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VIRTUAL REALITY: A TECHNOLOGY IN NEED OF IS RESEARCH

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ABSTRACT

Although virtual reality (VR) technology has been available since the 1970's, it is becoming increasingly sophisticated and cost effective. Architecture, education, medicine, electronic commerce, collaboration, and data visualization are some of areas where VR is beginning to be applied. Much of the reported research on VR is technological rather than social, leaving only a limited understanding of its behavioral and organizational impacts and its potential for novel situations. Immersion, interactivity, and presence are intriguing concepts that emerged as important to VR research, but are yet ill-defined. In this paper we argue that the information system research community offers a unique and valuable perspective on VR research, and that this capability represents a logical extension of the work in several IS research domains. Multi-methodological approaches using both positivist and emergent perspectives are needed. A research framework that can be used to begin this work is described.

Keywords: virtual reality, information systems research

I. INTRODUCTION

> *The philosopher of science, Karl Popper, suggested that we think of three worlds when we consider the spheres of human action: "First there is the physical world - the universe of physical objects . . . this I will call 'World 1.' Second, there is the world of mental states; this I will call 'World 2.' But there is also a third such world, the world of the contents of thought, and, indeed of the products of the human mind; this I will call 'World 3'".. (Popper and Eccles, 1977, p. 38).*
>
> *With VR [virtual reality], Popper's World 3 enters a new stage of growth . . . For millennia, the communication medium of the body has been an*

> *interface between World 1, physical nature, and World 2, mental states . . . With VR the growing environment of World 3 wraps around a body designed for World 1 . . . The natural World 1 is muffled, the senses immersed in the creations of our minds. A feedback loop is set up between the changing mental states of World 2 and the sensory experience of World 3 . . . How can we communicate most effectively using VR interfaces? The best answer is: We're not sure, but we'll soon find out.*
>
> *- Biocca and Levy [1995, pp. 18-19]*

Virtual reality (VR) technology can have profound effects on human perceptions through a synthetic reality that can realistically stimulate all human senses. Although sometimes criticized for not reaching its claimed potential, VR technology is now becoming cost effective for application in many domains and is expected to become even more so in the future. This seeming technological imperative is an area where the information systems research community can make important contributions. Long an over-hyped buzzword, readily available technology and new, more efficient development tools suggest that it is time revisit VR applications. When viewed in its utopian form as a fully developed synthetic world unto itself, but without the stresses or needs of a real world, VR moved forward only slowly and may never achieve such a goal. However, as a technology in which high quality, multi-sensory interfaces can be used to deliver rich forms of information and communication, its usefulness is apparent.

In 1999, Capps et al. recommended that VR research place more emphasis on the infrastructure of networks and standards because research in realistic imagery (a hallmark of technical VR research) had moved so far that it was time to put effort into its supporting infrastructure. Today this infrastructure is improving rapidly and is in the early stages of working on the Web. It is now appropriate to expand the emerging research foci to begin looking at what standalone and networked VR applications could and should provide to business and to the community.

The development of VR integrated development environments (IDE) and more standard file formats are quickly increasing the practicality of developing systems with VR capabilities. Products like Maya by Alisa|WaveFront, and 3D-Max by Discreet, are examples of VR-IDEs that became affordable as their purchase prices dropped by roughly a half between 1999 and 2002. Although most developers would prefer high-end technology, today's standard desktop computers can run these IDEs to develop useful systems. Further, the output of these tools can run on a standard PC platform, the Web, or a game machine like Sony's PlayStation series. Thus, the investment in equipment can be reasonable for many environments. In addition, the sophistication of the VR-IDEs makes shortened development times possible and potentially reduces some of the technical skill needed by developers.

Much reported VR research is technical in focus, studying how computer and interface technology can be enhanced for improved human interaction. Little is reported about the behavioral and information systems areas where there is pressing need to understand better how these technologies might impact business and society. There is much room, in fact, for developmental research that might invent new applications for VR technologies. For example, VR technology could address limitations of Web-based businesses that rely on personal or product contact, expanding the range of electronic commerce possibilities [Walsh, 2002].

"'VR' is a hybrid term. It refers to an individual experience constituted within technology, and it draws together the world of technology and its ability to represent nature, with the broad and overlapping spheres of social relations and meaning" [Hillis, 1999, p. xv]. It is this juxtaposition of technological and social concerns that suggests the skills and knowledge of the information systems researcher can be applied productively here.

The important concepts[1] of

- immersion,
- interactivity, and
- presence

[1] These concepts are discussed in Section V.

are emerging, but as yet, they remain ill-defined and are used differently in different contexts. Understanding the constructs that underlie these concepts can give new insight to VR research as well as to other areas of information systems research.

The purpose of this paper is to frame the opportunities for information systems research in VR. Section II briefly describes the history and current state of VR research. Section III summarizes some of the classes of applications of VR technology. Section IV outlines the rationale for inclusion of investigations related to VR technologies and applications into the IS research agenda. Section V proposes research directions, focusing on the development of conceptual models to provide understanding of the relationships between elements of VR application design, fundamental aspects of the user's experience, and potential outcomes of the use of these systems.

II. VIRTUAL REALITY

TOWARDS A DEFINITION OF VIRTUAL REALITY

VR does not yet have a single definition, but rather refers to a broad range of concepts and technologies that expand the sensory relationship with the user. Some argue that the first example of VR was the Sensorama Simulator, a multi-sensory multimedia viewing device invented by Morton Heilig in the early 1960's [Burdea and Coiffet, 1994]. Although the system was controlled by programmed analog logic and was not interactive, it displayed a 3D image that filled the user's peripheral vision as well as 3D sound, motion, and smell. Ivan Sutherland was also an early pioneer, setting forth an explicit vision of the ultimate virtual world display to the IFIP Congress in 1965 [Sutherland, 1965], the same year he created the first head-mounted computer display device. The term 'Virtual Reality' emerged in the mid-1980's and is credited to Jaron Lanier. As Biocca and Levy [1995] observe, "The medium that tantalizes us so has gone by a number of names: computer simulation, artificial reality, virtual environments, augmented reality, cyberspace, and so on. More terms are likely to be invented as the technology's future unfolds. But the enigmatic term has dominated the discourse. It has defined the technology's goal: the creation of a virtual reality" [p. 4]. Steuer [1995] proposed a useful technology-neutral definition of VR: "a virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence" [p. 37]. Steuer uses the term 'telepresence' similarly to other authors' use of presence, choosing it to differentiate from presence in a real environment. Consistent with Steuer, Biocca and Delaney [1995] define VR technology as "the sum of the hardware and software systems that seek to perfect an all-inclusive, immersive, sensory illusion of being present in another environment, another reality; a virtual reality" [p. 63].

Some argue that VR is not at all new. "The frescoes of Baroque churches blur the distinction between physical and pictorial space by turning the latter into a continuation of the former" [Ryan, 2001, p. 3], and many can relate to being 'immersed' in a good novel. Ryan [2001], for example, points out that the process of writing can be thought of as a two-step process linking the virtual and the real. In the first step, a virtual image of the author is actualized into real text and in the second the text evokes a virtual image in the reader. VR systems development can be seen as having a similar duality. Virtual, then, can be characterized as in the mind's eye. Virtual reality technology can be defined as technology that evokes virtual images. In this characterization, VR technology is quite real. It is made of real computers and software, but it is designed to evoke a virtual image in the mind of an end user. VR is also described as an advanced form of visualization [Tegarden, 1999].

VR technologies were used to create various types of VR environments, each with specialized goals, architectures, and capabilities. Multi user domains (or dungeons) (MUD), for example, provide textual interaction and extensible contextual space and could be considered as low-tech VR. CVE (collaborative virtual environment), net-CVE, shared VR and shared VE are terms that have been used to refer to the general topic of multi-user, distributed virtual experiences [Capps et al., 1999]. Although the terms are diverse, they describe an evolving and useful information technology. Collaborative virtual design environments (CVDEs), for example, are VR applications used in product and system design activities, providing capabilities such as 3D displays, rotational viewing and tactile response. Another example of a state of the art VR technology is tele-immersion. A tele-immersion system uses video projections that are the size of walls and a series of cameras to detect participant movement to create the illusion that two or more distant spaces are seamlessly connected [Lanier, 2001]. Although the technology is not yet perfected, this approach could lead to a system where the technology disappears and the participants cannot tell that they are not in the same room with the people with whom they are communicating. In a sense technology will have evolved to the point where human-human communications theories may apply as they do in the real world. Of course there is a twist. Since the communication is being run through a computer system, it can be modified. Lastly, an example of a VR technology that has recently become commercially available is the virtual retinal display (VRD) device, which transmits information and images directly into a viewer's retina by projecting a low-power light beam onto the back of the eyeball, displaying full-motion, high-resolution pixel images.

TOWARD A FRAMEWORK DESCRIBING VR SYSTEMS

As illustrated by the examples above, a key feature of many of the emerging VR environments is an embodied user interface that uses VR technology to "enmesh the user within a high-quality, animated, 3D world" [Fishkin et al., 2000, p. 75]. In such an environment, users are connected to the computer system in a way that the user interface may become invisible. The blurring line between the virtual and the real calls for a reexamination of previous conceptualizations of user interface, and may also change the boundaries of applicability of information technology. Nunamaker [1992] believes that "a major motivation in computing and computer application research is, 'What can be automated and how can it be done efficiently and effectively?'" [p. 2]. VR technology allows us to imagine automating in ways that were not possible with traditional information technologies and can motivate new types of systems and applications.

Although in the extreme case a virtual world with virtual agents may operate without any interaction with humans, most research is interested in precisely this interaction. VR technology can offer a number of forms of interaction, as illustrated in the following simple example.

Assume that a designer of an educational VR application developed a system to help individuals learn. In this case, the designer might embody communication to the student in the product, but may not incorporate any capabilities for ongoing communication. In other cases, following the same example, the system could be designed to support either synchronous or asynchronous interaction with an instructor who may or may not be the designer. Further, the system could be designed for either asynchronous or synchronous interaction with other students. In some systems, the instructor may be able to make changes to the virtual environment in real time. Some systems may even support a link to the real world such as real time control of a robot.

This example illustrates the number of roles and interaction modalities that can be found in many combinations in VR systems. One of the contributions of this paper is a conceptual framework, the Interaction Framework for Virtual Reality Systems shown in Figure 1, which can be used to describe these characteristics of a VR system.

The dimensions of the framework that can be used to describe the interaction characteristics of a particular VR system are:

- roles,
- virtual structures,
- real interface components, and
- interaction timing.

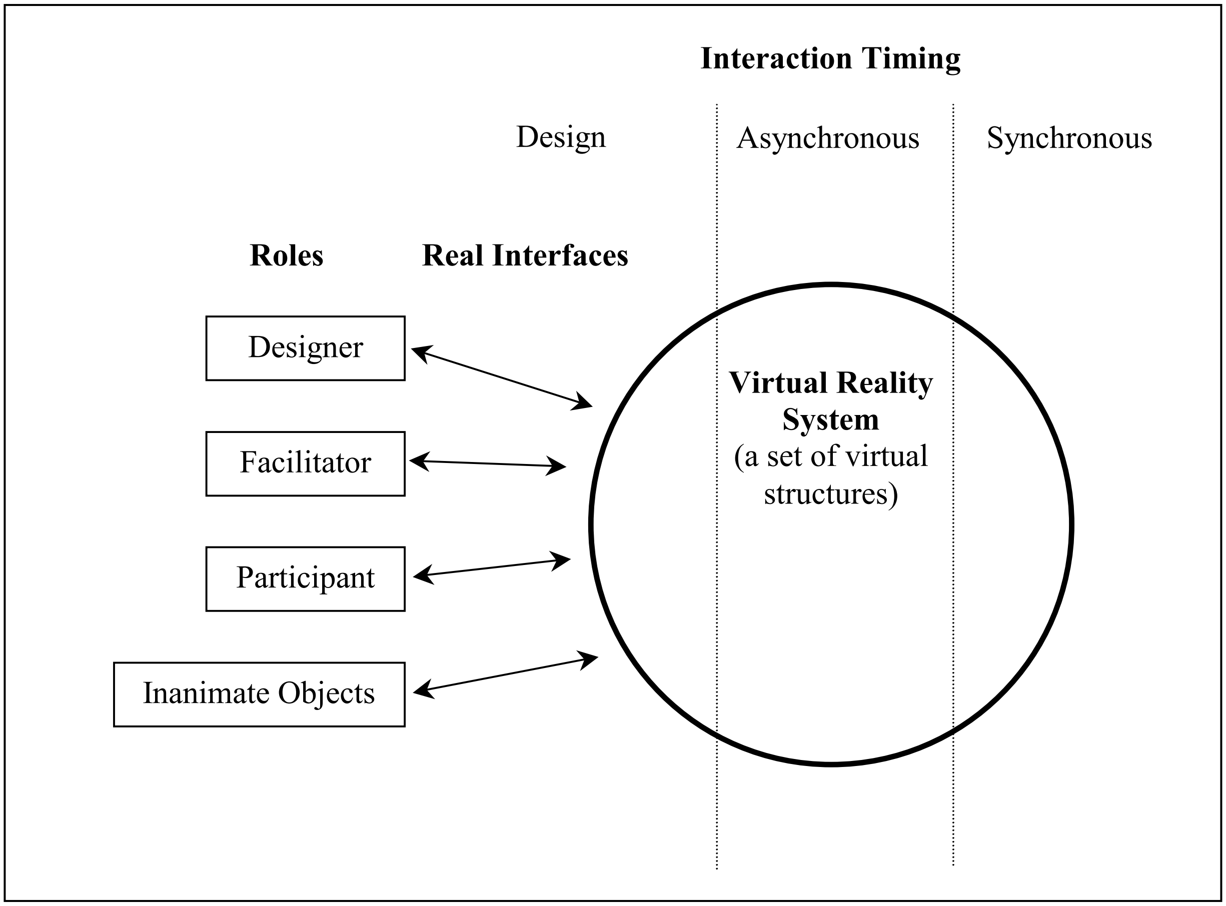

Figure 1. Interaction Framework for Virtual Reality Systems

Roles are real things (people or physical objects) that interact with the VR system. Within roles the following actors can be identified.

- *The designer*, who is responsible for the design of the virtual reality system,
- *The participant*, who is the targeted end user of the system,
- *The facilitator* who interacts with the system to help the system achieve its targeted goal with the participant, and
- *The inanimate object* which represents a real object that may interact with the system, such as objects that may be moved by a robot connected to the system.

Virtual structures are the system objects that allow for and guide interaction between the roles and the system. Within the category virtual structures can be identified items such as rooms, chat facilities, and avatars. In this conceptualization, the structures are objects that include their visible structure within the application as well as the logic that controls their behavior. The application of VR technology, then, can be thought of as the choice of structures included in a VR system for a particular purpose.

Real interface components are the physical devices that provide connections between a role and virtual structures. Within the category real interface components are real computer interface technologies that connect with roles. Head-mounted displays, full motion sensors, and wearable devices that support haptic interactions (to facilitate touching, grasping and moving virtual objects) are examples of the many interfaces available. Biocca and Delaney [1995] and Takemura and Kiyokawa [2001] provide descriptions, reviews and research initiatives related to some of these devices.

Interaction timing describes when the interaction takes places relative to other interactions. Within the category interaction timing are the different timeframes in which different roles interact with the system. Synchronous and asynchronous modes are apparent in VR systems, similar to other collaborative computing environments. Another mode, design time, can also be identified. Design time interaction can be viewed as a communication process between the designer and participant roles. VR systems design can be envisioned similar to traditional software development as occurring prior to usage or as ongoing, as in the potential reconfiguration of virtual structures while users use the system. The design time perspective serves to integrate the designer in the conceptual framework more closely than addressing system design separately, capturing this aspect of VR system interactions within the model.

The Interaction Framework for Virtual Reality Systems enhances our understanding of the interaction capabilities VR systems. The framework also raises our awareness of the complexity and layers of interaction possible in these systems, including various role-device-virtual structure combinations. Lastly, the framework can be used to describe and compare the interaction capabilities of different types of VR environments or applications and to facilitate the framing of research questions.

Clearly, one of the key differentiating characteristics of VR systems, compared with other types of systems, is the quality and structure of the interactivity and display provided to the user. While important issues are related to these forms of interactivity that warrant investigation, a review of VR systems research finds that the dominant focus to date is on the technical aspects of the participant interaction with the system (Table 1).

Table 1. Examples of Technical Research on Participant Interaction

Type of Research	**Problem Addressed**	**Reference**
Haptic research (simulation of touch)	Controls that offer well-controlled resistance varied by user input	Sakaguchi, et al. [2001]
	Techniques for dynamically changing texture of a surface	Nara et al. [2001]
Stereoscopic visual display for showing 3D images to remote users	A wide-angle display not dependent on special eyeware	Kunita et al. [2001]
Physics of avatars	Naturalness of virtual human movement	Ventrella [2000]
Infrastructure	Using the internet as a reliable infrastructure for collaborative virtual environments	Greenhaigh et al. [2001]

Although these forms of research are driving major improvements in VR technology, they tell us little about the potential impacts of these improvements such as how they may affect the roles in a VR system, and ultimately how they may affect the outcomes of VR applications. We argue that the current technology-driven focus for VR research needs to be expanded to include other types of investigation targeted at developing an understanding of the impacts of these technologies. We also contend that information systems researchers are best equipped to take the lead in this type of inquiry. As the examples of VR applications in the next section demonstrate, these technologies are beginning to move from research laboratories into organizations, thus making this type of research even more imperative.

III. VIRTUAL REALITY APPLICATIONS

The potential for application of VR technology is seemingly endless, particularly with breakthroughs in technology. Some areas with potential are described below, but the list is illustrative, not inclusive.

ARCHITECTURE, LANDSCAPE, AND THE ENVIRONMENT

One of the most direct applications of VR technology is the area where visualization of how the physical world could, would, or should look, such as in architecture, landscape architecture, and environmental planning. VR technology can provide a better understanding of physical design. Mahmoud [1998] suggests that VR technology is the best way to reduce the cognitive load of participants in environmental designers' proposal presentations. Environmental planning introduces the potential for incorporating dynamic simulations of environmental phenomena by using VR technology to make predictions and explain change [Bourdakis, 1998].

EDUCATION

Education has long been identified as a domain for VR systems. Flight simulators were an early example. More recently, surgical simulators allow medical students and doctors to learn new surgical procedures by using VR systems to conduct virtual operations. Currently under development is a surgical simulator application that would enable teachers and students in different locations to interact with one another in the learning experience [Baldwin, 2001].

As an education medium, VR systems can potentially provide student participants with the ability to enhance learning by 'visiting' virtual worlds that are remote from them in time and space, and to meet and learn from one another [Sykes and Reid, 1999]. VR can also be used to create virtual campuses [Tegarden, 1999].

Attention is being given to using VR technology to teach higher level cognitive skills. The ability of VR systems to engage the senses can make them an effective means of delivering educational experiences that include feedback and learner control [Walsh, 2001]. VR technology appears to have conceptual parallels to cognitive theories of mental model building. A VR system can coordinate the use of multiple models in a subject area to help the learner build his own mental model [Johnson et al., 2001].

MEDICINE

One area of medicine where VR is being applied is telemedicine where a doctor with the required expertise may not be available at the location needed. The VR system allows the doctor to diagnose or administer treatment remotely. In a situation where a doctor is present, the remote control of miniature equipment may reduce the invasiveness of a procedure. Virtual retinal display device applications for use by surgeons during operations are being developed. These applications would enable surgeons to view pre-operative data, images and planning notes during surgery without moving away from the patient in the operating theater [*The Economist*, 2001b].

Overlapping with the collaboration category discussed below is the use of VR to assist patient support groups. Patients may have difficulties attending real support groups and patients' families may be geographically dispersed. Cheng et al. [2000] demonstrated a prototype of a virtual world for use by patient support groups.

ELECTRONIC COMMERCE

In Web-based electronic commerce several factors may keep transactions from being completed without face-to-face interaction [Walsh, 2002]. For example, purchasing furniture may be problematic, if pictures do not provide enough information on how a piece may fit in its desired location. If a VR model of both the piece and the desired location were developed, it may be possible to make a purchase decision online. If the VR simulations were good enough, this experience may even surpass the in-store experience which lacks a representation of the buyers' target location.

On-line retailers, such as Sharper Image and Lands' End, use quick-time virtual reality technologies to present 360-degree views of their products to on-line customers. Maytag provides consumers with a demonstration of the digital displays on their Neptune model washer and dryer on-line. This demonstration informs potential buyers and provides an on-line virtual operations manual for those who have already purchased. Also under development are VR applications that provide users with face-to-virtual face interaction with 3-D ‘bots,’ making the online experience closer to real life experiences. For example, a virtual sales assistant - with a face created from real photographs and personalities based on psychological questionnaires answered by real people - could provide the user interface to online retail applications, even ‘remembering’ information about the customer to provide a more personalized shopping experience [*The Economist*, 2001a].

A current limitation to the adoption of VR technologies for e-commerce applications is the high bandwidth that some of these capabilities require. However, efforts are underway to develop system design strategies that reduce bandwidth requirements and high-speed connections are becoming more common in homes and businesses.

COLLABORATION

Collaboration between participants can be conducted within the rich context of the VR system. Collaborative Virtual Environments (CVEs) are virtual worlds shared by participants across a computer network. This rich context may aid in helping users from different parts of an organization, for example, to work together and understand the task at hand. It may also provide an environment where collaborative tools are easily accessible along with reference material. Tools such as the Java Collaborative Virtual Workplace (CVW), for example, can be used to create virtual collaboration environments for distributed analysis and decision support [Maybury, 2001]. In the future, VR systems might be designed to look like a virtual world version of a face-to-face group support system, although more novel approaches are likely to be discovered.

The collaborative and technical nature of product and system design processes has motivated the development of collaborative virtual design environments (CDVEs), such as “The Virtual Design Studio” [Maher et al., 2000]. CDVEs can provide 3D displays including rotation capability, and tactile response systems to give a sense of grasping, rotating, picking up, and movement. General Motors, for example, began using CDVE technology for collaborative car design in 1995 [Smith, 2001]. VR technologies in first-generation CVDEs include Helmet Mounted Displays (HMDs), the Binocular Omni-Orientation System (BOOM), and stereographic monitor systems. Second-generation CVDE systems use large projectors and stereoscopic glasses that allow several users to concurrently view virtual product or systems models while maintaining near-natural, human communications [Ragusa and Bochenek, 2001]. The Cave Automatic Virtual Environment (CAVE) developed by the Electronic Visualization Laboratory of the University of Illinois at Chicago is one example of this type of system [see Cruz-Neira et al., 1993].

It should be noted that the use of collaborative virtual design environments need not be limited to the design of physical products. For example, in the future, as innovative 3D approaches to data modeling are developed, their inclusion in a virtual world could make for a natural forum for collaborative data analysis and database design.

The potential for CVEs to meet organizational needs is only beginning to be explored. Briggs et al. [1998] suggest that VR technology may help distributed teams maintain a sense of group. Nunamaker et al. [2001] describe the need for “organizational bandwidth” which they define as understanding and collaboration. VR’s potential for integrating understanding and collaboration features, then, could be part of a strategy for increasing organizational bandwidth. Churchill and Bly [1999] found a MUD used in the workplace could be beneficial for geographically dispersed workers to maintain relationships and to coordinate. Although Churchill and Bly noted that the absence of social cues in the text based environment may be a barrier for some uses, the anonymity provided may be a facilitator for other uses, suggesting some of the open research questions in this area. Lastly, VR systems such as interactive virtual worlds (IVW) can scale to support large social systems such as conferences of ongoing communities [Damer et al., 2000], so that both small group and large group research related to these environments is likely to be useful.

DATA VISUALIZATION

Visualization techniques can potentially help decision makers to quickly make sense of vast amounts of data [Tegarden, 1999]. VR, as an advanced form of visualization, may be able to enhance other visualization techniques to make them more effective although little is known about when the addition of VR would be most helpful. Tufte [1997] suggests that visualization techniques need to display the data and not allow the graphic representation to be the object of interest, distracting the viewer from the message. What is not known is to what extent a VR system may distract the viewer versus providing additional insight. It is likely that the answer depends on a number of factors.

Modern computer technology enables new forms of vivid visualization [Tufte, 1977]. However, a close look at many scientific visualizations shows them to be without numerical reference to size, time, or quantity, rendering them far less useful than they could be [Tufte, 1997]. Further, authors can distort visualizations to draw viewers to erroneous conclusions [Tufte, 1997]. Issues of quantification and validity will also be important to the study of VR technology. The ability of VR technology to generate highly realistic but possibly invalid images makes the issue all the more important.

FINAL REMARKS ON APPLICATIONS

As this small sampling of applications indicates, advances in VR technologies, coupled with their commercial availability and lowering costs stimulate a wide range of applications that can be leveraged to achieve organizational goals. Moreover, VR technologies captured imaginations and stimulated new visions for future applications - from holographic sales associates for retailing [Colkin, 2001], to e-mail with emotion (where a user's own face and voice will read the letter aloud, winking or smiling in the appropriate place where 'emoticons' have been placed in the message) [*The Economist*, 2001a], to multi-sensory modes of data presentation.

IV. VIRTUAL REALITY AND IS RESEARCH

In this section we offer arguments in support of the inclusion of investigations related to VR technologies and applications into the IS research agenda. The rationale for this type of research is based upon the following observations:

(1) *The number of organizations utilizing VR technologies to achieve organizational goals is increasing rapidly*. Among the reasons for this increase in adoption are advances in VR technology, the commercial availability of VR applications and lower costs. A recent report from an ongoing study by CyberEdge [2001] valued the virtual reality market at more than $22B in 2001; and the Aberdeen Group [Harreld, 2001] projects the market for virtual collaboration applications alone to increase from $9M in 2001 to over $45M in 2005.

(2) *A VR research agenda focused primarily on technical research is inadequate, and should be expanded to incorporate research related to the organizational use of VR technologies.* The movement of these technologies from the laboratory into organizations requires expanding the VR research agenda beyond the technical focus that dominated in the past. Virtual worlds created by VR technologies potentially affect the social and organizational worlds. Investigation into issues related to the use of these technologies in the context of organizations is now needed.

(3) *The insights of earlier IS research will be valuable in the investigation of VR technologies.* We agree with Lee's [2000] argument concerning the value of applying the insights of earlier research to newer information technologies. The understandings that were developed through prior IS research are expected to contribute greatly to the development of our understanding of VR technologies and their application in organizations.

(4) *VR technologies are fundamentally different from other information technologies and hence may require new conceptual models and understandings.* As with any new information technology, caution must be exercised in assuming that understandings developed around earlier technologies will apply. The term 'user interface,' for example, is woefully inadequate in describing the type of user experience that VR technologies can provide such as immersion in

virtual worlds, sensory information, and experiences of 'augmented reality.' Experiencing a 3D representation of inventory levels, interacting with a 3D 'bot' in an e-commerce application or using avatars to interact with other team members in a collaborative work environment may be inherently different from experiences using other user interface technologies. These and other important differences may require a new set of assumptions and conceptual models.

(5) *VR research is a natural extension of several areas of current IS research.* One of the most compelling reasons for IS research related to VR technologies and applications is that VR can be seen as a natural extension of several current IS research domains and research streams, including:

- computer supported cooperative work (CSCW)
- group support systems/group decision support systems (GSS/GDSS)
- virtual teams
- virtual organizations
- e-commerce
- on-line learning
- organizational communications
- organizational learning (e.g., transfer of tacit knowledge)
- human/computer interaction (HCI)
- data retrieval and display
- collaborative software design and development
- system development methods (e.g., data modeling)

In addition, incorporating VR technologies into the IT architectures and application portfolios of organizations raises systems development and IT management issues such as methods and tools for developing VR applications and the skilling of IT professionals in this technology. The availability of VR technologies opens new opportunities for their application in areas such as requirements engineering (e.g., for requirements gathering, requirements negotiation, the development of new kinds of system prototypes), use for collaborative trouble-shooting/help desk support, and technical training. In these areas and others, IS researchers can become originators and developers of new types of applications of VR technologies.

As a last note, it is important to recognize that some IS research work related to VR technologies is beginning to emerge, particularly in CSCW and GSS/GDSS. However, in many of the other IS research domains, there have been no VR-related studies or only a handful. Illustrative of emerging new work are a study by Piccoli et al. [2001] on web-based virtual learning environments and a study by Jin [2001] to examine the relation between virtual and material representations in an e-business company.

V. RESEARCH DIRECTIONS

From the discussion in Sections III and IV, it is clear that many avenues are possible for future IS research related to VR technologies. In addition to investigations focused on a specific type or area of application, the advancement of knowledge related to VR technologies will also depend on developing understandings about fundamental aspects of the technologies and about the user's experience. Conceptual models of this type could also be applied in and unite the findings of application-specific studies. The purpose of this section is to outline some first steps in the development of conceptual models of this type.

THEORETICAL DEVELOPMENT - KEY CONSTRUCTS

Little theoretical work describes the effects of VR technology on humans. The constructs of VR technology are not clearly articulated and the existing conceptual work is contradictory. This area is one of the most important for beginning work so that researchers can proceed in an informed manner and build a collective base of knowledge.

Due in large part to the interdisciplinary nature of the field, wide variation in terms and the meanings of terms evolved. One example is the term immersion, a common term used in many genres of VR research. Some researchers use the label immersion to refer to a particular technology such head-mounted displays [e.g., Hillis, 1999] while others use immersion as a technologically-neutral term referring to a cognitive state [e.g., Ryan, 2001]. Immersion is likely to become a central concept in VR research, encapsulating other constructs. Explication of these constructs, then, will be critical to scientific progress.

The notion of realism in VR systems is another example where current research could benefit from insights provided by other disciplines. Research is being conducted into how to make virtual worlds more realistic, such as Perlin's [2000] work on creating avatars that can show emotion. However, this work is not well connected to social science research that might suggest why realism is desirable or what aspects of a VR system need to be realistic. In the same way that good models abstract away from the detail of reality, it may be that some VR systems ought to simplify reality to be more effective. In other situations, VR systems may be more effective when they enhance reality.

One of the first steps in theoretical development will be the identification and definition of a set of key concepts to describe the user experience of VR. Table 2 shows three key concepts seen most prominently in the VR literature: *immersion*, *interactivity* and *presence* - and a fourth concept, *togetherness*, that represents another dimension of the VR experience. It should be noted that this list does not represent a consensus within the research community. Burdea and Coiffet [1994], for example, suggest immersion, interaction, and imagination as the important concepts. However, immersion and presence appear to be more often defined as states of mind or focused imagination, so those terms appear more precise and less overlapping than Burdea and Coiffet's imagination.

Table 2. Key Concepts - Users' Experience of Virtual Reality

Concept	Citation
Immersion	Burdea and Coiffet, 1994; Witmer and Singer, 1998; Ryan, 2001
Interactivity	Burdea and Coiffet, 1994; Steuer, 1995; Ryan, 2001
Presence	Steuer, 1995 (telepresence); Witmer and Singer, 1998; Schubert et al., 2001
Togetherness	Durlach and Slater, 2000

- *Immersion* can be seen as the extent to which the subject's senses are isolated from the real world and are stimulated by the virtual world [Witmer and Singer, 1998]. Vividness is another suggested concept. It is defined as the representational richness of the mediated environment and has two dimensions: breadth and depth [Steuer, 1995]. In this definition, breadth refers to the range of senses employed and depth refers to the resolution used on those senses. Vividness, then, is similar to others' concept of immersion.
- *Interactivity* refers to the extent to which users can participate in modifying the form and content of a virtual reality environment in real time [Steuer, 1995].
- *Presence* is defined as "the subjective experience of being in one place or environment, even though one is physically situated in another" [Witmer and Singer, 1998, p. 225]. Steuer [1995] argues for the use of 'telepresence' to describe the extent to which presence is felt in the mediated environment. The telepresence concept highlights the potential for a real environment and a mediated environment to be competing for the user's attention and sense of presence [Steuer 1995]. Witmer and Singer [1998] describe the need to experience a "coherent set of stimuli" to achieve presence in a virtual environment over the current real location. They also argue that immersion and involvement (the importance placed on the stimuli) can lead to presence. Schubert et al.

[2001] argue that presence is a multidimensional construct made up of the components spatial presence, involvement, and realness.

Witmer and Singer [1998] proposed a presence questionnaire (PQ) that measures a user's presence within a VR system and an immersive tendencies questionnaire (ITQ) that measures an individual's tendency to experience presence. Slater [1999] suggests that the ITQ is a valuable tool while the PQ is not because it mixes subject characteristics with presence characteristics. Further research is needed to define and measure the concept of presence.

- *Togetherness* is a concept offered by Durlach and Slater [2000] to describe a dimension of the experience of shared virtual environments.

While much research reports on how technology can be used to create immersion and interactivity and how immersion and interactivity create presence, far less deals with the use and consequences of immersion, interactivity, and presence on business and society. Little is known about when and how, for example, these concepts can be used to improve the efficiency and effectiveness of human processes.

DESIGN THEORY DEVELOPMENT

VR technology can be applied in many ways to solving problems. If researchers apply the technology to problems and develop conflicting results it will be difficult to attribute the differences to the theory or the application of the technology. Information systems design theories can develop internally consistent links between basic theory and design for application and testing in certain contexts. By defining VR technology design theories, study results can be interpreted more precisely. Pinsonneault and Kramer [1989] and George [1992] both concluded that differences found in different collaborative computing projects may have been attributable to differences in the way the systems were implemented. In VR research, differences in implementation can be quite significant and there is a similar danger of conducting research that will not be replicable.

Walls et al. [1992] proposed an information systems design theory (ISDT) approach that is useful for linking basic theory to systems artifacts and their usage. Such a design theory is goal oriented and begins with design propositions which link technology and related factors to desired outcomes. Although well-articulated design propositions should have well defined constructs, which we do not yet have, we show how identified concepts may be linked to potential outcomes of such a system. Such a conceptual causal mapping can be viewed as a design proposition framework and can be used to guide development of design propositions. An example of such a framework is presented in Figure 2.

The development of a framework such as the one shown in Figure 2 would benefit from a variety of different research strategies and methods, including those discussed below. Similar to designing other types of visualization, for designs to be effective, a design theory needs to integrate diverse theories such as those in cognitive science and human computer interaction [Tegarden, 1999].

CONTROLLED EXPERIMENTS

With a strong theoretical foundation established, high quality experiments can be designed which measure the effects of VR systems. It may be appropriate to test some aspects of VR systems with captive audiences such as university students, while other aspects will need study in the richness of real world environments.

FIELD EXPERIMENTS

Field experiments can test VR systems in real world environments to understand how theories are applied in the complex context of real organizations under pressure to meet goals.

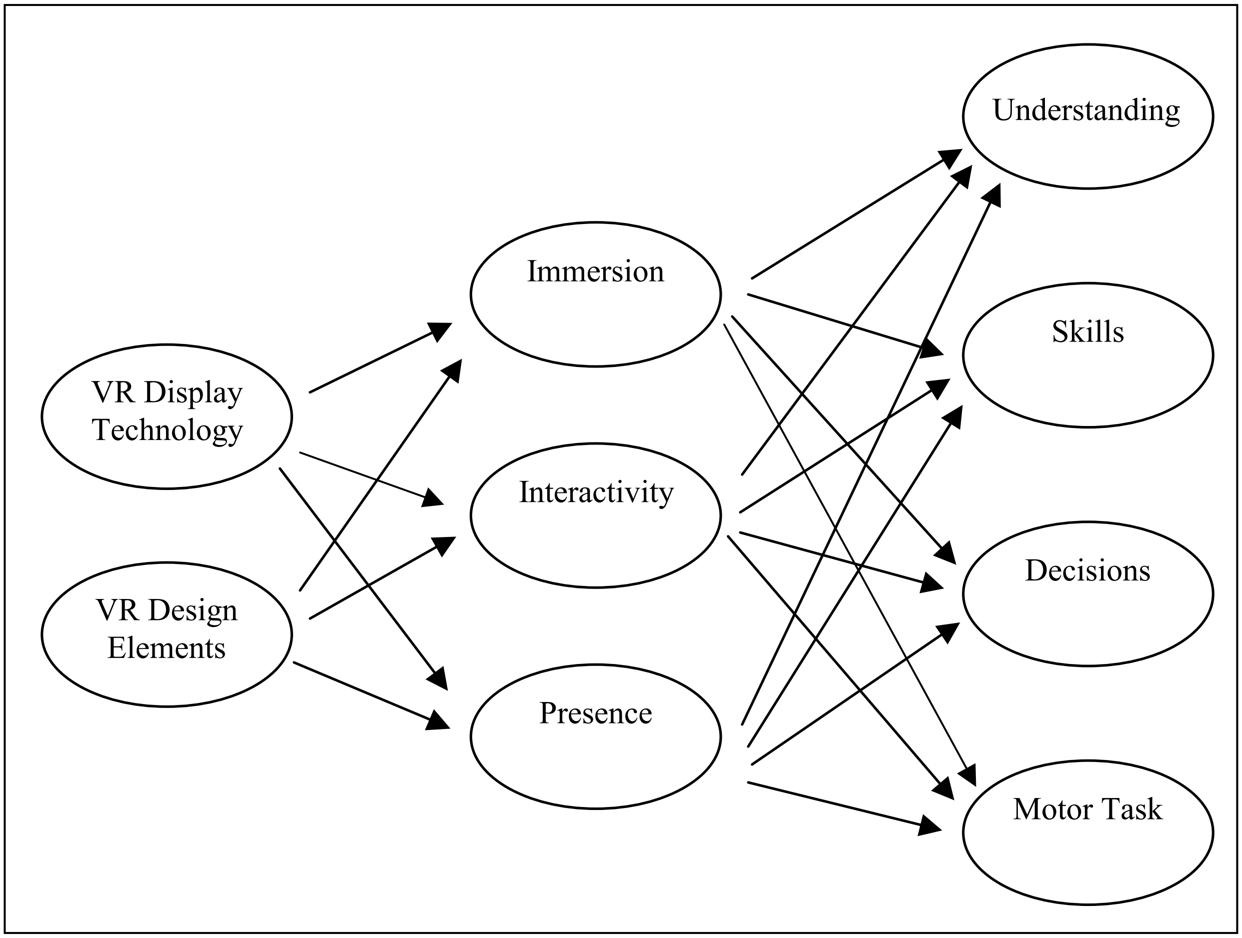

Figure 2. Design Proposition Framework for a VR-ISDT

EMERGENT STUDY

Although there is much room for positivist research in this area, there is also a need for emergent study. The way in which humans use and adapt to VR technology is bound to lead in some surprising directions. For example, an exploratory study using cognitive mapping techniques to discover the "construct system" (constructs and causal relationships) [Eden, 1988] of VR system designers and system users is one approach that could be used to develop an initial VR-ISDT framework.

VI. CONCLUSION

This paper calls for the information systems research community to consider VR research using multi-methodological approaches. The paper argues that the falling costs and rising performance of the technology is making VR viable for a wide variety of applications, and that there is a need for research in its use by humans, individually and collectively.

This paper identified architecture, education, medicine, electronic commerce, collaboration, and data visualization as broad domains where applied VR research is likely to be productive. Many important issues could be pursued within each domain. It is also likely that many other domains can and will be identified, making VR an extensive and rich multi-faceted field in which to work.

Because of its position at the intersection of computer, social, and organizational sciences, the information systems research community has a unique perspective to bring to the topic of VR technology. This paper began with a quote from Biocca and Levy [1995]: "How can we communicate most effectively using VR interfaces? The best answer is: We're not sure, but we'll soon find out." [p. 19]. Our expectation is that IS researchers will be major contributors in answering this and other important questions related to virtual reality technologies.

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EDITOR'S NOTE: The following reference list contains the address of World Wide Web pages. Readers who have the ability to access the Web directly from their computer or are reading the paper on the Web, can gain direct access to these references. Readers are warned, however, that

1. these links existed as of the date of publication but are not guaranteed to be working thereafter.
2. the contents of Web pages may change over time. Where version information is provided in the References, different versions may not contain the information or the conclusions referenced.
3. the authors of the Web pages, not CAIS, are responsible for the accuracy of their content.
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