Minimal Cues in Immersive Virtual Environments

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First Year PhD exam

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PhD start date: 11/2001

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Main Report

1. Introduction

This document is submitted as a 1st Year PhD report as required by the Computer Science Department at University College London prior to the 1st Year viva. It is based upon the guideline document authored by Stephen Hailes in November 2001.

1.1 Abstract

The aim of this thesis is to describe, identify, and support the concept of minimal perceptual cues for the benefit of Immersive Virtual Environment (IVE) design and application. The scope of this work shall be limited to consider visual perceptual cues only. This work will be carried out via the construction of a methodical and principled technique that shall be used to determine the required perceptual cues needed to represent a particular type of environment (for instance, a kitchen, or office.) In practice this will entail the measurement of the sense of presence in a particular type of environment, whilst the level of detail (which will include specific 'regions of interest') is increased until a presence threshold is reached.

The identification of minimal cues will be useful for the construction of future IVEs as they can then be created objectively, consistently, and with minimal effort and computation.

The evidence to support the results is determined using a novel objective measure of presence that should prove useful in its own right. At the moment, there is no objective measure that can be consistently applied to a wide range of environments, and this approach should prove to be a useful tool for future IVE work in general.

The sense of presence will be estimated using a modification of Stark's scanpath theory (Stark, Choi, "Experimental Metaphysics: The Scanpath as an Epistemological Mechanism", Visual Attention and Cognition, Elsevier Science, 1996)[36] so that it considers eye gaze (foveations) and movements (saccades) in IVEs rather than those directed at two or three-dimensional images.

Currently the scope and precise objectives of the work is being defined. Reading is focussed in the areas of eye gaze, scanpath theory, and analysis using Markov models.

1.2 Background and Motivation

One of the greatest problems in the field of Immersive Virtual Environments is that of the efficient presentation of the environments. This is due to the complexity of the real world environments that they endeavour to describe and mimic. As an example, consider the fractal nature of a typical room, which as you get closer to almost any object within it you find there is more visual detail. Fortunately, it turns out that the brain is easily fooled into feeling as though present in an IVE with far less detail than this.

This illusion in experiencing an IVE is brought about by the presentation of various cues (mostly visual cues in a typical set-up.) So while we have the apparent tension between the complexity of the real world and the more humble requirements that can induce a sense of presence in IVEs, it is of great interest and practical importance to find how we can be efficient in presenting just the cues necessary in IVEs.

A study of this sort using a principled and methodical approach to constructing IVEs has not before been carried out. This work utilises a particular methodology that can be consistently applied in many environments for measuring presence, and more centrally to this thesis will show the existence of minimal cues for types of environments that efficiently create an intended sense of presence.

1.3 Deficiencies in Existing Work

The concept of presence is key to IVEs. It has been studied for the purpose of creating compelling IVEs for use in areas such as teleoperation, simulation, and entertainment (Steuer, "Defining Virtual Reality: Dimensions Determining Telepresence", Journal of Communication, Autumn 1992, 73-93)[38] although its precise definition and relationship to other IVE pertinent factors is still to a great degree elusive. Despite this problem many studies have been carried out in which experimental subjects are placed within an IVE and measurements of presence have been recorded using subjective (such as questionnaires) and objective (such as physiological response) measures:

Witmer, Singer, "Measuring Presence in Virtual Environments: A Presence Questionnaire", Presence: Teleoperators and Virtual Environments, 1998 [44]

Lombard, Ditton, "Measuring Presence: A Literature-Based Approach to the Development of a Standardized Paper-And-Pencil Instrument", Presence 2000 Workshop [12]

Lessiter, Freeman, Keogh, Davidoff, "Development of a New Cross-Media Presence Questionnaire: The ITC-Sense of Presence Inventory", Presence 2000 Workshop [10]

Slater, Usoh, "Presence in Immersive Virtual Environments", Proceedings of the IEEE Conference – Virtual Reality Annual International Symposium, IEEE Neural Networks Council, Seattle, WA September 1993, 90-96 [23]

Slater, Usoh, "Representation Systems, Perceptual Position and Presence in Virtual Environments", Presence: Teleoperators and Virtual Environments, 2(3) MIT Press, 221-234, 1994 [26]

Slater, Usoh, Steed, “Depth of Presence in Virtual Environments”, Presence: Teleoperators and Virtual Environments, 3(2), 130-144, 1994 [24]

Slater, Steed, “A Virtual Presence Counter”, Presence: Teleoperators and Virtual Environments, 9(5), 413-434, 2000 [31]

Wiederhold et al., “An Investigation into Physiological Responses in Virtual Environments: An Objective Measurement of Presence”, Towards CyberPsychology: Mind, Cognitions and Society in the Internet Age, Giuseppe Riva and Carlo Galimberti (eds.), IOS Press, 2001, 2002, 2003 [43]

An objective measure for presence would be ideal as it would be more stable but so far all such measures have had limitations. Problems have varied from the effects of significantly confounding factors (e.g. skin temperature, (Meehan, M, “An Objective Surrogate for Presence: Physiological Response”, Presence 2000 Workshop)[13]), tenuous relationships to presence under most conditions (such as measurement of Galvanic Skin Response (Wiederhold et al., “An Investigation into Physiological Responses in Virtual Environments: An Objective Measurement of Presence”, Towards CyberPsychology: Mind, Cognitions and Society in the Internet Age, Giuseppe Riva and Carlo Galimberti (eds.), IOS Press, 2001, 2002, 2003)[43] when the environment is anxiety neutral), or being limited in application (such as the looming effect described by Sheridan, (Sheridan, “Musings on Telepresence and Virtual Presence”, Presence: Teleoperators and Virtual Environments, 1(1), 120-126, 1992)[20]. For these reasons as well as for simplicity and directness many studies have instead been dependent upon the completion of subjective questionnaires to elicit the level of the sense of presence experienced.

So far there has not appeared any work relating presence to eye gaze. However, Stark has shown evidence of visual recognition or perception occurring through the use of eye scanpaths (Stark, Choi, “Experimental Metaphysics: The Scanpath as an Epistemological Mechanism”, Visual Attention and Cognition, Elsevier Science, 1996)[36]. The work entails the recognition of various images by a number of subjects whilst their eye movements and fixations are recorded. This work has not however involved the recognition of egocentric environments – and especially not of the type found in an IVE system.

2. Hypotheses

2.1 Main Hypothesis

The main hypothesis of the thesis in progress is stated:

"For a given type of environment there exists a minimal set of perceptual cues that serve to provide a threshold for the inducement of a sense of presence and it is possible to discover and utilise these sets to construct presence inducing Immersive Virtual Environments efficiently"

2.2 Sub-Hypotheses

The main hypothesis as stated above is divided into three sub-hypotheses that are to support it. Each of these is defined and considered below.

2.2.1 Hypothesis 1

"Recognition and perception of an environment depends upon Bottom Up (visual sense) and Top Down (cognitive model/knowledge/memory) information simultaneously used for continual Hypothesis Testing and validation."

2.2.1.1 Reasoning

This is necessary to show that the visual information from an environment is collected to be used to both create hypotheses regarding the perception of the current environment and to act as evidence to validate or refute hypotheses.

2.2.1.2 Assumptions

The main assumption here is that visual cues around a person in an environment are considered to collectively determine the type of environment they are in and that this will follow from the work of Stark (Stark, Choi, "Experimental Metaphysics: The Scanpath as an Epistemological Mechanism", Visual Attention and Cognition, Elsevier Science, 1996)[36] and theories of Gregory (Gregory, R, "Eye and Brain: The Psychology of Seeing", 5th Edition, Oxford Press, 1997)[7] taken together.

2.2.1.3 Experimental Method

This hypothesis will be tested by comparing eye scanpaths of numerous experimental subjects within real world environments and IVEs. The data will be analysed similarly to Stark's that utilises a Markov model.

2.2.1.4 Expected Results

It is expected that perception of the current environment will be ascertained using similar methods to those used in the perception of images (Stark, Choi, “Experimental Metaphysics: The Scanpath as an Epistemological Mechanism”, Visual Attention and Cognition, Elsevier Science, 1996)[36].

2.2.1.5 Experiment Duration

The time allocated to this task will be three months.

2.2.2 Hypothesis 2

“For a particular type of environment, the matching of predetermined eye scanpaths to measured eye scanpaths from an IVE experience will produce a scale of presence of that particular environment.”

2.2.2.1 Reasoning

This will show that an IVE is perceived in the same way as real world environments and hence will show up any dissimilarity between that experience in an IVE and the real world. This will result in a new objective measure for presence.

2.2.2.2 Assumptions

It will be assumed that the additional detail in the real world will not create a significant number of extra regions of interest. It will also be assumed that head and body movement will contribute to eye scanpaths to extend it to cover an entire environment, and will not instead inhibit the construction of environmental scanpath patterns.

2.2.2.3 Experimental Method

The testing will be carried out by recording eye scanpaths in multiple types of environment (e.g. kitchen, office) in both the real world and in IVE representations. The results will then be compared.

2.2.2.4 Expected Results

It is expected that there will be correlation between scanpaths and regions of interest in the same types of environments, in both the real world and within IVE representations. What is not sure is how dependable the correlation might be as a presence indicator.

2.2.2.5 Experiment Duration

This part of the project should have a duration of approximately three months.

2.2.3 Hypothesis 3

"Level of Detail (LOD) can be used to determine a minimal set of cues, because increasing the LOD in a presented environment further substantiates the evidence used for Hypothesis Testing. This technique can thus be used to indicate the level at which sufficient cues are presented to create a sense of presence in a particular environment."

2.2.3.1 Reasoning

The technique as explained above will indicate the level at which sufficient cues are presented to create a sense of presence in a particular environment as directly required by the main hypothesis.

2.2.3.2 Assumptions

This hypothesis assumes that the level of detail of an IVE will be made up of a hierarchy of cues. Although not of primary importance it should be assumed possible that in some cases small changes in detail may result in more radical changes in the perception of the current environment.

2.2.3.3 Experimental Method

Objects in the presented IVE will consist of varying levels of detail and will initially be set at their lowest LOD. The direction of gaze will be continuously recorded, and after a set time the level of detail will be increased. This will continue until the highest level of detail has been reached. In practice this may require numerous subjects – one per each LOD – to avoid any effects of learning between LODs.

The data will then be compared to that taken from experiments in the same type of environment in the real world. Minimal cues will be said to be present at the point where presence in the type-of-environment-presented becomes statistically significant.

2.2.3.4 Expected Results

It is expected that at higher levels of detail the eye scanpaths will correlate more with those from the real world, and this will in turn correlate with the level of the sense of presence. The minimal cues will be expected to manifest themselves between the lowest and highest levels of detail.

2.2.3.5 Experiment Duration

This work will run for a duration of approximately three months.

2.3 Sufficiency of the Sub-hypotheses

Finally, each of the above hypotheses directly or indirectly supports the main hypothesis of this work that logically follows from them.

In order to provide evidence for the existence of minimal cues, a system is required that will present a particular type of environment with a number of perceptual cues. The number of these cues will be parameterised allowing the determination of the level at which presence in this particular type of environment becomes statistically significant. This will be shown via Hypothesis 3. To show this, a presence measure is required. An objective measure that to some degree relates directly to the notion of cues is eye scanpath theory, which utilises cues in the form of Regions Of Interest (ROIs.) Hypothesis 1 describes a possible relationship between eye scanpath theory and presence through perception and recognition of an environment. Hypothesis 2 exists to provide the connection between using eye scanpaths in the real world and in an IVE so that a presence scale relating to cues can be derived and used in Hypothesis 1.

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Literature Review

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1. Introduction to Virtual Environments

In the field of computer science a Virtual Environment (VE) is an artificial computer generated representation of an environment. The heart of a VE consists of the data describing it and the way in which it is interpreted. Of course, what makes a VE an *environment* though is the experience of it. To create this experience a system is required to interpret and present the data, and typically it will accept input(s) from a person in order for them to explore the environment. More often than not, these basic requirements are exceeded to provide additional application specific functions that might be necessary.

Virtual environments come in many forms. Some regard VEs in a particular light and here we shall consider a particular type, but it should be noted that a *virtual environment* is often used as a general term. Taking a broad view of VEs,[19][8] they range from those that are textually based e.g. MUDs (Multi-User Dungeons), and MOOs (Multi-user Object Oriented [environments]) to more graphical ones such as Club Caribe[2] or ActiveWorlds (http://www.activeworlds.com). Each of these allows a number of users to interact with each other using typed text, the graphical ones rendering representations of the users (avatars) and spatial renderings of their environment. The environments are segregated into various parts – typically thought of as places (e.g. chat rooms), and hence the inclusion of them all under the umbrella term *virtual environments*. Finally there are those presented by three-dimensionally projected systems that commonly thought of as being Virtual Reality (VR) systems. These are three-dimensionally rendered using graphical hardware projecting in two or (apparent) three dimensions.

2. Virtual Reality

Jaron Lanier coined the name Virtual Reality (VR) to use in his business that was founded in 1989. It has since had numerous interpretations, and its meaning was quite thoroughly investigated by Steuer [38]. The term Virtual Reality has been used in a much more general sense[19][8] to describe almost any virtual environment. In this document though we shall constrain our considerations to the types that are spatially three-dimensional and that consist of software and hardware that attempts to mimic reality in some way. We shall also include in this definition desktop systems that may present two-dimensional (or apparent three-dimensional) renderings of three-dimensional environments that can be considered as being particularly limited.

The VR systems used to present and interact with a virtual environment can vary widely. The system hardware invariably consists of a number of input devices and one or more displays, along with the central processing unit. Next we will briefly consider some of the common elements of a typical VR system.

3. Displays

For fiscal and technological reasons displays tend to be oriented toward individual human senses. Interestingly there appears to have been an unwritten rule determining their precedence. This has created a skewed offering of display devices based on their perceived utility. The two most commonly found types of displays are graphical and audio. Other devices are few and far between, though tactile and haptic systems are beginning to appear slowly.
(A comprehensive list of VR technologies can be found at http://www.presence-research.org/technologies.html)

3.1 Graphical Displays

Graphical displays come in numerous forms. Although head mounted displays (HMDs)[41] are the most often thought of devices in VR, there are of course others, including CAVE (CAVE Automatic Virtual Environment)[3] systems which are becoming common in larger institutes and organisations, the BOOM® (Binocular Omni Orientation Monitor – Fakespace Inc.) and the lowly desktop – which continues to play a part in research at the lower end of things, often being used as a point of reference. Many of these displays are capable of presenting apparent 3D (as opposed to true volumetric 3D) images. There are various methods of doing this, for example line-sequential, frame sequential, field sequential (interleaved), side-by-side, top-and-bottom, and polarizing systems – though of these only polarizing systems or frame sequential with LCD shutterglasses would be appropriate for CAVEs.
If the image is to change by being slaved to head movements (such as with the HMD or CAVE) then for correct perspective a 6 degree of freedom (6DOF) tracker is required, which will measure both direction and position of the head. A three degrees of freedom (3DOF) directional tracker could also be used providing a less realistic experience particularly due to the lack of motion parallax.

3.2 Audio Displays

Audio Displays are usually directional and are implemented with either stereo or surround-sound systems. Much research has gone on in this field for many years, and continues to though for some reason it has not yet been regarded as important enough to play a part in the vast majority of work that has gone on in the general field of Virtual Environments. “5.1” channel surround sound has become very popular even with desktop PC systems for the display of spatial sound. [21]

3.3 Input devices

There is a myriad of input devices that may be used with VR, many having been intentionally designed as such, for example the Wand™ (Pyramid Systems Inc.), and the Cyberglove (Immersion Corp – http://www.immersion.com).
Simpler more commonly found devices may also be used such as baseless trackballs or joysticks. Devices that are held in three-dimensional space will normally be tracked with a 6-degree-of-freedom (6DOF) tracking device. This allows effects such

as having a representation of the user's hand and/or arm displayed in the virtual environment. This can have a significant impact on the user's experience within the immersive virtual environment, which has been examined by Slater and Usoh [25].

3.4 Haptic and Tactile Devices

These types of devices both provide a user with a sense of touch within a VE. They both provide a complementing combination of input device and display, detecting the position and/or forces from the body (typically the fingers or hand) and outputting forces as these come into 'contact' with objects in the virtual environment. Although not very common, they are appearing more frequently in research labs. The SensAble PHANToM Desktop is one such device operating with 6DOF. (http://www.sensable.com) Also see tactile devices such as the aforementioned Cyberglove (http://www.immersion.com/products/3d/interaction/overview.shtml).

3.5 Trackers

The final device to be described here is also a component of many VR systems – the tracker. They are mostly 6DOF devices so that they can be used to derive both location and direction. They are used to track the users body and/or input devices, and are commonly attached to the head and hand. The head so that correctly rendered images may be produced and a general location established for the user, and the hand often to place some type of cursor device within the environment. Other physical locations are often estimated from these two points, though more complex systems are slowly becoming available that track many points – such as the body suit [16](VPL Research).

Slater, Usoh, "Body Centred Interaction in Immersive Virtual Environments" [25]
Slater, Steed, McCarthy, Marinelli, "The Influence of Body Movement on Presence in Virtual Environments" [29]

4. Immersion

4.1 The Meaning of Immersion

Immersion may be defined as the extent to which a person is enveloped by the VE. This is a fairly generic definition, and there are differing views of what immersion more specifically is. Witmer & Singer define immersion as:

> "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences".
> ("Measuring Presence in Virtual Environments: A Presence Questionnaire")[44]

Whilst this is valuable it is not certain whether this definition makes immersion independent of the concept of presence (which is discussed later.) This makes immersion a psychological factor, which being subjective is equally as difficult to measure as presence.
Slater & Wilbur however relate immersion directly to the enabling technology. For them, a more immersive system is one in which the technology provides a more compelling environment:

> "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."
> ("A Framework for Immersive Virtual Environments [FIVE]: Speculations on the Role of Presence in Virtual Environments")[28]

For instance, by noticeably improving the resolution of a display the level of immersion would be said to have increased. Again, a system that does not provide force-feedback would not be as immersive as the same system with a force-feedback capability. This objective view of immersion is certainly of value, as there must be a way in which to rate the technology's impact upon the user's feeling of envelopment.
Smith, Marsh, Duke & Wright [33] also look at immersion to determine its part in building a mental model of the immediate environment. They propose a person's senses should be the basis for the definition of immersion. This therefore could be seen as the other side of the coin to the Slater (et al.) argument, which they appear to uphold. They present this relationship as being the way forward to measuring levels of immersion.

The objective, technological definition of immersion allows it to be used as a referential point from which arguments can be made. Opponents of this idea may defend other definitions of immersion, but would surely accept that the specifics of the immersing technology to be of great value, and more than that, of great pertinence in the determination of the level of subjective presence.

In essence it seems that the main two viewpoints actually describe aspects of IVE immersion that aren't actually mutually exclusive, and therefore may be simply problems with terminology. Slater sets this out in "Measuring Presence: A Response to the Witmer and Singer Questionnaire"[30] where he proposes the use of the qualified terms *system immersion* and *immersive response*.

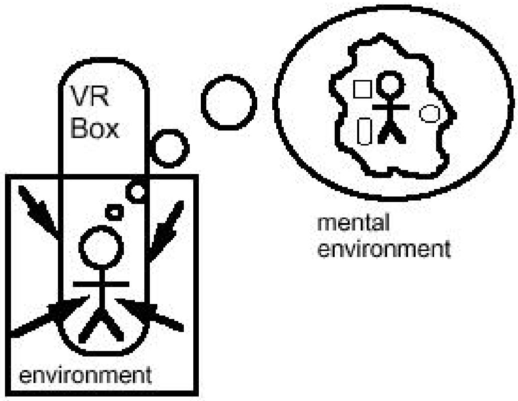
4.2 Immersive Virtual Environments

VEs appear in many forms, one of the most well known being the Goggles 'n' Glove system. This type and a number of others such as the CAVE are often described as Immersive Virtual Environments (IVEs) due to the high levels of immersion they create. Their display emphasis is largely upon the visual sense of the user, which is deemed to be the one that most easily influences the sense of presence in the virtual environment.

The intention of the IVE is to engage the user with the virtual environment directly, just as they would in the real world. This ideally means stimulating as many of the user's senses as possible, exactly as they would be in the real world.

The user's senses and perceptual systems are presented with information from an artificial source (i.e. the computer) and are at least in part fooled into believing that they are (1), physically elsewhere, and (2), that there is no mediating device between them and the virtual environment. This is described as the illusion of non-mediation (see "At The Heart of It All: The Concept of Presence"[11]), and is important in the sense that the user should not be reminded that they are within an artificial environment, but rather have only natural cues.

What happens then has been termed "the (suspension of dis-)belief" (Slater & Usoh [26]). This can be described as the disregard of the knowledge that the apparent environment does not originate directly from the real world and that it is rather the display of stimuli information from a database. So then, that information which would normally cause disbelief in the existence of the presented environment is suspended. This then is the immersive virtual environment (IVE.) Smith, Marsh, Duke & Wright created the following diagram[33] to illustrate immersion, expressing simply various factors involved.



A VR model.

It is an interesting diagram showing the user having been surrounded by the VR Box (hardware) and immersed in an environment made up of information outside and within the VR technology. The environment they perceive is described as the mental environment. (NB: It seems that at the point of drawing the diagram the stick figure was experiencing a sense of presence…)

5. Presence

5.1 The Importance of Presence

The sense of presence is a widely studied factor, due to its central role in IVEs. Along with virtual environments, it was teleoperation (perhaps more so) that boosted the importance of presence as a topic for study (see [20][39]). Teleoperation involved the operation of remote devices (such as sub-sea robots), and introduced the concept of telepresence, that is, the feeling as though present at some remote site. Of course telepresence presented much the same problems that presence in immersive virtual environments did as was noticed by Ellis [5].

The importance of presence lies in its potential to enhance many technological innovations including: teleoperation, conferencing and communication, learning and training, therapy, simulation, entertainment, design, and exploration[11].

5.2 More than one type of Presence

At first one might think that the nature of presence is a simple affair, you either feel as though you are standing in a room looking at or through a computer display, or you feel as if you really are in the virtual environment presented by an IVE system. However it is certainly more complex than that. There have been a number of specific types of presence identified, each of which looks at presence from a particular viewpoint. In Lombard and Ditton's work "At The Heart of It All: The Concept of Presence"[11] a total of six conceptualisations of presence (gleaned from their own and others' experiences) are described. Here an attempt to briefly describe each one is given:

Presence as social richness:

> This focuses upon presence as effected by interpersonal communication.

Presence as realism:

> This is presence determined by apparent realism of some entity, abstract, or otherwise (e.g. of objects, events, and people.)

Presence as transportation:

> This is sub-typed as "you are there", "it is here", or "we are together":
>
> The first of these "you are there" describes the sensation that you have been transported to some place.
>
> The second "it is here" describes the presence of objects that have been brought to you.

The final type, “we are together” relates to the a sense of presence in a shared space – typically found in conferencing systems.

Presence as immersion:

This is presence as determined by the scale that one has the real world ‘shut out’. It is described in general terms that include both the technological and psychological definitions of immersion as described previously.

Presence as social actor within a medium:

Here, one feels presence with some actor within a medium.

Presence as medium as a social actor:

This type of presence is felt when a user attributes social meaning to a medium itself.

Another definition of presence involves interaction. It was said by Zahoric and Jenison that

“Presence is tantamount to successfully supported action in the environment.”[45]

I would argue that while interaction can increase the level of presence, it should be considered a component or factor, but not related to this degree. Of course in most of our every day lives interaction is generally possible and in fact there are very few times at which we are entirely cut off from interaction with the world around us. Therefore, it would seem much more appropriate to state that *unsupported* action in an environment can *reduce* the sense of presence. If one expects to be able to perform an action and cannot, then surely this initiates a logical “why can’t I do this?”, and the very next thought may very likely be related to questioning the technology they are using and its limitations.

Similarly, Zahorik and Jenison conjecture:

”Successfully supported action in the environment is a necessary and sufficient condition for presence.”[45]

It seems feasible that successfully supported action is a sufficient condition for presence in its most general, and abstract form. Consider an example where an IVE is being used, but the user cannot form any idea as to what the surrounding images are (such as random coloured dots and lines). As they move their hand forward and back, they realise that the images changes somehow. At this point they are certainly interacting with the environment. In the most general and abstract terms they could be said to be ‘present’ in the world of randomly coloured dots and lines – perhaps not dissimilar to times when the mind is considering abstract concepts (such as performing mental arithmetic.) However, this is not so much related to the world of three-dimensionally rendered environments, but rather strongly related to ontology, psychology and philosophy.

The assertion that successfully supported action in an environment is a necessary condition for presence is also disagreeable. As mentioned above, most of the time we as humans can interact immediately with our environment. Sometimes however, this is not the case. "Patient Awareness During Anaesthesia", (published by Communicore Inc., 1996)[46] rather terrifyingly documents the hazards of using the combination of anaesthetic and neuromuscular blocking agents that are routinely used for surgery. From rather disturbing statements recorded from patients (such as "I was still perfectly lucid when the obstetrician plunged his knife into my abdomen.") and verifiable facts in the document, it is obviously possible for a sense of presence to be experienced when interaction is not possible.

5.3 Presence as Transportation

We shall be considering presence as being that of transportation – the sense that "you are there". That is, that as one uses ones senses to determine their immediate environment they 'read' the artificial stimuli from the VR system, and appear to be somewhere other than in their physical location – and they therefore feel present there. Other types of presence are just as important and useful. There is always overlap between types of presence in any VE system, and each of the conceptualisations is really another facet of presence, but in this work we shall limit our scope and interest to focus on this particular one.

The belief in a presented IVE gives rise to the feeling that the user is in fact there in that environment. That is, that the user feels present in the environment, even though many of their senses may indicate otherwise. Witmer & Singer describe their theory that one can be psychologically present in more than one reality[44]. They conjecture that at some threshold, the focussing of attention produces a heightened sense of presence in a particular 'environment'. This tends to suggest that their notion of an environment is more based on a cognitive model that has been created in the mind of the user. Slater & Steed however tend to see the sense of presence in an environment as being much more binary[31] – you're either here, or you're there. The experiencing of presence has much less emphasis placed upon cognitive models, and more depends upon the continuous and immediate interpretation of stimuli at a certain point in time. Their question seems to be more of the nature of 'how real does it feel to be there?' and this is the dimension that they are interested in measuring.

5.4 The Utility of Presence

Presence is highly esteemed in the world of VR. Early on in the study presence in virtual environments a few Held and Durlach[9] took it upon themselves (quite rightly) to point out the fact that presence has its place, but is not the 'be all and end all'. Presence should not be thought of as the measure of success of an IVE application. Held & Durlach were quick to explain that presence is of most use in a general purpose IVE. This is because the sense of really being in an artificial environment would promote the use of the natural problem solving skills that people use in every day reality. On the other hand, they argued that presence could also in fact be detrimental to task performance, as argues Ellis who uses two examples (an aircraft traffic display and an orbital manoeuvring planning tool) to illustrate this point.

Having said all this, presence certainly will have some bearing upon task performance, and can be a great influencing factor. This is pointed out by Slater & Steed in their experiment using Tri-Dimensional Chess, where they set out to prove this by comparing a low immersive desktop system to a highly immersive CAVE[27].

It almost goes without saying, but it should be added that presence is also required in any IVE in which the *point* of it is to feel as though one is present in a particular virtual environment. This would for instance, be true in most simulations and entertainment uses of an IVE, as well as in the teleoperator systems mentioned previously.

Many experimental studies (in fact a good proportion of published papers on the subject of presence) have been carried out to determine factors that affect the experienced sense of presence. This approach that intends to explore the nature of presence, causes, and effects, only seems to scratch the surface. Part of the problem appears to be the lack of systematic research as appreciated by Lombard and Ditton in [11], and although the many studies are valuable there seems to be little hope in producing a complete, comprehensive theory of presence. The problem is not only that there is a potentially infinite number of factors that will affect the sense of presence, but also this is compounded with the problem that – at least for now – there is no independent objective measure for presence.

5.5 Measuring Presence

After realising the importance of presence and its place in the future, we can only learn to manipulate and turn it into a useful tool by understanding it. To understand it, it must be measurable, both theoretically and practically.

As presence is a subjective phenomenon measures are not easily defined. Statistical methods are used to overcome this problem and will continue to do so. For certain VR applications such as simulation the greatest hope for systems that aim to provide a high sense of presence might simply lay with innovation and technology which in themselves *might* one day sidestep many of the issues if we decide to take a purely pragmatic stance.

Here we shall look at some of the methods and techniques used to measure presence. These are typically used to make measurements from experiments having multiple subjects. Standard statistical methods are used to derive the final results.

5.5.1 Questionnaires

One of the popular subjective techniques for measuring presence is the use of questionnaires. Some of these are taken from previously developed works and are modified such as "The ITC-Sense of Presence Inventory"[10], this particular example being the development of a new, more generic questionnaire for measuring presence across media. Rather than jointly producing a standard, the leaders in the field prefer their own tried and tested methods sometimes due to quite fundamental differences in their opinions and backgrounds. Studying the questionnaires of Witmer & Singer, and Slater an interesting difference between the two VE practitioners' questionnaires soon becomes apparent. Slater tends to ask subjects about their levels of presence using a number of (mostly) direct questions. Witmer and Singer however take the different approach of asking questions regarding other factors. These are factors that they believe both effect presence and are affected by it (i.e. have a two way causal relationship to presence.) Much of their questionnaire in fact relates to interaction rather than presence[44]. This is because of their previous assertions of interrelation between interaction and presence, and their strong belief in this relationship being fundamental.

There are a few particular problems with questionnaires that should be mentioned. Until presence is fully understood, we can never be sure whether we have an exhaustive (but ideally concise) list of independent, orthogonal questions. Also, the number of ill-considered answers must also provide a significant amount of skewed noise in the data, particularly as people become tiresome with longer questionnaires (even if they are multiple-choice.) Currently though, it seems that questionnaires are one of the most reliable and usable methods for measuring levels of presence.

5.5.2 Task Performance

Task performance is an excellent measuring device for use in IVE experiments because it is objective. It's greatest weaknesses lie in its application and the inter subject skills (or simply differences between individuals which are inevitable) and other variables that may cause variations in the perceived context. Inter-subject skill differences are unavoidable in most experiments involving a human component, but task performance experiments do tend to put more weight skill - often (ironically) without accounting for the differences between people (Having said this, Witmer & Singer do however make special effort to deal with this issue in [44].) Not only may the difference in skills prove to be an unstable component, but experiments must also be designed very carefully to avoid misunderstandings, and incorrect priority emphasis (i.e. designed to communicate the exact requirements made of the subjects.) The second problem that has been seen to arise is found in the relationship between task performance and the actual factor being measured. Task performance must be utilised carefully if intended to be a predictor or correlate and should not be thought of as some kind of 'silver bullet'. Ellis pointed this out in a paper[5] where two examples from his experience are used to prove that task performance and presence are not necessarily related – and are certainly not proportional in the general case.

5.5.3 Responses

A more objective method for measuring presence was suggested by Held & Durlach in [9]. It was proposed that the observation of subjects' involuntary responses to phenomenon such as the Looming effect were recorded, and interpreted as a presence measure. Although still subjective data (with respect to the experimenter), the necessary interpretation of the experimenter(s) should at least provide more consistency to the measure, seeing as the interpretation is performed by the same person(s) throughout the experiment (i.e. the experimenter[s].) Interpretation may also be performed by a host of experimenters or qualified experts independently; who can reach a collective agreement – further stabilising the results statistically.

5.5.4 Physiology

Probably the most objective method for measuring presence is to utilise some kind of physiological measuring device or devices. Unfortunately many of these make readings that are confounded with pretty much un-related phenomenon, particularly physical movement of the subject. Heart rate and galvanic skin response (GSR) are currently in the running for use as a presence indicator, and are presently being investigated (Wiederhold et al.[43], Meehan[13], Dillon[4])

It is also hoped that electroencephalograph (EEG) devices might shed further light into the state of a present/non-present mind by recording signals from the brain. Similar in purpose are the Functional Magnetic Resonance Imaging (fMRI) systems that allow the movement of blood in the brain to be monitored, showing the most active parts to be identified over time. Until now little work has been done using such systems as regards presence, but monitoring the brain whilst in VEs could yield impressive results in the near future. The greatest limiting factors are often the expense of the equipment, the coupling of the technologies required for this purpose (which can create difficulties due to technical constraints), and the basic logistics involved in having experts in normally separate fields get together.

5.5.4.1 Eye Gaze

Measurement of eye-gaze movements (saccades) and fixations (foveations) has been considered as a possible measure for presence as they can be used to determine what it is that a user sees in an environment. This is important because these ‘regions of interest’ and saccades greatly affect and drive the perception of the environment that the user is in (Gregory, “Eye and Brain: The Psychology of Seeing”[7]). Stark closely studied foveations and saccades where images were presented to subjects and their eye-gaze upon particular parts of the images recorded[36]. The saccades and foveations together form what has been named *eye scanpaths*. These eye scanpaths were then shown to correlate across subjects for particular images.

5.6 Effectors of Presence

There is an infinite number of influencing factors for presence. It is possible however that there could be some classification of these that would render presence a unified and comprehensible concept. At this point there is no existing consensus on any taxonomy though ideas have been proposed (see [20]) and discussed (see [5]).

Issues that relate to the effectors of presence and immersion have been studied already, examples being:

Field of view was determined to have a significant effect on presence when studied by Prothero and Hoffman[17].

Tracking – The influence of head tracking studied by Pausch, Shackleford and Proffitt[15].
Slater, Steed, McCarthy, and Marinelli (see [29]) show the importance of bodily tracking for movement in IVEs.
Slater and Usoh, show the significance of a proprioceptive to virtual-body relationship[25] via a tracking device(s).

Latency reduction is examined by Ware in "Reaching for objects in VR Displays" [42].

Haptics was studied by Basdogan in relation to presence[1].

Body centered interaction (embodiment) and proprioception are identified by Slater & Usoh as being an important part of the presence jigsaw[25]. Proprioception is "the reception of stimuli produced within the organism" and can be thought of as being, for example, the sense that one can feel the location of one's limbs.

Each of the following have also been related to presence in the thesis of Snow:
("Charting Presence in Virtual Environments and its Effects on Performance"[34])

- Frame Rate
- Field of View
- Audio
- Motion parallax
- Resolution,
- Stereopsis
- Textures
- Environmental Detail

5.7 Effects of Presence

Once presence is invoked it is interesting to explore its consequences. The knowledge of the consequences of presence is also required in order to wield it as a tool for future research. The effect of presence should not create new phenomena but rather allow "normal" perception and interaction to occur. In itself this may not appear to be exciting or even useful, but taking this fact into account along with the knowledge that the virtual environment is entirely flexible allows one to see the potential of such systems.

Until the 'Holy Grail' of virtual reality is reached, where all our senses (including those which are entirely psychological) are fully immersed, we shall be especially interested in measuring how close (or distant) we are from it. We shall want to know what is possible with the technology and knowledge we currently have. Experiments have been carried out to this end, for example the looming effect has been studied successfully (particularly by Slater in [25] [22] [23]) and demonstrates the invocation of the sense of presence indirectly, and in addition the fact that the effect is producible by the virtual reality system. (The looming effect occurs when a subject ducks to avoid an object travelling toward them at the level of their upper body or head.)

Some of the other effects that have been studied relate to phobias. Acrophobia, the fear of heights (also known as vertigo) has been studied, showing it to be reproducible in an IVE. Despite having cognitive knowledge, the perception's inhibition of heights persists. ("Virtual Reality Treatment in Acrophobia: A Comparison with Exposure in Vivo"[6])

These effects are proving to be of value to individuals who suffer from such phobias, as the flexibility of the VE allows full control over the environment, and the object of the phobia. This then means that phobia exposure therapy can be implemented using finely and well-targeted controls, and can be suited to an individual's needs[40] [14].

So in simple terms, the effects of presence should simply mirror those we see in every day reality, and this mirroring should be as extensive as technically possible.

6. Perception

Much of presence can be attributed to perception. Consider how the information arriving at ones senses combines (both immediately and over time) to provide a 'complete-picture' of your environment in every day reality. This continuous 'picture' is what most people have lived with since birth. It has been used to build their perception of what it *is* to be present in the normal, every day, real world. So, the perception of your current environment makes you feel present within it.

6.1 General Real World Perception

From birth (and it seems even prior to that moment) perceptions are developed, consolidated, reviewed and confirmed. As we age our perceptive understanding increases, as we come into contact with new environments, situations, objects, and experiences. Our understanding of what is "normal" and what is "not normal" is learned. (NB: This is not believed by everyone, for instance an empiricist's view would generally disagree with this statement.)

Ironically, we rely upon our perceptive system so much that it enables us to be fooled. For instance stage magicians rely upon this fact by providing basic cues that purposely misinform our perceptual system and leave us wondering how we have apparently jumped from one world-state to another.

6.2 Perception in an Immersive Virtual Environment

6.2.1 Illusion

To instil a sense of presence then, ones perception of the stimuli presented by a virtual reality system should linearly map to ones normal perception of reality. Any incoherencies such as loss, lack, or imbalance of information would, if noticed, reduce or even nullify presence. The converse of this situation is also possible - for instance, under certain circumstances the mind can insist that a strong stimulus is more reliable than other weaker ones when there is an apparent contradiction between the strong and the weak stimuli[18].
Slater, Steed & Chrysanthou describe this detail with examples and other related phenomena in "A Phantom World of Projections"[32].

On the other hand, given certain types of misinformation the perceptual system may find itself simply unable to comprehend its inputs, as they are too inconsistent. This can happen for instance when the interocular distance (a parameter to stereographical systems) becomes too great, and instead of visualising a three-dimensional image, an incoherent double image is viewed (this is phenomenon is called diplopia and is mentioned in papers such as Ware and Balakrishnan's "Reaching for Objects in VR Displays, Lag and Frame Rate"[42]).

6.2.2 Realities

Upon entering IVE a number of your most compelling senses are presented with an alternative view of your physical-local environment whilst your real-world environment is shut out. It seems that the perceptual system that has been trained to recognise reality has little experience in discerning *between* realities. An immersive virtual reality is actually a new experience for us. The mind would therefore attempt to subjectively classify the experience, and most likely identify it as reality. This is to some degree conjecture, but if accepted as true leads to questions such as "how does the mind classify realities?" And "how extreme could they be and yet still be perceptible?"… questions that currently have no exact answers.

6.2.3 Hypothesis Testing

As mentioned earlier, eye scanpaths can be used to provide us with some information for us to investigate how images are perceived and recognised. It seems that at times the mind enters a mode of recognition[35], in which a process that has been named Hypothesis Testing occurs[7]. To keep things simple we shall only consider the visual sense, though this general theory would certainly be applicable to other senses such as touch. Hypothesis Testing is a cycle of Bottom Up (BU) and Top Down (TD) (Stark, Privitera, et al. 2001 [37]) information gathering that seeks to determine the nature of sensed image. The BU information is that taken directly from the physiological senses. The TD information is from the cognitive models, knowledge, and memory (which admittedly are probably not separate entities.) Using both the TD and BU information, hypotheses are generated which conjecture the nature of the sensed image(s). These are tested against the given evidence, and perhaps further evidence taken from the BU senses, and the hypothesis is regenerated continually until the image is recognised. The acquirement of further information as evidence consists of eye scanning of the image in particular. It would seem that if no recognition occurred after some time, then a new model would be created (or learned.)

This theory that has evidence from Stark's work can therefore be used to determine how the subject is classifying images (from the eye scanpaths) and which parts of it are deemed to be important (called 'regions of interest'.) As an extension of this work it is possible that such eye scanpaths could be used to explain perception of not just images, but environments – perhaps being thought of as a single surrounding image.

7. Conclusion

We have seen that immersion, presence, and perception are interrelated concepts of key importance to the IVE experience. Some of the general technologies used have been briefly described, and the relationship between VEs in a broader sense has been mentioned.

A number of techniques that are used for the measurement and determination of presence and perception have been discussed.

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Appendix B

Work to Date

Since joining the Computer Graphics and Virtual Environments group in November I have taken part in a number of projects read in the subject areas for my thesis. Reading has been concerned with the following fields: presence, Collaborative Virtual Environments, Haptics, and Visualisation. A comprehensive list of the papers read so far can be found in the 'Reading List' in Appendix D. As my thesis has become for focussed reading has recently concentrated upon presence and perception, and on the eye scanpath theories of Stark.

From November until January I was involved in a project that investigated presence in an Immersive Virtual Environment through the notion of persecutory ideation. My role was in the conduction of the experiment in the CAVE, as well as the rudimentary tasks of recruiting and scheduling. The experiment consisted of twenty-four participants who were asked to spend time in a virtual environment that was essentially a small library room containing several avatars, the aim of which was to investigate the potential for IVEs to provide cues that could catalyse persecutory ideation. The experiment made use of pre and post questionnaires, video recording, and interview (which I did not perform). The experiment ran smoothly and resulted in significant evidence to support the hypothesis, with a paper to follow (Freeman, Slater, "Can Virtual Reality be used to Investigate Persecutory Ideation?").

Since December I have been responsible for a co-presence and haptic project. The project's aim is to examine how the use of haptics in virtual environments can affect the sense of co-presence. Two other people were involved in advisory positions, J. Mortensen who had previous experience with the device used and who had previously ran a related project (Mortensen, et al., "Collaboration in Tele-Immersive Environments", 8th Eurographics Workshop on Virtual Environments, 2002), and M. Oliveira who specialises in the fields of network and communications. M. Slater both inspired and prompted the work. Although the technology (software) was simple to implement, the project progressed slowly due to the lack of a second haptic device for testing and debugging – this being compounded by a lack of driver source code from the manufacturers (and their reluctance to provide it.) Fortunately, the generosity of those in the Cybernetics Department of Reading University enabled the utilisation of their resources, and debugging and testing was carried out at their site until the system was completed.

The experiment ran as a pilot in June, and produced the expected results. The experiment, recruitment, scheduling, set up, monitoring and organisation was carried out by myself. Video recording was set up and run by J. Mortensen. J. Kim at MIT also conducted the experiment remotely as a confederate. An extended abstract presenting the experiment, method and results has been written and submitted to the Presence 2002 Workshop in October. We also hope to run the experiment again under more ideal conditions with an improved version of the software, and to write up the work in a final paper. In addition we are hoping to demonstrate the project work at the Internet2 meeting in Los Angeles, again, in October.

Between the months of January and March 2002 I acted as demonstrator for the Virtual Environments lectures of Dr Anthony Steed. The lectures were part of MSc and 4th year computer science courses at University College London. This involved learning and teaching VR-Juggler, a three-dimensional rendered graphical interaction framework for Virtual Environments. Also involved was the tutoring of C/C++ to a number of the students on the course. This was a very valuable experience; particularly in the teaching of subject matter I had only recently learned myself.

As part of the Equator Interdisciplinary Research Challenge (IRC) I have attended both the local and national meetings to learn more about the existing projects, future directions and to become familiar with the other members of the group. One of the meetings involved the presentation of posters, at which I presented an informational poster describing the co-presence/haptic project I have been involved in.

As well as presenting the aforementioned co-presence/haptic paper, I also helped in the submission of the paper (Oliveira et al., "The Pitfalls in System Design for Distributed Virtual Environments: A Case Study") primarily authored by M. Oliviera, who is also a part of the CGVE group at UCL.
I also took a support and recruiting role in the haptic (nanoManipulator) project of Professor Mary C Whitton of the University of North Carolina.

I have regularly attended a locally run statistics course recognising it to be an invaluable tool for my future work as well as being required for understanding many of the results and techniques used in numerous papers. My intention is to take at least one further course in statistics (to consolidate the teaching thus far – as I am not yet experienced in this area) and a course in psychology (the psychology of perception, visual perception, behaviour, and cognition are fields I should study in particular.)

In order to improve my skills in presentation I presented two external papers relating to software engineering in three-dimensions. I also presented some preliminary ideas for my thesis work for the first time in July. As mentioned earlier it is hoped that the co-presence/haptic project presentation will be made at the Presence 2002 Workshop in Porto, Portugal in October.

As a member of the CGVE group I attended the weekly seminars held by visiting and internal speakers. As a postgraduate student I attended the PhD workshops ran and organised by Dr Angela Sasse (PhD Tutor). As a member of the Equator group I also attended the agoraphobia project meetings.

Through my direct work and related project meetings I have begun to establish contacts with a number of academics who have been greatly helpful and I'm sure will contribute and advise me in my future work.

I have become familiar with many of the technical facilities available in the Computer Science Dept. at UCL, including the CAVE (Reactor™), Head Mounted Displays (HMDs) and related equipment, the Phantom Desktop haptic device, and the eye-tracking device (which I have been helping set up.) I have also spent time looking at the various virtual environments available in the CAVE for future reference and possible use.

In addition I have learned OpenGL, and intend to learn more of the available virtual environment frameworks for use in my own future experiments. Doing this would of course help speed up the development times for the creation of the experimental virtual environments.

Appendix C - Timescales

			2002-2003			2003-2004			2004	
Jul		**2002**	1st yr report		**2003**	Expt 3 Development		**2004**	Thesis Write Up	
Aug		**2002**	Haptic Project		**2003**	Expt 3		**2004**	Thesis Write Up	
Sept		**2002**	Experimental Design		**2003**	Results Analysis		**2004**	Submission Viva Preparation	
Oct		**2002**	Expt 1 Development		**2003**	Write Up		**2004**	Viva	
Nov		**2002**	Presentations		**2003**	Final Analysis				
Dec		**2002**	Expt 1		**2003**	Write Up				
Jan		**2003**	Results Analysis		**2004**	Lit Review				
Feb		**2003**	Write Up		**2004**	Conclusions				
Mar		**2003**	Expt 2 Development		**2004**	Conclusions				
Apr		**2003**	Expt 2		**2004**	Thesis Write Up				
May		**2003**	Results Analysis		**2004**	Thesis Write Up				
Jun		**2003**	Write Up		**2004**	Thesis Write Up				

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Appendix E – Thesis Table of Contents