A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments

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"We modern, civilised, indoors adults are so accustomed to looking at a page or a picture, or through a window, that we often lose the feeling of being *surrounded* by the environment, our sense of the *ambient* array of light... We live boxed up lives." (Gibson, 1986)

Abstract

This paper reviews the concepts of immersion and presence in virtual environments. We propose that the degree of immersion can be objectively assessed as the characteristics of a technology, and has dimensions such as the extent to which a display system can deliver an inclusive, extensive, surrounding and vivid illusion of virtual environment to a participant. Other dimensions of immersion are concerned with the extent of body matching, and the extent to which there is a self-contained plot in which the participant can act and in which there is an autonomous response. Presence is a state of consciousness that may be concomitant with immersion, and is related to a sense of being in a place. Presence governs aspects of autonomic responses and more gross behaviour of a participant in a VE. The paper considers single and multi-participant shared environments, and draws on the experience of Computer-Supported Cooperative Working (CSCW) research as a guide to understanding presence in shared environments. The paper finally outlines the aims of the FIVE Working Group, and the 1995 FIVE.

Keywords
Virtual Environments, Immersion, Presence, Tele-presence, CSCW, multi-participant environments.

1. Introduction: Through the Looking Glass

Those of us old enough will remember working in institutions many years ago that had a special "computer room". This was a glass encased temperature controlled room, with banks of large whirling tape drives, discs, large blue boxes with lots of flashing lights, attended by priest-like operators in white coats. Day after day we would pass by that

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room, and maybe we were able to see through the glass, to observe that essentially sacred place and the objects of worship and rites and rituals within it.

One of the authors had quite an unusual experience one day after about four years of passing by such a Computer Room in College: he had to go inside it. It was rather a shock. What had been seen on the outside, only ever through the glass, only ever from the limited range of viewpoints afforded by the architecture and room layout, was now suddenly surrounding - he was inside it, he saw (and experienced) the computer room in a way that had never been possible before for him, in a way that was impossible from the outside.

When we look at a TV screen or movie, it is much the same as looking through this glass - except that the scenario and unfolding events are typically distant in place and time. The glass of the TV screen forms a discontinuity between the place of our current reality, and the reality showing through the display. This discontinuity between different spatial and temporal realities, and its sudden unexpected collapse, is a recurring theme in popular culture. Considering this in relation to a Robert Henlein novel (The Unpleasant Profession of Jonathon Hoag), regarding a scene where a couple in a car roll down a window pane to find an Absolute Nothingness outside, Slavoj Žižek (1991) writes:

> '...To those sitting inside a car, outside reality appears slightly distant, the other side of a barrier or screen materialised by the glass. We perceive external reality, the world outside the car, as "another reality", another mode of reality, not immediately continuous with the reality inside the car. The proof of this discontinuity is the uneasy feeling that overwhelms us when we suddenly roll down the windowpane and allow external reality to strike us with the proximity of its material presence. Our uneasiness consists in the sudden experience of how close really is what the windowpane, serving as a kind of protective screen, kept at a safe distance. But when we are safely inside the car, behind the closed windows, the external objects are, so to speak, transposed into another mode. They appear to be fundamentally "unreal", as if their reality has been suspended, put in parenthesis - in short, they appear as a kind of cinematic reality projected onto the screen of the windowpane. It is precisely this phenomenological experience of the barrier separating inside from outside, this feeling that the outside is ultimately "fictional", that produces the horrifying effect of the final scene in Henlein's novel. It is as if, for a moment, the "projection" of the outside reality had stopped working, as if, for a moment, we had been confronted with the formless grey, with the emptiness of the screen...'

When we look at a computer screen the scenario and events are now not "real" but computer generated: the environment that we are looking at is "virtual", it is a representation of something - some underlying process, or computation, rather than what it appears to be.

The grand aim of immersive virtual environments research is to be able to realise that same "stepping through the glass" or "rolling down the window" with respect to computer generated environments, as can be experienced when stepping through a barrier that in normal circumstances screens some aspect of reality from us. But this stepping through the barrier has some paradoxical elements: on the one hand, it is a surprise, when the previously remote suddenly becomes immediate, it is essentially *unreal*. Simultaneously though, we wish to preserve something in the passage through the barrier, that is the sense of our *self* being in a place, the sense that we are really through the barrier - that is, preserving the invariance of our sense of "being there", commonly referred to as the sense of *presence*, or tele-presence. As has been argued by Steur (1992) presence is the central goal of "virtual reality", perhaps a defining feature.

The need to maintain a sense of presence even after passing through the barrier therefore has become a guiding principle for our research, and formed the cornerstone of the philosophy of the FIVE group. In this paper therefore we will review our approach to the definition of presence, and the emerging model for understanding the factors that influence this. We will also consider the concept of presence in shared environments, and then return to how this can be a guide for research. This will lead to an explication of the FIVE programme, and an introduction to some of the papers that were presented at the first conference of the FIVE Working Group in London, December 1995.

2. Immersion and Presence

2.1 Immersion

We distinguish between immersion and presence. *Immersion* is a description of a technology, and describes the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant. *Inclusive (I)* indicates the extent to which physical reality is shut out. *Extensive (E)* indicates the range of sensory modalities accommodated. *Surrounding (S)* indicates the extent to which this virtual reality is panoramic rather than limited to a narrow field. *Vivid* (V) indicates the resolution, fidelity, and variety of energy simulated within a particular modality (for example, the visual and colour resolution). Vividness is concerned with the richness, information content, resolution and quality of the displays.

These aspects of immersion are concerned with display of information. *Matching* requires that there is match between the participant's proprioceptive feedback about body movements, and the information generated on the displays. A turn of the head should result in a corresponding change to the visual display, and, for example, to the auditory displays so that sound direction is invariant to the orientation of the head. Matching requires body tracking, at least head tracking, but generally the greater the degree of body mapping, the greater the extent to which the movements of the body can be accurately reproduced.

Immersion requires a self-representation in the VE - a Virtual Body (VB). The VB is both part of the perceived environment, and represents the being that is doing the perceiving. Perception in the VE is centred on the position in virtual space of the VB - e.g., visual perception from the viewpoint of the eyes in the head of the VB (*egocentric* as opposed to *exocentric*, Ellis, 1991).

Each of these dimensions of immersion has, in principle, associated scales, indicating the extent of their realisation. For example, “surrounding” can be delivered by a small external screen at one extreme and a wide field of view HMD, or a CAVE system at the other. “Inclusive” in the ideal situation would, for example, have the HMD completely weightless, so that this aspect of external reality is not perceived by the participant. “Vivid” would include, for example, the quality of the visual rendering (from wire frame to photo-realism) as well as more basic considerations such as the pixel resolution.

Each of these dimensions exists on multiple levels. The most fundamental levels may correlate with the responses of the autonomic nervous system - for example, whether the VE visual display has the capability to induce changes in visual accommodation and vergence (Ellis, 1991). Higher levels may correlate with cognitive responses and behaviours. For example, whether or not the system can exhibit dynamically changing shadows may influence a participant’s behaviour in certain tasks such as picking up objects, or aiming projectiles before firing them (Slater, Usoh, Chrysanthou, 1995).

The case of “matching” requires at the most basic level a minimal lag between motor actions and the corresponding system response. At a higher level matching has implications for the interaction paradigms employed. The concept of “body centred interaction” (Slater and Usoh, 1994), developed as a result of these ideas, requires that actions be carried out in a way that maximises the match between proprioception and sensory feedback at the perceptual and cognitive level. A very straightforward example, is that ideally a participant should virtually walk by really walking - in which case the whole body movements associated with walking match the corresponding optical flow.

Finally we mention *plot*. This is the extent to which the VE in a particular context presents a story-line that is self-contained, has its own dynamic, and presents an alternate unfolding sequence of events, quite distinct from those currently going on in the “real world”. This includes Zeltzer's (1992) notion of “autonomy” (the extent to which objects in the VE have their own independent behaviour) and also the response of other virtual actors to actions of participants (Heeter, 1992). It also includes Zeltzer's notion of “interaction”, that is the extent to which the participant can influence the unfolding of events, and effect changes to the virtual world. Plot is in a sense the extent to which the VE can potentially “remove” the participant from everyday reality and realise and act in an alternative self-contained world with its own drama in which the individual can participate.

2.2 Presence

Immersion can be an objective and quantifiable description of what any particular system does provide. Presence is a state of consciousness, the (psychological) sense of being in the virtual environment. Presence has been studied by many researchers in recent years, for example (Heeter, 1992; Held and Durlach, 1992; Loomis, 1992; Sheridan, 1992; Steur, 1992; Barfield and Weghorst, 1993; Barfield et. al., 1995). The fundamental idea is that participants who are highly present should experience the VE as more the engaging reality than the surrounding physical world, and consider the environment specified by the displays as places visited rather than as images seen. Behaviours in the VE should be consistent with behaviours that would have occurred in everyday reality in similar circumstances. Presence therefore requires that the participant identify with the VB - that its movements are his/her movements, and that the VB comes to “be” the body of that person in the VE.

There are several working hypotheses that have emerged from and latterly guided a number of our practical experiments:

(a) Presence is both a subjective and objective description of a person's state with respect to an environment. The subjective relates to their evaluation of their degree of “being there”, the extent to which they think of the virtual environment as “place like” (subject to suspension of disbelief). The objective is an observable behavioural phenomenon, the extent to which individuals behave in a VE similar to the way they would behave in similar circumstances in everyday reality. The subjective may be correlated with the higher levels of immersion mentioned above. The objective may be correlated with more fundamental aspects of immersion.

(b) We think of presence as an increasing function of immersion in all its aspects. However, the impact of the display aspects (I, S, E, V) is mediated through two filters - the application or task context and the perceptual requirements of the individual. The first is obvious - for example, an application concerned with understanding the relationship between location within a chamber and the auditory quality of an orchestra must have high quality auditory rendering to be meaningful, whereas the visual representation is less important. Secondly, individuals seem to differ in their preference for information in the various modalities to enable a successful construction of their internal world models. For one person the absence of auditory information might be a crucial hindrance, whereas for another it might be hardly noticeable.

(c) The more the “plot” line potentially removes a person from everyday reality, and presents an alternate self-contained world, the greater the chance for presence. On the subjective side the more that a person is susceptible to displacement of their sense of reality, the greater the chance for presence. This might be measured, for example, by their degree of susceptibility to hypnosis.

2.3 Influence of Immersion on Presence

In their 1992 paper Held and Durlach (op. cit.) note regarding understanding of the factors that explain presence that “there is no scientific body of data and/or theory delineating the factors that underlie the phenomenon”. Although this remains largely true, there have since been a few experimental studies which we now briefly consider in relation to some of the aspects of immersion considered above.

(a) Inclusive

Held and Durlach argue that presence requires that the displays be free from signals that indicate the existence of the device, which, of course, belongs to the physical rather than the virtual reality. Such signals would include three categories - those directly due to the information display systems, such as aliases and slow update rates; the input systems - such as interference caused by metallic objects in the electro-magnetic sensors; and the physical properties of the devices themselves - weight, cables, and so on. In our first experimental study (Slater and Usoh, 1992) we found from questionnaire responses after an experiment that in answer to the open question "Were there any circumstances that especially *decreased* your sense of being 'really there'?" 4 out of 17 subjects mentioned outside events including the voice of the experimenter, and 6/17 mentioned poor screen updates, low resolution, and high lag. However, when in the same study a deliberate attempt was made to cause outside interference (making a loud and incongruous noise by dropping a cup and saucer) those who reported the highest sense of presence actually *incorporated* this noisy event into their VE experience - i.e., the source was experienced as if it had occurred from within the environment rather than from external reality. (This recalls Freud's observations in the *Interpretation of Dreams*, that dreamers weave outside events into the fabric of their dreams. He mentions Maury's famous dream about being guillotined as being prompted by something falling on his neck while sleeping).

In a small pilot study to study the effects of auditory phenomena on presence Patel (1994) carried out an experiment where the subjects were grouped according to the quality of sound they received - sound only from the real world of the laboratory, white noise generated by the HMD speakers, non-directional sound generated by the speakers, and finally spatialised directional sound. The result was that the largest change in the influence on presence was from the "no virtual sound" condition to the "white noise" condition - suggesting that the white noise isolated the subject from the real world sounds, supporting this notion of inclusion.

Finally, a study by Barfield and Hendrix (1995) examined the influence on reported presence of update rate. They found that there was such an influence, that presence generally increased with increasing update rate, but that the reported presence was approximately constant between about 15Hz and 20Hz.

(b) Vividness

Welch et. al (1996) reported an experiment with a driving simulator where two levels of pictorial realism were presented. There was a significant difference in level of reported presence between the two levels of pictorial realism, with the more realistic resulting in a higher level of reported presence. Hendrix and Barfield (1996a) studied the effects of stereopsis, and geometric field of view on subjective presence. Each of these significantly affected reported presence, with stereopsis and a wider geometric field of view each positively correlated with the presence score.

We mentioned shadows as an example of "high level" vividness. In the cited study subjects were asked to carry out a task involving the selection and firing of a projectile at a target. The extent of dynamic shadows was an independently varied factor, and all subjects carried out the same task. In this experiment presence was measured subjectively, using a questionnaire, but also there was an attempt to measure "behavioural presence" - in this case the discrepancy of a pointing angle between a real and virtual source (the greater the angle the more that the subject was influenced by the virtual). The extent to which the subjects experienced dynamic shadows was positively and significantly correlated with both subjective and behavioural scales of presence.

In a recent study Uno and Slater (1997) examined the influence of the visual simulation of the physical laws on reported presence. In this study with 18 subjects, each was exposed to differing combinations of elasticity, friction, and collision response in the context of a virtual bowling alley. It was found that in this application, the more realistic simulation of friction was significantly and positively associated with reported presence, but that more accurate simulations of elasticity and collision response did not have such an effect.

(c) Proprioceptive Matching

In the same study by Welch et. al., delay in visual feedback was another independent factor. A higher level of presence was reported under the condition of minimal delay, and this was a more important factor than the level of pictorial realism. Hendrix and Barfield (1996a) found that head-tracking significantly increased the reported sense of presence in an experimental study, and also led to subjects becoming more animated in the use of their bodies, such as standing on a chair, bending down, leaning forwards and backwards, and turning around.

Walking was mentioned earlier as a high level example of matching. In an experimental study (Slater, Usoh and Steed, 1995) we found that subjects who walked through a virtual environment using a "walking in place" technique reported a higher sense of presence than those who navigated the environment using a pointing device We speculate that this relationship was due to the greater match between optical flow and proprioception for the walking technique compared to use of a hand held pointing device for navigation.

(d) Extensiveness

Hendrix and Barfield (1996b) carried out experimental studies to examine the impact of sound on subjective presence. In one study spatialized sound was introduced or not into a visual VE. In the second study, the comparison was between non-spatialized sound and spatialized sound. In each case there was a significant effect on presence - spatialized sound led to a higher reported presence than both no sound and non-spatialized sound.

(e) Plot

We know of no study that directly attempts to examine the influence of plot in the sense of "story line". However, the study by Welch et. al. (1996) included interactivity as one of the independent variables. Again, interactivity, in the sense of whether or not the subjects drove the simulated vehicle or merely observed the VE, had a positive association with reported presence.

2.4 The Utility of Presence

Why is it important to study presence? One answer is simply to do with a strategy for research. The distinguishing feature of immersive VEs (IVEs), compared with exocentric desktop display systems, is that they afford a sense of presence. This therefore provides a direction for research - if we can find important factors that contribute to presence, then this can guide the future of the technology.

Another answer is to do with the utility of presence itself, and its relationship to "task performance". For example, this is stated, for example, by Welch et. al. as one of the reasons for studying presence (though not necessarily the main reason). Our view is that there is no reason to expect a positive association between presence and task performance. Presence is hardly the most important factor in this regard; the quality of the user interface is, for example, a crucially determining factor. In our view presence is important because the greater the degree of presence, the greater the chance that participants will behave in a VE in a manner similar to their behaviour in similar circumstances in everyday reality. Hence if a VE is being used to train fire-fighters or surgeons, then presence is crucial, since they must behave appropriately in the VE and then transfer knowledge to corresponding behaviour in the real world. There could obviously be cases where presence would diminish performance, just as being present in a situation in real life using a machine with a poor "user interface" similarly affects performance adversely.

The utility of immersive VEs in psycho-therapy relies very much on this connection between a similarity of behaviour in real and virtual environments, as has been pointed out by Strickland (1996). Responses such as acrophobia (Rothbaum et. al., 1995), claustrophobia, and fear of flying (Hodges, et. al., 1995) have been observed in immersive VEs. Clearly, these are excellent examples of behavioural presence (without presence the psychotherapy would not be possible) and yet are poor examples of "task performance", for example, the task of "travelling in an airplane", on the part of the subjects involved.

In (Slater, Linakis, Usoh, Kooper, 1996) we explored the relationship between immersion, presence and performance. This concerned a task involving comprehension and memory of a complex 3D object, events in relation to that object, and the subsequent reproduction of those events in the real world. The results suggested that increased immersion in the form of egocentric rather than exocentric viewpoint, and greater vividness in terms of richness of the portrayed environment, does indeed improve task performance (other things being equal such as relevant background knowledge and ability). The study also found that reported presence was higher for egocentric compared to exocentric immersion, but that presence itself was not associated with task performance.

2.5 Comparison with Other Proposals

The most important idea that we have presented here is the idea of external, objectively measurable characteristics that lead to a capability of placing an individual inside a computer generated environment. This is what we have called immersion, and have considered immersion ideally requiring inclusive, extensive, surrounding, and vivid display systems, where there is real-time matching between proprioception and sensory data. The VE should portray a story line, in which the individual can participate and modify. On the other hand, presence is the potential psychological and behavioural response to immersion. A highly present individual should identify with the virtual body portrayed in the VE, and therefore consider him or her self as being located in the environment in which that body is portrayed. Such a highly present individual would be observed to behave in a VE in a manner similar to how they would behave in a similar environment in everyday reality.

These ideas are only a particular distillation of the approaches of others mentioned previously (Heeter, 1992; Held and Durlach, 1992; Loomis, 1992; Sheridan, 1992; Steur, 1992; Barfield and Weghorst, 1993; Barfield et. al., 1995). In particular, Sheridan (1992; 1996) proposed three orthogonal attributes that could form a scale for presence: (a) the fidelity of the multimodal displays, (b) the ability to modify sensor position, (c) and the ability to change the configuration of the environment. In the scheme proposed in this paper, (a) is an elaboration of vividness, (b) is included in the concept of "matching", and (c) in the concept of "plot". The attributes of inclusive, extensive and surrounding can be considered as additional orthogonal attributes that may be added to Sheridan's scheme.

In his response to Sheridan, Ellis (1996) points out that a required characteristic in any proposed equation purporting to describe presence, it must be possible to demonstrate iso-presence equivalence classes, where a group of factors vary in a compensatory way so as to demarcate constant levels of presence across the variation in their range. The factors in the model presented here must, in future studies, be constructed in the manner suggested by Ellis, towards the achievement of a useful scale capable of leading to a valid measure of presence.

We take issue, however, with Ellis' remarks concerning the possible dis-utility of presence in task performance, since there is an association of the notion of "presence" with "realism". Two examples are given where it is clear that a realistic visual representation of information (air traffic display, and orbital trajectories in the vicinity of a space station) could lead to deficiency in task performance compared to a distorted representation. However, first, both environments are external, seen through a "window". Our notion of presence is that it is related to the environment in which the (virtual) body of the participant is acting. It is the relation to the interior of the aircraft cockpit that is relevant for presence, not the environment that can be seen through the window of the cockpit. Secondly, presence does not imply realism. Here is where the conceptual distinction between immersion and presence is useful. The question to ask is: what display characteristics (relevant to a certain application domain) maximise presence? It may be the case that a non-realistic display enhances presence, or that the characteristics that enhance presence are not the same as those that enhance a particular type of task performance. The separation between immersion and presence allows both to be investigated, and even if it turns out that they are correlated in a particular application, this may not be due to causal connection.

3. Shared Environments

3.1 The Abstract Society

In *The Open Society and its Enemies*, written more than 50 years ago, the philosopher of science Karl Popper envisaged a future society where most contact between humans was mediated electronically:

> '... an open society ... may ... lose the character of a concrete group of men, or of a system of such real groups ...We could conceive of a society in which men practically never meet face to face - in which all business is conducted by individuals in isolation who communicate by typed letters or by telegrams, and who go about in closed motor cars.... Now the interesting point is that our modern society resembles in many of its aspects such a completely abstract society.'
> (K. Popper, The Open Society and its Enemies, Vol. I, 1945)

This "abstract society" foreseen by Popper in 1945 is really happening now, under the popular embracing name of "cyberspace" - a huge growth in use of the Internet, and several systems that support distributed virtual environments (for example, Carlsson and Hagsand, 1993; Macedonia, 1994; Greenhalgh, 1995).

Popper envisaged the electronically mediated society as the antithesis of collectivism (the Open Society was written as a philosophical polemic against Plato - Volume 1 - and Hegel and Marx - Volume 2). We find though that there is a contradictory trend in the development of this media. At one it increases the possibility for totalitarianism and at the same time increases the chance for personal empowerment and creativity. The electronically mediated society is more likely to be like the anarchic Cyberspace of William Gibson's Neuromancer[3] than Popper's vision. In this section we consider some of the research issues for shared virtual environments.

3.2 Presence in Shared Environments

In shared environments, the concept of presence takes on additional meaning. First, the extent to which the individual has a sense of belonging to a totality that is more than just the sum of the individuals - the extent to which the group as a whole takes on behaviour that is not a conscious decision of any particular individual. An example might be the group as a whole showing gross patterns of movements, or where, say, in the context of meetings individuals always take up the same spatial position with respect to others, whether done consciously or not.

Secondly, the sense of being in a place which others share involves more than 'meets the eye'. Experiencing simulated people who can engage in conversation is just the starting point for what is needed to communicate with others in a virtual environment. We assume that a shared VE will mediate not only simple communication, but will also support more focused collaborations. Block-like humanoid figures can most likely be tolerated (like poor quality video in desktop conferencing), provided the environment can

[3]William Gibson, Neuromancer, Grafton.

mediate the cues people need to interact effectively with others. By this is meant not only the ability to share in the manipulation of objects, but also the ability to experience the more subtle experiences of social interaction - such as being aware of who is looking at us, noticing when people join or leave a meeting, and knowing where group attention is focused (gaze awareness). In video-mediated collaborative environments, tools are provided at the user interface to support these aspects of *awareness*. These CSCW (Computer-Supported Cooperative Work) tools use telepointers, icons, and images to provide the cues users need for collaboration. The challenge for shared VEs is to find alternative solutions to satisfy these and other needs that people experience when sharing a meeting place with others.

3.3 Space as a Context for Communication and Collaboration

The importance of space for contextualising communication has been emphasised by Harrison (1992). Traditional CSCW systems for real-time collaboration among distributed groups also aim to create a feeling of *telepresence* - the sense of being present in a remote place (Bly et al, 1993; Cool et al, 1992). The aim of abolishing distance is, of course, much older than CSCW research (which originated in the 1960s but only took off in a big way in the mid 1980s). The telephone inspired these notions almost a century ago:

> 'If, as it is said to be not unlikely in the near future, the principle of sight is applied to the telephone as well as that of sound, earth will be in truth a paradise, and distance will lose its enchantment by being abolished altogether.' (Mee, 1898).

CSCW design is dominated by spatial metaphors such as “proximity”, “media space”, and virtual meeting rooms, corridors, and hallways. In media spaces, the aim is to overcome the boundaries of physical space by creating a parallel, virtual space based on audio and video connections (the notion of media space was originally conceived by two architects, in fact). A media space promotes informal interactions, and uses video connections to let users ‘glance’ into remote offices, or to link coffee areas in remote sites. Virtual meeting room systems support a different model of interaction, providing a persistent virtual environment for collaboration, accessible over the network. A recent system, Archways, based on the Rapport architecture incorporates a 3D user interface and spatial audio (Seligmann et. al., 1995). In other CSCW systems, virtual corridors are simulated at the user interface for social browsing over video, or video-walls are used to link remote coffee areas (Cool et. al., 1992).

The abstractions and spatial metaphors embedded in collaborative technology, then, have strong links with the notion of presence in VEs. A strong sense of presence may be even more essential for interpersonal interactions in shared VEs than it is for single-user applications. Are the properties of vividness, extensive, inclusive, matching, surrounding and plot as significant for collaboration? Some initial answers to this question are suggested by CSCW research.

3.4 Dimensions of Immersion in Shared Environments

We consider *vividness* first. CSCW research shows that the ability to create a sensory-rich environment is an important aspect of virtual meeting places. The quality of communication channels impacts the effectiveness of both verbal and non-verbal interaction among distributed groups. Electronic communication strives to emulate face-to-face, the richest communication environment people ever experience. Comparisons of video-mediated communication with face-to-face confirm vividness as a key dimension in interactive shared environments (Rutter et. al. 1981; Cohen 1982; O'Conaill et. al., 1993). For example, comparisons of low-quality and high quality video with face-to-face communication in (O'Conaill op. cit.), showed that measures such as turn-taking, back-channelling, and speaker behaviour were all affected by the quality of the media. While it was not possible to isolate whether it was the quality of the audio or video that had affected interactions, the similarity of these results to other studies confirmed the significance of vividness. Levels of interaction seem to be directly affected by the richness of communication.

The impact on group interaction of the level of *extensiveness* of a virtual space is harder to demonstrate. Many studies have found no evidence, for example, that adding a video channel to an audio link for remote collaboration improves task performance when compared to audio alone (Ochsman and Chapanis, 1974; Gale, 1990). More recently, however, it has been proposed that adding video affects the processes of collaboration, rather than task outcome (Isaacs and Tang, 1993), a lesson perhaps for evaluation of shared VEs.

Matching, surrounding and inclusive are properties of immersion, and so CSCW research has little to say about the significance of these for collaboration. Support for some kinds of gesture are, however, generally accepted as essential for remote collaboration. Use of telepointers to convey pointing actions, and simulated hand-raising (to gain a chairperson's attention), are examples of remote gesturing. Also, it is worth noting that some systems are designed to ensure that real reality is *not* shut out (in CSCW terms, this means communication with the external environment). In Rapport, for example, a telephone call can be accepted from outside the virtual meeting room.

Finally, we consider *plot*. Here the notion of autonomy is important for collaboration. In (Lewis and Mateas, 1994) environmental autonomy is defined to mean the degree to which an environment is perceived to contain autonomous agents. A high level of environmental autonomy is important in spaces peopled by simulated collaborators. In CSCW, users are aware that shared interactions are supported indirectly, through screen-based communication, WYSIWIG interfaces and telepointer tools. In shared VEs, although the techniques to support sharing are essentially the same, interactions should appear to be direct. If I feel present, my virtual body should seem to be communicating directly with my fellow participant in virtual space, who can react autonomously.

One more aspect of shared immersive technology needs to be mentioned. This is *interactivity*. Interactivity refers to the extent to which a user can create and modify the form and content of objects in the shared VE. Collaboration almost always involves the creation and joint manipulation of shared objects such as documents, designs, and other artefacts. For some types of collaborations, such as informal meetings, low interactivity may be sufficient. But if the shared VE is to support a wide range of collaborations, then not only is high interactivity required, but also the ability to bring new objects to the virtual space and to make objects persistent.

Some of these aspects of shared presence are being studied by the DEVRL group in the UK (DEVRL, 1995).

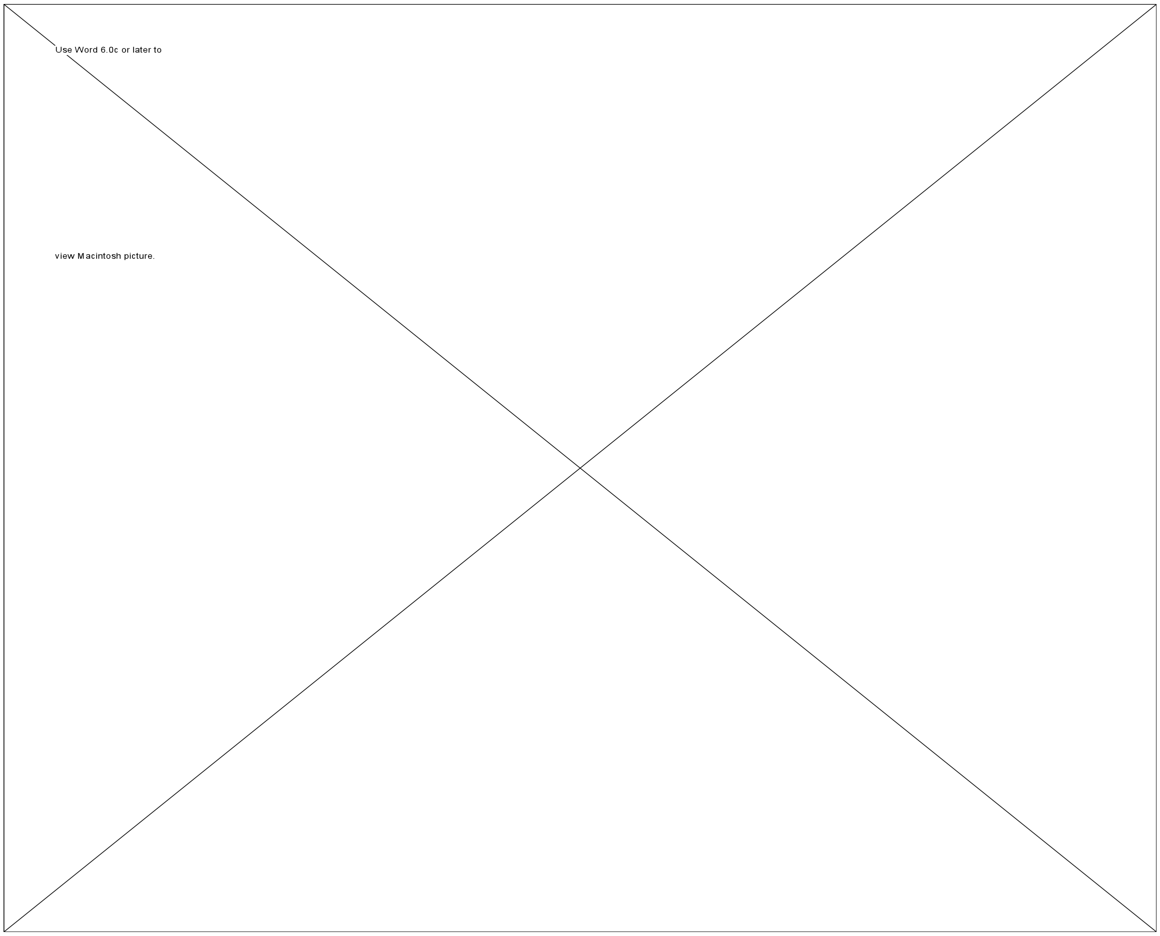

Figure 1

A View of FIVE

4. A Framework for Research

If we take presence as the central feature of VEs, then the research can lead to a new understanding of the psycho-physics, display systems and simulation factors that reinforce the sense of presence. This in turn makes possible the construction of VEs that properly maintain these factors.

The structure adopted by the FIVE group is shown in Figure 1. Here the fundamental research aspects are shown leading from the central concept of presence to the implications for the various components of the VE. These same components can, from the practical point of view, also be thought of as computational servers maintained through a VE System Kernel, which is at the other end of the structure, such as the Actors in the dVS system (Grimsdale, 1991). There are, of course, research issues that belong exclusively to each component - for example, the algorithmic issue related to rapid shadow generation in the Display system, in itself has nothing to do with presence. The problem of the representation of time in the VE kernel, again in itself is a research issue independent of presence. However, the research programme identifies these issues, and poses the questions of assessing whether indeed, and for example, shadows do contribute to the sense of presence, and whether time-lags decrease the effectiveness of the VE for the activities of the participants.

5. The 1995 FIVE Conference

The partners of the FIVE group do research in the various areas mentioned in Section 4. In the Conference the Sessions were divided into these areas, with each introduced by a paper from the FIVE group (Slater, 1995). The opening talk was based on an earlier version of this paper. This was followed by a review of visual displays in virtual environments by FIVE member Gavin Brelstaff of the University of Bristol, UK. This was followed by that of a contributed paper by Jolande Tromp from the University of Nottingham, UK, who returned to the concept of presence, specifically drawing more on the relevant psychological literature. This was followed by the contributed paper of Dave Snowdon, Chris Greenhalgh and Steve Benford from the University of Nottingham UK, who discuss the notion of subjective views in shared environments, a method for individuals to see that part of the information space that is of interest to their application.

The session on Interactivity was introduced by FIVE member Massimo Bergamasco, of Scuola Superiore S. Anna in Italy who presented a paper about the most difficult aspect of virtual environments, sensory feedback - that of tactile displays including heat. A revised version of this paper is presented in this journal. This was followed by two contributed papers by Marc Cavazza and colleagues from Thomson-CSF in France, a revised version of which appears as a Lab Report in this journal, and Andy ColeBourne and Tom Rodden of the University of Lancaster UK on the construction of virtual environments. The session on Interactivity was closed by a FIVE paper from Holger Strauss and Jens Blauert of Ruhr-Universitat Bochum in Germany who discussed auditory environments.

The area of physically based simulation and behaviour in the FIVE group is represented mostly by the Universities of Geneva and EPFL in Switzerland. Nadia Magnenat Thalmann (Geneva) and Daniel Thalmann (EPFL) presented a joint paper with colleagues Tolga Capin and Igor Pandzic on the representation of humans in a networked environment. This appears as a Lab Report in this journal. Efficient collision detection methods are a fundamental requirement for simulation and interaction in VEs and this topic was considered in the paper by J.J. Fang and colleagues from Heriot Watt University UK.

It is vital for the future success of VE research that we learn from the experience of more than a century of perceptual research and bring this knowledge to VE community. The talks by Gavin Brelstaff, Massimo Bergamasco, Holger Strass and Jens Blauert represented this within the FIVE group. This was continued at the end of the first day of the conference which was concluded by a talk from Richard Gregory of the Perceptual Systems and Research Centre University of Bristol on applications of VEs to the presentation of science, including uses and possible abuses of the technology.

Steven Ellis of NASA Ames Research Centre in the US returned to the concept of presence and perception, opening the second day with his remarks on Sheridan's (1992) paper, reported in Ellis (1996). This theme was continued with the papers by Alan Murta of the University of Manchester UK who was concerned with vertical axis awareness - considered as an important measure of the accuracy of visual perception in VEs.

The emergence of VEs as an important topic for research in recent years has had a profound effect on computer graphics. The necessity for real-time performance has led to a rethink about object representation, and the realisation that it is not feasible or sensible to have a single representation for an object, used for rendering no matter what the current viewing parameters. There were four papers in this section, opened by the FIVE members R. Schraft, J. Neugebauer, T. Flaig and R. Dainghaus of the Fraunhoffer Institute, IPA in Stuttgart, Germany, on a new method for level of detail control based on fuzzy logic and genetic algorithms. This was followed by a contributed paper from Martin Reddy of the University of Edinburgh, UK, who presented an interesting application of ideas from visual perception to the problem of level of detail representation. Another application of the perceptual theory concerning peripheral vision leads to a study by Benjamin Watson, Neff Walker and Larry Hodges of Georgia Institute of Technology USA evaluating a level of detail method for peripheral vision. Subsequent to the conference, the authors from the Georgia Institute of Technology and University of Edinburgh joined forces to produce the two companion papers on level of detail in this journal.

Three contributed papers on health and safety aspects of VEs were presented at the Conference. The first was by Robert Kennedy and colleagues from Essex Corporation in Florida USA, who provided a wealth of information on cybersickness. Peter Lassig of the University of Leipzig, and Jens-Uwe Molski of doppeldecker VR design, Liepzig, Germany discuss notions of cybersickness in relation to HMDs. Sue Cobb, Sarah Nichols and John R. Wilson of the University of Nottingham presented their current work on developing an experimental methodology for health and safety within virtual environments. The Essex Corporation and University of Nottingham papers were revised and appear in this journal.

6. Conclusions

Computers were once remote and sacred objects to be seen only through glass and serviced by a priesthood of operators and programmers. Over the years they have become closer and closer to human beings, expanding to the mass of workplaces and homes, providing everything from accounting to entertainment. Now with immersive VEs they are beginning to supply us with new places to inhabit and share, determining our very sense data, resulting in new bodies, new powers. It is our optimistic belief that as we become more and more intertwined with computers they can become more and more liberating, the science fiction presented in novels such as Gibson's *Neuromancer* and Stephenson's *Snow Crash* [4] are becoming reality before our eyes. The purpose of the FIVE group is to try to bring together some of this research, and present a framework for it based on the concept of presence as a contribution towards its realisation.

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