State University. The second lab at Ohio State University opened in April 1999. The labs were initially supported by a $1.5 million endowment from the Ameritech Corporation and $300,000 in equipment funding from Michigan State University. In this first year, the labs have also obtained an additional $800,000 in funding and contracts from the National Telecommunication Initiative, MSU Foundation, Ameritech, and National Council on Aging. The lab has applied for a patent on collaborative teleimmersive environments using projective HMD displays called the Teleportal system. Most of the grants and projects in 1999 dealt with research on the psychosocial implications of Internet2, human factor issues in teleimmersive systems, and medical visualization.

Although the grant funding is quantifiable, the findings are softer. "It's difficult to obtain a quantitative measure of our psychosocial results. The metrics for the hard quantification of presence and certain aspects of spatial cognition are not there. We also can't measure the exact amount of and transfer of knowledge and learning from the virtual environment to the real world, but we can gain understanding of intellectual tasks even though we can't look inside someone's head." Nevertheless, "soft" findings in this field are worthwhile and a definite return on investment to the larger HCI research community, governmental policy makers, and corporate training community.

Qualitative Return

The qualitative ROI is based in the emotional response to the systems. The demonstrations "fire up the imagination of the visitors, add visibility to our efforts, and undoubtedly assist in attracting grant moneys and students." Biocca reflected somewhat humorously, "Build a field of dreams, and they will come."

STAFFING PATTERNS

The number of people affiliated with the lab has grown by 200-400% per year since early construction in 1997 when the lab had only three people. By late 1999 staffing had grown to include 25 researchers and support staff who can be sorted roughly into three groups: 1) Faculty and research associates from Michigan State University and Ohio State University who develop projects correlated to the lab's mission. These staff members include specialists in computer science, telemedicine, engineering, educational technology, telecommunication, Internet design, psychology, and electronic commerce. 2) A dedicated M.I.N.D. Lab staff that includes a full-time lab manager, graduate assistants/students, two graphics artists, three programmers, and interns who labor for credit. 3) A third group that includes visiting researchers who are funded by other sources and whose labor costs are low.

Three kinds of sessions are routinely scheduled with the immersive visualization systems: 1) Experiments that manipulate an interface research and observe changes in human cognition or behavior. These experiments are typically run every day for several weeks, but not more than an hour at a time. 2) Graduate students and faculty use the systems to examine 3D data sets, e.g., from zoology and radiology. 3) The public relations category is ongoing with one- to two-hour demonstrations of configurations to administrators, funders, executives, and visiting dignitaries.

PROJECTS

- Human/computer interface (HCI) theory (tests of the effect of embodiment, presence, and spatial cognition on performance in teleimmersive environments)
- Communication design (design of visualization and applications; current projects include a system in pediatrics, supernova explosions for physics, and veterinary medicine visualization)
- HCI evaluation (testing and evaluation of commercial or governmental software systems and applications)
- Psychosocial effects of virtual environments (experiments on the psychological and social effects of short-term and long-term use of teleimmersive systems)

HARDWARE

- Onyx InfiniteReality
- Polhemus trackers
- Intersense trackers
- Fakespace gloves
- Logitech input devices
- Virtual Research V8 HMD
- Fakespace ImmersaDesk
- Sony Glasstron HMD

SOFTWARE

- MPI MultiGen
- MPI SmartScene
- EAI/Sense 8 WorldToolKit
- Java™ 3D
- VRML
- Kinetix 3D Studio

4.2 Iowa State University

VRAC—Virtual Reality Applications Center
Physical Research and Technology
www.icemt.iastate.edu/about.html
Interviewee: Dr. Carolina Cruz-Neira, Assistant Director of VRAC

The Virtual Reality Applications Center, formerly known as the Iowa Center for Emerging Manufacturing Technology, is an exemplary multidisciplinary center devoted to computing and visualization resources for synthetic environments. The research involves the integration of humans and computers with advanced interfaces that enable haptic and audio interaction between users and computer-generated environments.

VRAC moved into a new facility in the summer of 1999. This facility enhances the university's industrial research in the use of virtual prototypes and human-in-the-loop simulations with tools that aid new product design and data visualization.

CONFIGURATIONS ON-SITE

Systems

VRAC has the latest in surround-screen virtual reality technology. The initial immersive visualization configuration on-site, called the C2, is the facility within which much groundbreaking research has taken place. VRAC will have two immersive configurations in operation by June 2000. VRAC's newest immersive visualization configuration-called the C6-will officially open June 2000. Still in the design and construction stages, the C6 will provide a fully enclosed immersed "space" once in operation. VRAC will also have a 250-person auditorium with large-audience VR capabilities.

Once in operation, the C6 will be networked with the C2 and the auditorium and will enable VRAC to investigate the use of distributed synthetic environments for solving challenges in engineering and science. The research conducted within the two systems networked together in VRAC's facilities will eventually advance technology for collaborative efforts across states, countries, and continents.

Rationale for Systems Chosen

Cruz-Neira explained, "We are very oriented toward engineering applications." Within that specialization, VRAC designs software and hardware mixes that best meet project requirements. For example, VRAC uses HMD technology for projects best suited to single-user tasks and uses projection technology for projects involving teamwork.

The C2 and C6 immersive visualization configurations particularly support group collaborative engineering research. For example, VRAC is concerned with the refinement of methods that best evaluate virtual prototypes and with investigating forms of interaction between multiple people in a virtual environment. Also, Cruz-Neira's work continues to deal with software issues in real time and with the next generation of software toolkits to control advanced immersive environments.

RETURN ON INVESTMENT BENEFITS

Quantitative Return

"We have a lot of industrially funded research, and the immersive visualization research results have been positive." Cruz-Neira's team has performed tallies in which an engineer working in a desktop environment is compared with an engineer working on the same implementation within an immersive environment. Findings indicate that the engineer is significantly more accurate with the data within the immersive system and also significantly quicker in reaching conclusions with the immersive system.

Second, the C2 configuration has put Iowa State in a highly competitive position for attracting industrial and governmental funding. In terms of industrial funding, Cruz-Neira remarked, "If we didn't have the C2, the cutting-edge work we've done with Deere & Company, Shell Oil, and Proctor and Gamble would not even have been possible with traditional visualization methodology." In terms of government funding, VRAC is particularly well-positioned to respond to governmental proposals that are directed toward collaboration and visualization research. "These systems are accepted as serious research tools, and having these sort of facilities tips the scale in the competition for research funds."

The return on individual projects has provided breakthroughs for those organizations providing the funding as well. Cruz-Neira recalled a senior engineer from a major industrial equipment company who walked inside his data for the first time and immediately found a feature that could be improved in a design that was already in production. He had known about this feature, but was unable to determine a way to improve it until he walked into the data. This company was able to make the improvement and add it to upcoming products.

Qualitative Return

Cruz-Neira spoke of the emotional impact of the systems and the concomitant benefits. What she called the "wow-impression thing" that happens when a first-time guest steps into an immersive visualization room continues to bring returns to VRAC. The emotional impact of the system is "like a magnet that attracts good students and good faculty."

STAFFING

VRAC has over 15 faculty and 75 graduate and undergraduate students.

PROJECTS

Research projects are categorized as:

- Virtual prototyping
- Manufacturing
- Haptics
- Architecture
- Human factors
- Software tools
- Art
- Human in the loop
- Visualization

A complete alphabetical listing of 37 research projects can be found at: http://www.vrac.iastate.edu/research/complete/index.html

HARDWARE

- 6-pipe, 24-processor Onyx2® InfiniteReality2™
- 15 Silicon Graphics® Indy® systems
- 4 dual-processor Silicon Graphics® Octane® systems
- Silicon Graphics® O2® systems
- 2 deskside Silicon Graphics Onyx2 systems
- 1 Silicon Graphics® Challenge® system
- 2 Onyx2 rack systems
- 1 SGI™ Origin™ system
- 2 Indigo2™ systems
- 1 Crimson™ system
- 1 SGI PC
- 1 C2 room
- 3 HMDs
- 1 Wall
- 1 Fakespace Boom 3C

- 1 3D sound system
- 5 tracking systems
- 2 SensAble PHANTOM haptic feedback systems
- Several Virtual Tech Cybergloves and Fakespace Pinch Gloves
- A variety of 3D joysticks, wands, and mice
- A motion platform

SOFTWARE

VRAC has a variety of software packages, both in-house and commercial. The primary in-house software is VR Juggler (to control VR devices). VR Juggler is an open-source project: www.vrjuggler.org.

Commercial software

- IRIS Performer™
- Multigen
- Softimage
- EAI/Sense8 WorldToolKit

4.3 University of Paderborn

Heinz Nixdorf Institute
www.hni/uni-paderborn.de/vr/
Interviewee: Dr. Peter Ebbesmeyer, Division Manager Virtual Reality

The Heinz Nixdorf Institute is devoted to finding new ways to support industrial business processes with VR technology. Their work ranges from the development of new concepts and methods that utilize VR in the industrial business arena to the realization of customized VR system solutions. The institute specializes in the area of computer-integrated manufacturing and teaches about manufacturing processes with immersive visualization technology. The research and educators use the virtual factory for such tasks as factory planning, plant engineering, and all planning tasks necessary in large and complex facilities such as the automotive industry and power plants.

CONFIGURATIONS ON-SITE

Systems

The system used at Heinz Nixdorf Institute is located at the Heinz Nixdorf Museum's Forum, which is next door to the institute. It is a rear-projection system, the "Software Theater," set up in a theater-like environment with seating for 30 participants. The system presents real-time 3D computer images using stereoscopic projection technologies and also includes 3D audio. It is possible for an individual user to wear a head-mounted display with the images from the HMD projected onto the screen at the same time for simultaneous viewing by the audience seated in the theater.

Rationale for Systems Chosen

The institute's department of mechanical engineering found the immersive theater to be the best technological configuration suiting both its budget and training applications needs. Early in the 1990s, the institute studied the feasibility of building an actual demonstration factory with real machine tools and robots and all other necessary training equipment. Construction and operation of an actual factory for educational purposes was found to be too expensive. At this point, the institute turned to the building of a virtual reality 3D factory and began to use the VR factory for planning and teaching purposes. The projection system was found to be the best means of showing a large number of people a 3D model in an interactive manner.

RETURN ON INVESTMENT BENEFITS

Quantitative Return

As the institute has become more experienced in the use of the immersive visualization system, more and more outside industry funding has been invested. "It's a growing effect," said Ebbesmeyer, "and very positive." Ebbesmeyer reported that the Heinz Nixdorf Institute received about 100% growth in funding of research, which is attributable to the use of the Software Theater. Industry has found it very useful and cost-efficient to collaborate with the institute since that's much less costly than to buy the system or attempt training on their own.

Qualitative Return

There is a solid relationship between the quantitative and the qualitative returns. As researchers have had more contact with industry, the overall relationship has matured and become better for each side.

STAFFING

The immersive visualization work has involved one assistant professor, six Ph.D. candidates, and 20-30 graduate students. Ebbesmeyer reported that "the staffing changes for different projects, and it would be difficult to give numbers of staff and times on-task." He commented that preparation for use of the immersive technology takes a great deal of up-front time. The actual immersion is only 10% of the research time while the additional 90% of the time is for the creation, setup, and conceptualizing of the system.

PROJECTS
- Computer-integrated manufacturing
- Education and training
- Cyberbikes
- Design review
- Virtual Web plant
- Rapid prototyping
- Layout planning

HARDWARE
- Two-pipe Silicon Graphics Onyx RealityEngine2™
- TAN passive stereoscopic rear projection wall (viewers wear polarization eyeglasses)
- Virtual Research VR4 and V6 HMD
- Polhemus tracking system
- Division Flying Mouse 3D input device
- BG Systems FlyBox
- Fakespace Pinch gloves

SOFTWARE
- MultiGen/Paradigm
- In-house custom toolkit based on IRIS Performer
- PTC/Division dVISE

4.4 University of Houston and NASA/Johnson Space Center

Virtual Environments Research Institute (VERI)
www.vetl.uh.edu/overview/overview2.html
Interviewee: R. Bowen Loftin, Director of VERI and Chair of Computer Science

The Virtual Environments Research Institute (VERI) is a joint enterprise of the University of Houston and NASA/Johnson Space Center. The laboratory performs research and development focused on virtual environments for training, education, and scientific/engineering data visualization. Projects have included training for NASA's Hubble Space Telescope Repair and Maintenance Mission of 1993, the construction of unique learning environments for science students at many levels, and the application of virtual environments to surgical training. In addition to support of NASA training technology development, the VERI is aiding in the transfer of NASA developed technology to the private sector by pursuing collaborative work with industries throughout the Houston region, concentrating on the use of virtual environment technology in oil/gas and medicine.

(**Note:** The Virtual Environments Research Institute was known as the Virtual Environment Technology Laboratory until September 1998, when it was granted research institute status by the university.)

CONFIGURATIONS ON-SITE

Systems

A virtual reality pioneer, VERI began experimenting with head-mounted displays (HMDs) in the early 1990s. Today, VERI has what Loftin describes as a "spectrum of virtual environment systems," including monitors, stereoscopic HMDs, and projection displays including Collaborative Workbench visualization systems and a four-surface CAVE. The Lab's CAVE is driven by a three-pipe Onyx InfiniteReality system with two channels-per-pipe capability. For maximum results, the fourth wall can be driven with a separate Onyx i-station (a deskside Onyx with one InfiniteReality pipe), or an Onyx2 InfiniteReality single-pipe deskside workstation.

Rationale for Systems Chosen

Loftin stressed that there is "no one answer on display technology." Rather, he advises "don't fit a solution to the problem" and instead he advised to "mix and match systems for the purpose of the interaction needed for a specific application." Loftin cited different systems for a number of different projects. For example, VERI, in partnership with George Mason University, completed the educational deployment of five immersive VR systems in schools in Fairfax, VA. It was important that the first serious VR system installed in the pubic schools be cost-effective, "deployed cheaply," and for this reason the project uses one O2 system (R10000®, 256MB RAM, dual-channel option with custom support for driving an HMD), VR6 HMD from Virtual Research, and a Polhemus Fastrak (two regular sensors and one stylus).

Further up the cost ladder, VERI finds stereo desks to be effective in the geosciences, because scientists are already accustomed to collaborating around a light table.

The CAVE configuration is most useful when the research or teaching would benefit from a "break from the normal world." Loftin stressed that the CAVE is most valuable for "interpretation of data, not so much for manipulation in that the CAVE is not well-suited to fine grain manipulation of data due to the imprecision of tracking in its larger volume. Further, the CAVE has served extremely well when unencumbered movement is beneficial-as for the NASA training application and collaborative engineering design."

RETURN ON INVESTMENT BENEFITS

Quantitative Return

The hard ROI for the VERI projects is realized when their research is transferred to the application arenas, and the lab enjoys an indirect return thereby. For example, NASA's shuttle missions now routinely train astronauts in VR environments based in part on VERI's research, and NASA receives the cost benefit versus the previous training in water tank environments. The economics ROI transfers to the application and indirectly back to VERI with additional projects.

Hard-dollar return in terms of research moneys can be attributed to the presence of impressive visualization technologies. Loftin explained that the presence of such world-class virtual environment facilities enables VERI to compete aggressively for funding from federal agencies and the private sector.

Qualitative Return

Immersive visualization systems are an "attractor not just of numbers, but a great attractor of diversity." He believes that the most important qualitative benefit of the high-end displays is that they enable VERI to attract a stellar, multidisciplinary collection of students and extraordinary staff. The VERI is truly multidisciplinary; the nature of the population at the lab is very diverse. "We have student and collaborators from computer science, chemistry geosciences, optometry, education, psychology, hotel and restaurant management, medicine, engineering, mathematics, and optometry." Loftin reflected, "No one discipline really owns VR or immersive visualization; we must deal with the human being from all perspectives."

PROJECTS

- Aerospace training
- Space science (for science education)
- Medicine
- Military operation other than war
- Data visualization (mostly medical, geoscience, and engineering)
- Intelligent-computer-aided training

HARDWARE

- Three-pipe Silicon Graphics Onyx InfiniteReality
- Silicon Graphics Onyx InfiniteReality i-station
- Onyx2 InfiniteReality deskside
- Onyx RealityEngine™ deskside
- Silicon Graphics Octane
- SGI™ Origin™ 200
- Silicon Graphics O2
- Silicon Graphics Indigo2 Maximum Impact™ graphics workstation
- Silicon Graphics Indigo2 High Impact™ workstation
- 8 Silicon Graphics Indy workstations
- 2 Silicon Graphics® 320/VGS Windows NT® workstations
- SGI Model 85/GTX™ UNIX® workstation
- CAVE system housed in a 50'x35'x14' room (4-Electrohome 8500T, P43 phosphor, video projectors, StereoGraphics CrystalEyes system, Ascension trackers)
- 4 Flogiston personal motion platforms
- 2 Electrohome Marquee 8500T projectors
- 3 Virtual Research VR3 HMDs
- 2 Virtual Research EyeGen3 HMDs
- Virtual Research VR8 HMD
- Kaiser VIM HMD
- 2 VPL Research HMDs
- SGI Spaceball
- Virtual Technologies CyberGlove
- Rutgers/Burdea Force Feedback Glove
- VPL Research DataGlove
- Tele-Tac Tactile Feedback Glove
- VPL Research Model2 VR systems
- 4 Polhemus tracking systems
- Ascension tracking system
- Crystal River Acoustetron II
- VPL Research AudioSphere
- 2 SensAble PHANTOM haptic feedback systems

SOFTWARE

- VERI's "homegrown" software, VrTool: www.vetl.uh.edu/~lincom/
- MPI Vega
- MultiGen
- EZ3D
- Lightwave
- Alias|Wavefront
- Kinetix Studio 3D
- Autodesk AutoCAD
- Rendering/interaction: VrTool, Vega (as modified in the lab)
- Open Inventor (as modified in the lab)
- SGI IRIS Performer™
- EAI Transom Jack

VERI also uses commercial and homegrown software for data translation, polygon reduction, texture editing, etc.

4.5 Ohio State University
Biomedical Applications Research Initiative
www.osc.edu/Biomed
Interviewee: Dr. Don Stredney, Senior Research Scientist

The Biomedical Applications Research Initiative involves an interdisciplinary group comprising research scientists, computer scientists, and clinicians. The goals of the group include applying high-performance computing to biomedicine and applying advanced interface technology for use in virtual exploration of complex computational data. The Biomedical Applications Research group is currently involved with the development of biomedical applications for the next-generation Internet, the virtual simulation of temporal bone dissection, the visualization of extremely large data sets, and a virtual simulation for tractor certification.

Senior Research Scientist Stredney explained the biomedical applications research process. His group works with colleagues in computer science who are volume visualization specialists developing specialized techniques. Those techniques are not necessarily solutions, and the biomedical group must take the techniques and apply them to a specific discipline and then evaluate the techniques' efficacy while being used as a solution. "Once we complete this process," Stredney explained, "we present the findings by publishing papers and speaking at professional events."

CONFIGURATIONS ON-SITE
Systems
The Biomedical Applications group has a Fakespace ImmersaDesk in-house and also dovetails with nearby Wright Patterson's CAVE. A current project that simulates tractor rollovers uses an HMD. The temporal bone dissection simulation utilizes a binocular display. Additionally, the Biomedical Applications group uses a Silicon Graphics Onyx2 system with an HDTV-size screen for visualizing the data sets reconstructed.

Rationale for Systems Chosen
The hardware and software for each project are chosen for their functionality and suitability to specific applications. For example, the tractor project must allow the user to arbitrarily look around the environment.

BENEFITS
Quantitative Return
OSC is under the research auspices of Ohio State University. On this direct line from the Ohio State Board of Regents, the Biomedical Applications Group is charged with helping the state of Ohio remain competitive and on the forefront of medical research. The availability of cutting-edge immersive visualization configurations and the research potential these technologies promise are seen as a direct investment in the state's future. The long-term return on investment will be the future competitiveness of Ohio's scientific and medical infrastructures.

The most readily quantifiable ROI is currently the reduction in transfer overhead costs for training medical professionals. Immersive visualization technologies are beneficial for medical education, helping medical professionals learn techniques in a noninvasive environment. Such virtual education enables residents to become comfortable with advanced surgical methods with very little transfer overhead, which can be assessed for efficacy, but not for dollars.

ROI also comes in terms of the practical benefits that medical professionals are gaining from the research and technologies developed by the Biomedical Applications Research group. These technologies have direct implication for improving medical treatment as well as medical research and education. The new technologies enable methods by which "we can better peer into people." Visualization enables the surgeon to "hold a digital model of patient in her hand and almost perform surgery on it."

Qualitative Return
The qualitative return from the research work is most "rewarding and humbling" in the words of Stredney. The Biomedical Applications Research team works with these specialized medical professionals who need information technology, but who don't want to become computer scientists or interface designers. He especially cited the value derived from assisting medical professionals who are dealing with head and neck cancer patients. Stredney emphasized, "Cancer is a damnable disease and extremely frustrating. It's very exciting and rewarding for us to facilitate the work of

medical clinicians, researchers, and educators in thwarting the disease."

STAFFING

The group has two to three staff people and one to two graduate students assigned to a project. The technologies are used daily in development. Stredney mentioned that the numerous requests for tours and demonstrations have "a somewhat problematic effect on the lab" and impact the lab and the work being done. The equipment is in constant use for development. Visitors may be faculty researchers who are interested in collaborating or starting their own projects. There also high school tours from throughout the state of Ohio and college tours as well.

PROJECTS

- Virtual simulation of temporal bone dissection
- Using virtual simulations for evaluating safe practice for tractor certification
- An image-based approach to scientific visualization

SUPERCOMPUTER EQUIPMENT

- 4 processor Cray™ T94 Vector computer, with 1GB of memory and 100GB of disk
- 128 processor Cray™ T3E with 16GB of RAM 200GB of disk space
- 16 processor Cray™ SV1 with 16GB of RAM 400GB of disk space
- 32 processor SGI Origin 2000 with 16GB of memory and 100GB of disk
- 8 processor SGI Origin 2000 with 4GB of memory and 1TB of data
- Attached to the Origin server is an IBM 3494 storage repository capable of storing 60TB of data
- 132-processor Beowolf cluster with 66GB of RAM and 624GB of disk

Interface Lab

The Ohio Supercomputer Center has a 400-square-foot Interface Laboratory. In addition to providing high-performance graphical displays for both interactive and recorded presentations, the Interface Laboratory offers dexterous devices to precisely localize and track 3D digitization, user movements, morphometrics, and haptic (force reflecting) interaction with complex data. The Interface Laboratory also provides equipment for recording and generating various types of audio for both interaction and presentation.

Interface Lab Computer Equipment:

- 4-processor Onyx2 InfiniteReality with 1GB of memory
- 4-processor Onyx InfiniteReality with 512MB of memory and 45GB of disk
- 2-processor Octane/MXE with 256MB of memory
- 4-processor Silicon Graphics® 540 with 2GB of memory
- 2-processor Silicon Graphics® 320 with 512MB of memory

Interface Lab Equipment

- Polhemus tracking system with two receivers
- Polhemus tracking system with four receivers
- Logitech infrared headtracker
- 2 SensAble PHANTOM haptic feedback systems
- Immersion Impulse Engine 1000 Needle Insertion Simulator
- Immersion Impulse Engine 2000 Force Reflecting Joystick
- InteractiveIO Force Feedback Steering Wheel
- Virtual Research V8 HMD with stereo sound capabilities
- Fakespace ImmersaDesk
- StereoGraphics CrystalEyes eyeware
- Immersion Microscribe 3D
- SpaceTec Spaceball
- Virtual Technologies CyberGlove with CyberTouch system, 18 sensors

SOFTWARE

- Kinetix 3D Studio Max
- Advanced Visualization Systems AVS/Express
- VRCO CAVELib
- Xtensory XVSlink
- Virtual Research VirtualHand Suite 2000
- SensAble GHOST SDK

4.6 Old Dominion University

Center for Coastal Physical Oceanography (CCPO)
Interviewee: Dr. Glen Wheless, Ph.D., Lab Co-Director
www.ccpo.odu.edu/~wheless

The Center for Coastal Physical Oceanography's Virtual Environment Lab is renowned for its development of the Chesapeake Bay Virtual Environment (CBVE), a multidisciplinary, collaborative project that fuses 3D visualization of numerically generated output, observational, and other data products into a large-scale, interactive virtual world. Wheless commented on CCPO's

Virtual Chesapeake and other immersive visualization projects, "We have become VR applications developers rather than oceanographers."

Beyond its current efforts with virtual oceanography, the CCPO is part of the ultrahigh-speed data network effort that is pushing into Internet2. "Our goal is to have a permanent, collaborative virtual environment," Wheless says. Those efforts are part of the National Computational Science Alliance, funded by the National Science Foundation. CCPO also has projects with NASA, with the Office of Naval Research for mission rehearsal, and with the Department of Defense for 3D battlespace visualization.

CONFIGURATIONS ON-SITE

Systems

The CCPO has had a Fakespace ImmersaDesk installed and in operation since 1996. The lab opened a four-walled CAVE in 1999.

Rationale for Systems Chosen

The ImmersaDesk was the CCPO's initial configuration because of its easier affordability. The ImmersaDesk system comes in at a third to a fourth of the cost of a CAVE and doesn't require a multipipe graphics system.

However, the ImmersaDesk does have strong immersive capabilities that have already enabled the CAVE to prove useful in the scientific investigation of how physical and environmental processes affect circulation in the bay along with the ImmersaDesk's general ability to display advanced visualization of environmental data. Wheless commented on the ImmersaDesk and explained "you can see fluid flows on the ImmersaDesk, and it is quite suitable when the research question can be satisfied by 'looking out the window into another world.'" But he stressed that "a CAVE has a 'different feel' with the data (fluid flow) all around you." He believes the CAVE allows viewers to see "more intuitively." The CAVE also allows more complete geospatial control of data in order to fix the relationships "in your head," especially the relationships between variables in large data sets.

RETURN ON INVESTMENT BENEFITS

Quantitative Return

Many projects at CCPO are dependent on soft money, and the ability to attract additional grants and projects is essential to continuing this important research. The presence of highz-level Reality Center/immersive visualization configurations in-house has brought in project moneys from outside funding agencies such as the Office of Naval Research, NASA, and DARPA.

Qualitative Return

"Immersive visualization demonstrations cause a 'fantastic' emotional reaction in first time viewers. They 'try to put their hands into the screen.' This emotional reaction is especially important when demonstrations for potential funding. It enables viewers to 'get the vision.'"

STAFFING

The Virtual Environment Lab group has six full-time staff members. Wheless, who was interviewed for this study, oversees the lab with fellow oceanographer Cathy Lascara. Their team also includes three undergraduates employed under a special NSF research grant for involving undergraduates in cutting-edge research.

In terms of system usage patterns, Wheless commented that "we use it all the time." The CCPO is specializing in the development of persistent usage, meaning the scientific environment will be left in operation all the time. Updates will be made as appropriate from the database, if network collaborators enter the environment from afar, their "virtual droppings" will be left as messages for when CCPO staff come back online.

PROJECTS

- Cave5D software application research
- Ocean VR vBNS for interactive collaboration (very high-speed backbone network service)
- VSWAPS, developing VR-based mission planning tools for Naval Special Warfare

HARDWARE

- 8-processor multipipe Onyx2 InfiniteReality
- 2-processor Onyx2 Reality
- Silicon Graphics Indigo2 Impact workstations
- Silicon Graphics O2 workstations
- Fakespace ImmersaDesk
- Fakespace CAVE

SOFTWARE

- Cave5D release 1.4
- CCPO has integrated Vis5D and CAVE libraries to provide interactive visualizations of time-varying, three-dimensional data sets in a virtual environment

• SGI IRIS Performer
• OpenGL®

5.0 Potential of Reality Center Implementation in the University

These future trends are apparent:

1) There will be an explosive growth in the number of networked, immersive visualization applications in the future due to ongoing improvements in display technology and network access. Immersive visualization configurations will become common on all university campuses within a few years. As Wheless from Old Dominion's Center for Coastal Oceanography commented in his interview, "These systems are the way science will be done in the future."

   As the technology improves and price drops, immersive visualization desktop systems for a broader audience will also become widespread. Applications development for a wider audience will follow closely behind the technology development cycle, as has already been seen with the haptic ReachIn device developed in Australia and marketed by a Swedish company.

   Interviewees for this study forecast a personal teleimmersion work cubicle with interactive ImmersaDesk style walls displaying streaming media via broadband networks to individual workers.

2) The research and development conducted under the auspices of Internet2 will coincide with and accentuate immersive visualization research, development, and implementation.

3) Collaborative processes and technologies designed to support optimal human collaboration within Reality Center generated spaces will be the focus of intensive research over the next few years.

4) Within five years, immersive visualization systems will also include haptic and auditory capabilities with a resultant increase in human bandwidth. Research and development will move to most efficiently exploit interaction within a 3D multisensory environment form. To date, the majority of the technical research has concentrated on visual graphics.

5) Multisensory data representation will be the next frontier for immersive visualization research. Over the long term, this research will result in an interface device that immerses the senses and motor channels completely. Biocca of the M.I.N.D. Lab believes that "ultimately the interface has to use the maximum amount of the senses and the body. The only way into the mind is through the body."

6) Research will also focus on the psychosocial human communication needs in networked immersed spaces. As Iowa State's Cruz-Neira mused, "we are seeing a different kind of communication take place." Research concerning communication within Reality Center configurations will provide guidelines on effective processes for industry purposes, but will also reveal new insights about human communication itself.

7) At the individual level, immersive visualization systems will enable people to augment their respective unique mental capabilities and facilitate cognitive diversity. Immersive visualization technologies build upon our natural processes; as Stredney of Ohio State explains, "The prefrontal cortex naturally runs simulations in our minds."

8) Reality Center configurations are ideal systems for multidisciplinary research projects. Reality Center facilities will increasingly be used to combine data representations from the hard sciences with the interpretive context of the social sciences.

6.0 Appendix

6.1 SGI's Strategy for Supporting University Customers

SGI's strategic strength in the university community is based on mutually shared devotion to excellence and innovation. Any business strategy embodies a consistent course of action that is aligned with its staff's ways of acting and responding. The core values that drive research institutions to be world-class in their fields are the same values that have brought SGI computers to undisputed eminence. SGI is the world leader in visual computing platforms that range from the desktop to supercomputers. SGI pioneered immersive visualization in the 1980s and is the acknowledged leader, having time-proven experience coupled with hardware and software designed specifically for real-time immersive visualization. Universities strive to be outstanding leaders as well in fulfillment of their threefold mission: research, service, and teaching. The drive toward excellence and innovation is the same within research universities as within SGI.

SGI understands the cultural values of the research university. "Prestige is an elusive quality," said SGI Director of Marketing Chodi McReynolds, "and can't be equated to dollars on an emotional level." Universities must have leading-edge technology to attract the leading minds and Nobel prize winners. The prestige of an institution is paramount in attracting the best research faculty and the brightest students that follow top-notch professors. The presence of SGI immersive visualization/Reality Center configurations has brought prestigious grants to each of the projects profiled in this white paper. The list of granting institutions for Reality Center based projects is stellar. Government agencies such as the National Institutes of Health, National Aeronautics and Space Administration, Department of Defense, National Occupational Safety and Health Association, National Science Foundation, Office of Naval Research, and others have all invested in Reality Center based research. John Deere, Ameritech, and Texaco are only a few of the industrial giants that see immersive visualization as a serious business tool and are also funding cutting-edge Reality Center research at various universities around the world.

SGI understands the university research process. Visualization and simulation complements traditional theory development and laboratory experimentation in the university context. SGI's performance with supercomputer and visualization power has already led to major research breakthroughs in physics, chemistry, and engineering. SGI's traditional strength in simulation-based research is accelerated when immersive capabilities are added to the configuration. McReynolds explains, "Researchers better understand their data when they are actively involved in the environment." Immersion adds to the discovery factor and accelerates the basic research process.

SGI understands the needs of research faculty. Many of the principals in the immersive visualization projects double as faculty and research managers. Every one of the interviewees for this white paper mentioned his/her SGI representative with great respect and commented on the technical assistance given the project by the SGI staff. McReynolds reported that "SGI does not 'seed' ideas for projects, but when researchers come to us and articulate an idea, we show them what can be accomplished with our computing configurations. They are then able to go off and design studies, write grants, and put together project teams and technologies."

SGI understands the university's need for community service. SGI itself is a contributor to the academy's community service efforts. Presentation of research at leading-edge conferences is key to the world's advancement of new knowledge as well as an important vehicle by which professors contribute to the academy. SGI is very often a conference cosponsor, a contributor of equipment for demonstrations, or a host of breakouts or socials in conjunction with important technical events.

SGI understands the learning environment of the university campus and classroom. SGI solutions already enable universities to provide around-the-clock access to educational materials via networks and the Internet. Immersive visualization will become more and more important as actual learning curriculum spaces as the technology matures and becomes more available. Teaching and learning will be empowered by visually rich content and enactment of experiences. The digitized curriculum in SGI's future immersive visualization spaces will strengthen the learner's natural neurological processes for learning.

SGI understands university administration as well. As McReynolds explains, "Every university purchases for different reasons; their discipline needs are different—one may specialize in fluid dynamics while another may specialize in mechanical engineering. We are flexible in order to meet their needs." A modern research university cannot be all things to all; instead universities develop specific areas of expertise. Administrators evaluate equipment allocations to determine whether expenditures will expand and build upon the key research areas in which a university specializes.

SGI has been infused with the spirit of learning, research, and experimentation ever since 1982 when Stanford University professor James Clark and seven of his graduate students put 3D on a single computer chip and launched this multibillion-dollar company.

- SGI is the world leader in strategic partnerships with immersive visualization software developers
- SGI is the leader on university campuses worldwide in the implementation of immersive visualization-based research
- SGI is the world leader in providing fully integrated, scalable Reality Center solutions of all types and sizes

SGI supports its university Reality Center/immersive visualization clients with the same ideals and values that have built the company's world-leader status and will continue to provide Reality Center facilities that enable world-class research and return on investment as well.

6.2 Case Study Methodology

The Chicago School's inductive case study approach was the research methodology used for this white paper. An ethnographic case study does not present a sample but offers the opportunity to expand and generalize theories although not to enumerate frequencies (statistical generalization). It is a superior method of description, and the tactics bridge the transformation of the premise from local to global because the methodology produces comprehensive descriptions that reveal the condition of a society through appropriately chosen microsocial units.

The premise of this effort is that immersive visualization configurations provide quantitative and qualitative ROI benefits within the university setting. The approach to identifying the benefits was ethnographic-an interpretation of closely examined social discourse. The methodology was describing, understanding, and explaining.

Descriptions of Reality Center case study sites were compiled. The first stage in describing was to collect and assemble the information about each of the immersive visualization projects that were profiled for this study. Interviews were conducted with the directors as a means of capturing their immediate experiences with immersive visualization/Reality Center configurations. Further information was gathered from primary and secondary source documents, including Web sites.

Understanding is the step within the case study process that establishes the relationships that link the parts within the whole entity under study. A comprehensive sectioning encourages relationships to emerge between the fragments of the whole. The content for the descriptions was organized into these sections for each profile:

- Overall description of project
- Configurations on-site:
  - Systems
  - Rationale for systems chosen
- Benefits:
  - Quantitative
  - Qualitative
- Staffing and usage patterns
- Hardware
- Software

Explaining is the final step within the case study approach that transforms the singular relationships within the individual projects into the global premise. The relationships can then be understood in the context of the overall picture.

The experiences of the individual case study subjects (microsocial) are generalized to the global community in this process. The benefits found within the singular university setting where Reality Center configurations are installed can thus be generalized to apply to other universities that may be contemplating the potential benefits of immersive visualization/Reality Center configurations.

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