Journal of CyberPsychology and Behavior, Special Issue on Presence, 4:2, April, 2001.
(Accepted for publication August 2000)

Evaluation for the Design of Experience in Virtual Environments: Modelling Breakdown of Interaction and Illusion

Tim Marsh, Peter Wright and Shamus Smith
Human-Computer Interaction Group
Department of Computer Science
University of York,
YO10 5DD, UK.
tmarsh, pcw, shamus @ cs.york.ac.uk

Keywords: experience, voyeuristic, visceral, vicarious, film, invisible style, usability, evaluation, presence, virtual reality, virtual environments

Abstract

New and emerging media technologies have the potential to induce a variety of experiences in users. In this paper, it is argued that the inducement of experience presupposes that users are absorbed in the illusion created by these media. Looking to another successful visual medium, film, this paper borrows from the techniques used in 'shaping experience' to hold spectators' attention in the illusion of film, and identifies what breaks the illusion/experience for spectators. This paper focuses on one medium, virtual reality (VR), and advocates a transparent or 'invisible style' of interaction. We argue that transparency keeps users in the 'flow' of their activities and consequently enhances experience in users. Breakdown in activities breaks the experience and subsequently provides opportunities to identify and analyse potential causes of usability problems. Adopting activity theory, we devise a model of interaction with VR - through consciousness and activity - and introduce the concept of breakdown in illusion. From this, a model of effective interaction with VR is devised and the occurrence of breakdown in interaction and illusion is identified along a continuum of engagement. Evaluation guidelines for the design of experience are proposed and applied to usability problems detected in an empirical study of a head-mounted display (HMD) VR system. This study shows that the guidelines are effective in the evaluation of VR. Finally, we look at the potential experiences that may be induced in users and propose a way to evaluate user experience in virtual environments and other new and emerging media.

1. Introduction

Performing activities within 3 dimensional (3D) virtual environments (VE) is widely believed to induce a unique experience in users. However, standard human-computer interaction (HCI) usability evaluation methods (e.g. usability inspection or empirical) do not address the vicarious nature of activities performed through either a first person (point-of-view as if one is in the VE) or third person perspective (point-of-view from behind, over the shoulder or viewed from a fixed position, an object or person representing the user) within a 3D VE or space. Although no consensus definition of this experience yet exists, it is commonly described as 'being there' or 'being in' the illusion created by 3D virtual space. Referred to as presence, it is seen as a primary driver for VE design and evaluation and consequently, has prompted much research in an attempt to elucidate its underlying determinants and find measures for their assessment. For summaries see [1].

More recently, there has been a shift in research into presence. This is well captured by Lombard and Ditton [2] who suggest an alternative to the views that originate, in most part from research in virtual reality (VR). They define presence as the 'perceptual illusion of non-mediation'. Central to this notion is that unawareness of enabling or mediated technologies induces a sense of presence or 'illusion of non-mediation'. This widens the scope of presence to include various traditional and emerging electronic visual media and technologies, both interactive and non-

interactive, including: television, cinema, IMAX, the Internet, computer games, simulation rides and VR. According to Lombard and Ditton's [2] definition, the inducement of presence from these media is dependent on the invisibility or transparency of the enabling or mediating technologies.

In a way, this is similar to an old agenda advocated by many in the HCI community in the design of traditional interactive user interfaces. For example, Winograd and Flores [3] view the success of a task by the way the interface remains 'transparent', Laurel [4] cites Bodker [5] as advocating 'transparency' of work-related activities and Norman's [6] idea that 'direct engagement' with the object of work renders operations with the interface as cognitively imperceptible. See also [7]. Whilst all promote the transparency of user interfaces, Bodker [5] and Norman [6] confine their arguments to theories of work and work-related activities. Although as Laurel [4] points out, 'it is not simply work that we do with computers' but other things as well, such as, 'learn, explore, noodle around, play, and entertain ourselves'. Also see [8] [9]. Clearly, the same can be said of VR. In addition to work-related, activities within VEs can be performed to acquire more knowledge and for fun and/or enjoyment (for example, see [10]). Generally activities fall in one of four main categories: work-related, informative, education and training and entertainment. However, the development of traditional HCI evaluation methods presuppose work-related activities and commonly employ criteria such as that advocated by the International Organization for Standardization: effectiveness, efficiency, and user satisfaction [11]. Although these may be satisfactory criteria for the evaluation of many work-related activities, they are inappropriate to evaluate all activities and their related experiences with VR systems. This problem is not only confined to VR but also, highlights serious limitations of standard HCI methods to evaluate new and emerging media technologies and applications.

Building on work proposed by Marsh and Wright [12], the work contained herein argues that effective evaluation of VR must facilitate firstly, the vicarious nature of activities and secondly, activities other than work-related. In this way, we instigate the evaluation of VR by user experience. In addition to presence, this paper argues that interacting within a 3D VE has the potential to induce other kinds of experience in users, such as, spatial, emotional, thrills and sensations. We argue that experience with VR comes from users' attention or engagement to content and is best described by 'perceptual illusion of non-mediation'. Essentially this is advocating transparency and invisibility. By content we mean the virtual environment (imagery and audio that shape the 3D virtual space) and the scenario that takes place within it. Hereafter content will also be referred to as the illusion of VR. Scenario refers to the situations, circumstances, narrative, story and settings that come from performing one or a combination of activities (see section 2.1) within a VE. In an attempt to inform design and evaluation methods for VR we look to a highly successful visual medium, film.

The success of Hollywood filmmaking comes from its technological and artistic innovations leading to the development of the 'invisible style'. The 'invisible style' of film, like that advocated by the 'perceptual illusion of non-mediation', owes much of its success to its ability to keep spectators' awareness from the mediating/enabling technologies and thus, maintain their illusion of non-mediation. Hence, regardless as to the complexity of the underlying mediating technologies, spectators are able to focus on the content of film and immerse themselves in uninterrupted levels and varieties of experience intended by filmmakers. Indeed, this is the overriding motivation of filmmakers, that is, 'shaping experience' [13]. Disruption to film breaks experience for spectators. Borrowing from film, this paper argues for an 'invisible style' of interaction in VR. In terms of evaluation for VR, we argue that like film, disruptions or breaks to the seemingly invisible interaction or/and the content break user experience and this may identify potential problems of design. The main advantages of this are that evaluation of user experience of interacting within the VR content may be considered independently from the technology that supports it. Furthermore, this may support the evolving nature of the enabling technologies of VR as well as other new and emerging media technologies.

We begin in section 2 by modelling interaction with VR using activity theory and introduce the concept of breakdown in interaction. In section 3, we describe how the 'invisible style' maintains spectators' illusion in film and how this supports the making of films for increased experience. Using this to inform section 4, we extend the model of VR interaction (from section 2) introducing the concept of breakdown in illusion. Further developing these concepts, in section 5 we propose a model of engagement in virtual environments and identify on this model breakdown in operations of interaction and breakdown in illusion. Using this model, we propose criteria for the evaluation of VR. In section 6, this criteria is tested against usability problems identified in an earlier empirical study of a head-mounted display (HMD) VR system. Finally in section 7, we discuss the potential for shaping users' experience through the evaluation of VR design using breakdown.

2. Modelling breakdown of interaction in VR

Virtual environments unfold in real or continuous time in response to users' interaction within 3D virtual space. Instead of passively receiving information or narrative like spectators of film (see section 3), participants in VE create their own journey or narrative. That is, their interactive contribution determines the outcome. As Laurel et al. [14] state, "the experience of VR hinges on human action and the environment's response", and unlike a spectator of film, "in VR one is not done unto but doing". The additional interactive component of VR is what sets it apart from cinema. This is shown in the hierarchical framework of VR developed by Marsh et al. [15]. Whereby, a range of navigable VR systems can be identified as consisting of three main components:

i. 3D environment containing 3D objects (representation can be anything that is real, abstract or imaginary, and is constructed of anything from cartoon-like to photo-realistic)
ii. potential to navigate and explore the 3D environment
iii. potential to manipulate 3D objects

As identified by the framework, generally all interaction with VR falls in one of two main groups: navigation and exploration, or object manipulation. Any one or a combination of these is how all activities are performed with VR systems. For example, consider the selection of a book from a bookcase located in a virtual library. The user moves (*navigates*) in between chairs, tables (possibly moving obstacles en route – *object manipulation*) and along the aisles of bookshelves, searching (*exploration*) for the book's subject category, scanning (*exploration*) the shelves until the book is located and selected (*object manipulation*).

2.1 Using activity theory to model and analyse interaction in VR

In order to model interactions with VR this paper looks to activity theory. The discussions contained herein will be restricted to the concepts of activity theory that provide a way to model and analyse interactions with VR systems. For an in-depth treatment of activity theory and the potential benefits to HCI refer to [16][17][18][19]. Developed from Russian psychology in the 1920's (See: [16][20]), activity theory provides a way to represent interactions through consciousness and activity. In activity theory, the basic unit of analysis is an activity. Activities are hierarchical and composed of the activity, actions and operations. Its application to activities in VR is explained by way of an example. Consider for instance the activity of selecting a book from a virtual library as introduced in section 2. In reference to figure 1, all activities with VR are performed vicariously within a 3D VE (represented by the rectangle in figure 1) through either a first or third person perspective. The activity can be decomposed into the *activity* itself of selecting a book from a bookcase in a virtual library. This is made up of one or a combination of *actions*. Nardi [19] states that actions can be considered to be similar to what the HCI literature refers to as tasks (for example, [6]). Actions are planned and directed towards achieving a goal. For example, these are the navigations (e.g. movements in-between chairs, tables and along the aisles of bookshelves) and explorations (e.g. searching for the book's

subject category and scanning the shelves), and object manipulations (e.g. moving obstacles en route and selecting the book). Actions are performed by a combination of *operations*, such as, the actual 3D mouse movements, mouse button presses, and HMD movements.

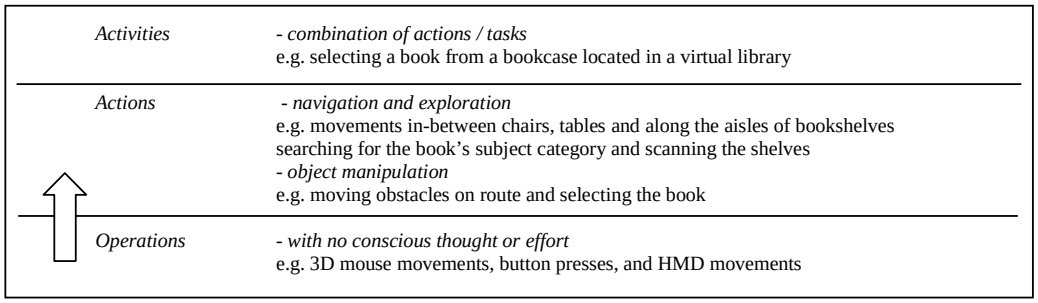

Figure 1. Modelling VE interaction with activity theory: breakdown in interaction

These lower-level operations do not need to be planned and require no conscious thought or effort. However, as cited by Nardi [19], all levels of activity theory are not fixed and can move up or down [20]. For example, to a novice user of VR, 3D mouse movements and button presses are an action that will require conscious attention until they have become routine. At such a point, these actions become operations. Likewise, operations become actions when for example, something impedes their execution or something unexpected occurs. Consequently, this triggers a shift in focus of attention and either 'opens up opportunities for learning' (for example, an unusual or unfamiliar interaction that requires more attention) [17] or identifies that something has gone wrong or broken down. This can occur with the VR enabling technologies (e.g. 3D mouse buttons pressed in error, 3D mouse/HMD cables becoming entangled or through fatigue, e.g. interactive device or style demands constant or excessive energy), or with the VE/objects and their behaviour (e.g. colliding with objects, walking through objects or unusual/distracting object/environment behaviour). Shifts in conscious attention from operations to actions are represented in figure 1 by a vertical arrow and will hereafter be referred to as breakdown in interaction.

A similar notion to that of focus shifts is 'breakdown'. Winograd and Flores [3] borrow from the philosophical concepts of Heidegger [21] to inform in particular, the design of computer-based systems from breakdown. Like focus shifts, breakdown occurs with 'transparent' operations when something impedes their execution. Heidegger asserts that everyday activities involving everyday objects are part of the *background*. By *background* he means "without explicit recognition or identification" and he uses the term *readiness-to-hand* to describe the state in which we are not consciously aware of our everyday interactions. Hence, we are "immersed in *readiness-to-hand*" in our everyday interactions in the world around us. When an object becomes part of our consciousness then a *breakdown* has occurred. That is, "the interrupted moment of our habitual standard, comfortable *being-in-the-world*" and only when "*things*" do not perform or function in the way that they are intended to behave do we become aware of their existence. In the virtual library example, operations present themselves or become part of our consciousness only when some kind of breaking down has occurred. For example, as identified earlier: the 3D mouse cable becomes entangled, the buttons pressed in error, or the HMD becomes hot, heavy or uncomfortable to wear. The 3D mouse and HMD and the activities they perform are now described as *unreadiness-to-hand* or *present-at-hand* and are no longer part of the *background*. Additionally, like focus shifts, breakdown with the VE and objects, and their behaviour can occur (e.g. walking through or collisions with objects within the environment).

Breakdown and focus shifts have been instrumental in the analysis of human-computer interaction [17] and facilitate the detection of usability problems of applications with traditional computer-based systems. For example, see Holtzblatt, Jones and Good [7], Bodker [17] and Wright and Monk [22]. However, an empirical study of a HMD VR system demonstrated

limitations of traditional methods (see section 6) to evaluate VR [23]. In particular, it was found that evaluation criteria are required that address the vicarious nature of activities performed within the content or illusion of a VR system. Furthermore, performing activities induce experience in users. Widely referred to as presence, this paper argues that interacting within a 3D virtual world has the potential to induce other experience in users, such as, spatial, emotional, thrills and sensations. We agree that experience comes from transparency or invisibility and this is described well by the 'perceptual illusion of non-mediation' [2]. However, in addition to breakdown with normally transparent operations as described above, breakdown also occurs to activities performed in scenarios within the illusion of the VE. Consequently, this shifts users' attention from the virtual to the real world and hence, breaks users' experience. This is hereafter referred to as breakdown in illusion and will be discussed further in section 4. Breakdown as potential negative cues to presence in VR and other media have previously been suggested [1] [2] although to our knowledge the only empirical work using this approach is that of Slater and Steed's [24] 'virtual presence counter' (see section 5).

3. Film: 'shaping experience'

Film is a highly successful and mature visual medium whose success comes from its ability to present narrative in such a way that the artificiality of the mediated technologies remains invisible to the spectator. Previous work has explored the relevance of filmmaking techniques to interface design [25][26] and to the design of virtual environments [27]. This latter paper takes a further step by developing guidelines (from cinematography conventions) to inform the design of 3D virtual space to reduce the occurrence of user disorientation during navigation [28]. For further readings on the development of cinematography conventions, their articulation of time and space, and their relevance to VE design refer to Marsh and Wright [27]. Revisiting the example of film, this section explores techniques to keep spectators' attention in film and identifies the causes of breaks to spectators' attention (and experience). This is used in subsequent sections to inform guidelines for the evaluation of VE design for experience.

Film is entertaining, educational, informative and provides an excellent storytelling medium. Film is the culmination of many technological and artistic developments and innovations to capture, manipulate and then project a smooth and continuous sequence of visual images and provide the illusion of movement to spectators. See for example [29]. Developments in film include the cinematic and editing conventions used to manipulate the spatial and temporal dimensions of the narrative and consequently provides a language for filmmakers which allows the making of films of 'increasing complexity and power' [14]. The illusion of movement in film and its manipulation of time and space are hereafter referred to as the illusion of film. Film's success is due to the powerful and wide ranging emotional, thrilling and sensational experiences that it provides spectators and this gives us the motivation to want to experience more films. In classical Hollywood mainstream cinema, this experience comes from its ability to pull and hold spectators' attention in the film projected within the borders of the projection screen. The screen is the window into the illusion of film as illustrated schematically in figure 2.

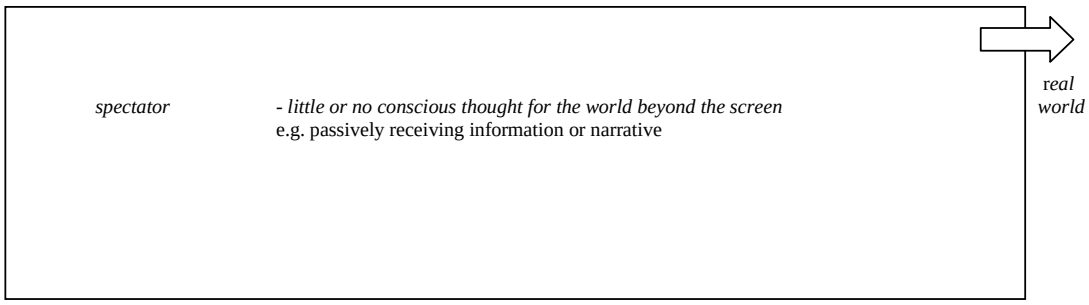

Figure 2. Breakdown in the illusion of film

Referred to as 'invisible style', it encapsulates the type of filmmaking that encourages spectators to lose sight of the underlying artificiality of the medium to capture sound and imagery. By grabbing our attention in this way we 'become absorbed exclusively in the represented act itself' of people, places and events, etc., of the narrative [30]. For further reading of the 'invisible style' of Hollywood cinema and its manipulation of time and space the reader is referred to [30][31][32].

The most telling criticism of film editors', camera operators' and actors' work isn't that it's phoney or crude, but that it takes the spectator out of the picture – 'when the audience is self-consciously examining its own responses, watching itself watch the movie, then all the razzle-dazzle in the world can't save the film' [13]. A shift in spectators' focus of attention from the film world to the real world results in a break in the illusion of film and is denoted by the horizontal arrow in figure 2. The 'invisible style' is in contrast to other styles that aim to break the illusion. For example, at precise moments in their presentation, French New Wave films intentionally draw attention to themselves, sometimes pulling spectators' attention out of the illusion of film, through devices such as jump cuts and repeated and reverse action. See for example [13][32]. Just how far spectators are pulled out of the illusion of film (totally into the real world or somewhere in-between) remains an area for further research. Boorstin [13] notes that the pull of film stars draws spectators right back in.

Three causes of breaks in film are identified: *internal, external or subjective.*

i. *Internal breaks:* are anything relating to the film, the techniques and equipment of filmmaking and its projection. This is divided into two subgroups. The first of these is the content (illusion of film). Breaks in content can be anything from bad script, story, plot, acting, sound, lighting and imagery, to awareness of cinematic and editing conventions. The second is anything belonging to the film and the filmmaking process that is not intended to be within the film's content. This is the mediating technology used to capture and project the imagery and sound. An example is the glitches in the technology/synchronization to project the film. It is acknowledged that some breaks fall in both groups (e.g. sound boom appears in frame or identifying back-projected or cut-out scenery).
ii. *External breaks:* are anything external to film, such as noise or distractions in the film auditorium or an uncomfortable viewing environment.
iii. *Subjective breaks:* are an individual's lack of interest in the film presentation/genre or an automatic momentary shift in focus of attention, such as, making a mental note of something or contemplating past/future events.

This division facilitates the simple and quick classification of breaks as being internal or external to the film content. If a break is internal, then it is classified as either a break to the content or to the film's mediating technologies that are not part of the content. Breaks result in drawing attention to the artificiality of film and lead to spectators' awareness that they are spectators of a film presentation and hence, the illusion is broken. Like film, it is argued that a kind of invisible style of VR is required in an attempt to draw users' awareness away from the artificiality of the enabling/mediating technologies of a VR system. It is anticipated that this will support the design of 3D virtual spaces of 'increasing complexity and power' and help shape experience for users.

4. Invisible style of VR: maintaining the illusion of interaction within 3D VE

In this section it is argued that, like film, one of the main goals of VR is to maintain users' attention in the content/illusion of a VR system. Consider for instance, a user interacting within a VE. In a VE the interactive contribution determines the outcome, as described in section 2. The outcome is the user's feedback in the form of a dynamically changing 3D VE and objects within the VE. Effective interaction in a VE can be considered to lie somewhere along a continuum. From totally engaged in a VE without awareness or conscious thought for the world external to

the VE, to awareness of the external world. In this latter situation, although a user may be consciously aware of external activities, noise/distractions, or/and the presence of others around them, they are still however, able to remain sufficiently attached to the illusion created by the VR system and thus, able to interact effectively within the virtual world. By effective interaction we are referring to users' focus of attention remaining within the content or illusion of VR (e.g. the activities of a scenario performed within a VE).

Breakdown of the VR illusion occurs when a shift in user's allocation (or focus) of attention from the virtual to the real world reaches a point that is detrimental to their attachment in the illusion, and thus, impedes their effective interaction within a VE. Anything that pulls users out of the illusion of interacting within a VE is detrimental to its purpose and will reduce the user's experience attained from it. Therefore, the cause of breaks in user's illusion of interacting within a VE may identify potential problems of usability. The shift in conscious attention from the virtual to the real world is represented in figure 3 by a horizontal arrow and will hereafter be referred to as breakdown in illusion.

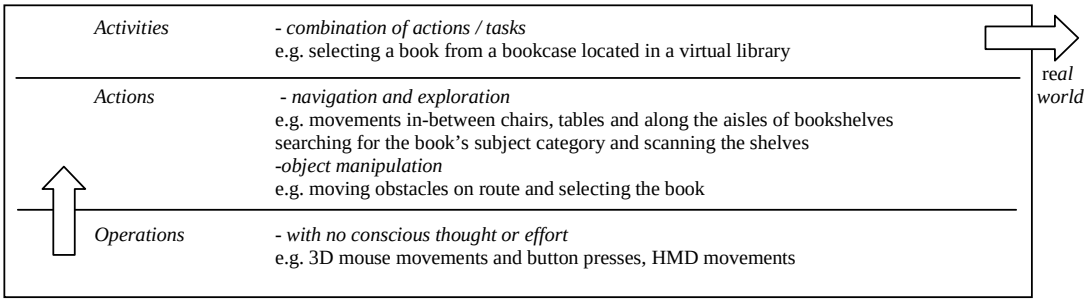

Figure 3. Breakdown in VE interaction and illusion

Like film, the cause of breakdown in illusion is either: *internal, external or subjective.*

i. *Internal breaks:* are anything relating to the VR system. These are similar to breakdowns in interaction (as described in section 2.1), however, here the experience of interaction is such that it shifts the user's focus of attention from the virtual to the real world. This is divided into two subgroups. The first of these is the content (illusion of VR). Breaks in content are from the imagery (e.g. colliding with objects, walking through objects or unusual/distracting object/environment behaviour), audio (e.g. unusual/distracting sounds) and sensory information from interactive devices, such as haptic-feedback (e.g. inaccurate force/tactile information). The second is anything belonging to the mediating technologies that support the VR content (e.g. 3D mouse buttons pressed in error, 3D mouse/HMD cables becoming entangled or through fatigue, e.g. interactive device or style demands constant or excessive energy).

ii. *External breaks:* are anything that is external to the VR system, drawing user's attention away from the VE, such as external noise/distraction or awareness of people surrounding them.

iii. *Subjective breaks:* are an individual's lack of interest for interacting within the VE illusion or an automatic momentary shift in focus of attention, such as making a mental note of something or contemplating past/future events.

This division facilitates the simple and effective classification of breaks as being internal or external to the VR system. If a break is internal, then this can be categorized as either a break to content or to part of the VR system's mediating technologies that are not part of the content.

5. Evaluation of VR using two levels of breakdown

As proposed in section 4, breakdown in VR occurs on two levels. The first is a breakdown in interaction (see section 2.1). In this situation, the user is aware that a breakdown has occurred and although this may interrupt or impede their interaction, they remain attached in the VR

illusion. The second type of breakdown occurs when a user's focus of attention shifts from the virtual to the real world. This can be either momentarily or can be so severe as to shift a user's allocation of attention totally from the virtual to the real world. As represented schematically in figure 4, a user's engagement can be considered to lay somewhere along a continuum from totally engaged in the illusion of VR without awareness or conscious thought for the world external to the VE (i.e. to the left, the virtual world), to awareness of the world external to the VE (i.e. to the right, the real world).

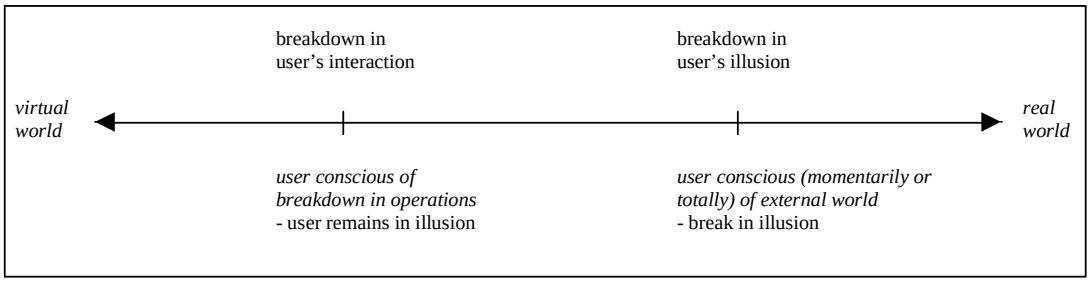

Figure 4. Continuum of engagement in virtual environments: user experience comes from interacting to the left of breakdown in illusion

Breakdowns in interaction and illusion are identified along this continuum and effective interaction (that is, the participant remains in the illusion) is identified as being that which is carried out to the left of breakdown in illusion. As suggested in section 4, although a user may be consciously aware of external activities (e.g. noise/distraction, and/or the presence of others around them), their allocation of attention is such that, they are able to remain sufficiently attached to the illusion created by the VR system and thus, able to interact effectively in the scenario within the VE. Interacting effectively is used here to mean that a user remains attached to the illusion of VR. We acknowledge that a breakdown in interaction (in which the user remains attached to the illusion of VR) may be more detrimental to the completion of an activity than would a breakdown in illusion. However, a central argument of this paper is that the experience of transparency keeps users in 'flow' [7] with their activities and it is anticipated that this will lead to enhanced user experience. Conversely, breaks in transparency break the experience and this has informed the development of guidelines for the evaluation of VR design for user experience.

5.1. Developing guidelines for the evaluation of VR design for user experience

Breakdown and focus shifts are by their nature reliable only if accessed at the moment of their occurrence or whilst they are part of user' short-term memory. To gain access to this information we need a continuous assessment method and one in which users are able to exteriorise their thoughts. Many presence measurement and assessment methods have been devised that may prove useful. For summaries see [1]. In particular, Freeman et al. [33] and IJsselsteijn et al. [34][35] adopt a simple and ingenious continuous presence assessment method using a sliding potentiometer. Users make on-line judgements as regard to their level of presence and reflect this in the position of a hand-held slider. Slater and Steed [24] propose a similar concept to that of breakdowns in which a user verbalises transitions from the virtual 'V' to the real world 'R'. Thus, data collected indicates the incidence of breaks in presence, highlighting potential concerns of usability and the duration of a users' sense of presence. For the assessment of presence, it could be argued that both methods suffer from the requirement of the user to divide their attention between the mediated illusion and the control of a hand-held slider and to keep in mind the verbalisation of the transition, respectively. However for present purposes, our interest is not so much in the direct assessment of presence but in methods that enable users to exteriorise their thoughts for the evaluation of VR design for experience of transparency and breakdown. One approach is for users to concurrently think-aloud whilst interacting within the VE. Thinking-aloud is an effective way to trace cognitive thoughts [36] and may provide a rich source of information to evaluate for the design of experience through breakdown. Specifically,

breakdowns and focus shifts will be detected through explicit verbalisations or complaints made about the normally transparent VR system, the enabling technologies of the VE, or questions from the user concerning operations or what action to take next. Table 1 shows the causes of breakdown in interaction and illusion and this can be used as guidelines for evaluators to assess the design of VR systems for transparency.

break in interaction (remain in illusion)		**break in illusion**	
Internal:	a. break in content: imagery, audio, force-feedback, etc.	*Internal:*	a. break in content: imagery, audio, force-feedback, etc.
	b. break in VR mediating technologies		b. break in VR mediating technologies
		External:	a. noise/distractions external to VR system
			b. awareness of activities external to VE
		Subjective:	a. lack of interest in interacting within VE
			b. attention wanders from VE

Table 1. Guidelines for VR evaluation: breakdown in interaction and illusion

6. Evaluation of virtual reality using breakdown in interaction and illusion

In an attempt to test the concept of breakdown in interaction and illusion, the guidelines (listed in table 1) were applied to 108 usability problems identified in an empirical study of a HMD VR system [23]. Developed at Rutherford Appleton Laboratory, UK, the test VE used in this earlier study is a simulation of the control room of the EISCAT (European Incoherent SCATter) radar facility. The purpose of the simulator is to familiarize scientists with the installation's location and layout and to train them in the use of typical control procedures prior to commencing their experimental programme at the real installation in Norway. Whilst concurrently thinking-aloud, eight users (4 males and 4 females) carried out three standard tasks to test the usability, functionality and effectiveness of the VR configuration (i.e. VR enabling technologies: HMD, 3D mouse, etc.,) and the VE (3D VE, objects and their behaviour). Verbal reports were transcribed from audio taken from video material. Failing the existence of commonly accepted VR usability evaluation methods or guidelines, the two study evaluators relied on their own judgment to identify potential problems of usability through analysis of users' think-aloud comments and observation.

All 108 usability problems could successfully be classified as being a breakdown in interaction, illusion or falling into both categories using the guidelines as listed in table 1. For brevity, table 2 shows the usability problems grouped into 12 similar or duplicate categories. Additionally, the sub-groupings of internal breakdown (i.e. breaks to content and mediating technologies, see section 4) are grouped together. Usability problems that were identified as being both breakdowns in interaction and illusion were allotted a half score. Identical usability problems were in some cases classified differently (i.e. either interaction, illusion, or both) according to the circumstances surrounding them. Hence, this highlights the flexibility of the guidelines in classifying usability problems to reflect the experiential differences of users.

Although the guidelines proved effective to capture internal breakdowns in both interaction and illusion through users' think-aloud verbalisations (and observation), external and subjective breakdowns in illusion were however, few and far between. As the study was conducted under laboratory conditions, this may account for the low occurrence of external breakdowns (e.g. lack of ambient noise and distractions). Whereas, infrequent subjective breaks may simply be as a result of the low breaks from this category, or as we suspect that the data collection methods (think-aloud comments and observation) are insufficient on their own to be able to capture the subtleties of users' individual subjective experience. This is an area for future research and is discussed in section 7.

Usability Concerns			Breakdown				Occurrence of usability problem
No	**Effect** *(observed / verbalised)*	**Cause** *(most likely)*	**Interaction**	**Illusion**			
			internal	**internal**	**external**	**subjective**	
1	▪ user's physical movements are restricted	▪ HMD and/or 3D mouse cable entangled around user/chair	16	20			36
2	▪ walking through/too close to objects ▪ getting lost / loosing position in VE ▪ user appears startled / disorientated	▪ no collision detect ▪ lack of knowledge for VE layout	17 ½	4 ½			22
3	▪ virtual hand going through objects ▪ virtual hand jitters ▪ virtual hand interaction awkward	▪ no collision detect ▪ inaccurate hand tracking ▪ too far from tracker source	9 ½	1 ½			11
4	▪ erratic movements through the VE ▪ hesitant movements in VE ▪ difficulty with movements ▪ movement/interaction is abandoned	▪ mouse button selection in error ▪ movements through VE too fast ▪ compounding difficulties ▪ external disruption to VR system	5	2	1	3	11
5	▪ eye-level position point-of-view (POV) becomes higher/lower	▪ looking up/down whilst travelling through the VE changes the POV ▪ HMD too heavy	7	1			8
6	▪ menu appears occluding user's field-of-view (FOV).	▪ selection of 3D mouse's middle button	6				6
7	▪ user supporting HMD with hand ▪ difficulties fitting / putting-on or wearing HMD	▪ HMD too heavy ▪ HMD incorrectly fitted / doesn't fit all head shapes / sizes	½	2 ½	1		4
8	▪ user cannot identify or misidentifies part of the VE model / object or its purpose / function	▪ inaccurate representation / model of real world object	2 ½	½			3
9	▪ caution signs ignored ▪ the purpose of the caution signs are not obvious to the user	▪ text signs in graphical VE unnatural / unexpected ▪ interpretation of signs unclear	1	1			2
10	▪ graphic lag / delay in response to quick head movements	▪ too many models to update ▪ frame rate too slow	-	2			2
11	▪ nausea	▪ HMD associated	-	2			2
12	▪ chair's swivel movement affect user's interaction within VE	▪ chair permitted to move freely in all directions	-		1		1
		Totals:	*65*	*37*	*3*	*3*	*108*

Table 2. Categorization of causes of usability problems through breakdown

6.1 Discussion

A central argument of this paper is that transparency keeps users in the 'flow' of their activities and it is anticipated that this will enhance user experience. Breakdown in activities breaks the experience and subsequently this provides opportunities to identify and analyse potential causes of usability problems. Informed from this, guidelines have been developed and applied to usability problems that were captured in an empirical study of a HMD VR system. This showed that all usability problems could successfully be classified as being a breakdown in interaction, illusion or falling into both categories. Hence, the guidelines provide a simple, quick and effective way to guide evaluators in finding potential problems of usability with VR systems.

7. Future Work: 'shaping experience' in virtual environments

Regardless as to how transparent or invisible the mediating technologies are, if the content of VR is uninspiring, dull or boring to use, it will not hold users' attention for any long periods of time. One approach that has been argued in this paper as a way of overcoming these difficulties is to enhance user experience. So how do we enhance experience to grab and hold users' attention and maybe provide the motivation to want to interact within more VEs for long periods of time? To answer this question we need to find out just what kinds of experience can be induced in users and how we can design/evaluate to create these experiences. Hassenzahl et al. [9] call for an 'expanded concept of usability', one that promotes users' fun and enjoyment, and is additional to traditional task and work-related design and evaluation criteria (e.g. effectiveness and efficiency [11]). They cite earlier work that make similar observations arguing that the 'narrow focus' of traditional usability doesn't extend well to consumer or home products. In an

effort to find design principles to promote fun and enjoyment of a software system they suggest analysing 'what makes computer games fun'. In particular, Malone [8] in his work on intrinsic motivation identifies three broad design categories: 'challenge', 'fantasy' and 'curiosity' and each consists of 'recommendations for designing an appealing computer game'. However, we argue that VR has the potential to evoke a greater wealth of user experience than just enjoyment and fun. Like film, we anticipate that VR is capable of evoking core universal human emotions, such as, happiness, sadness, disgust, surprise, anger and fear, through empathic, thrilling and sensational experiences. Therefore, again this paper looks to the example of film. Consider how we rate a good film. Maybe by the story, plot, script, acting, imagery, and so on, delivered at a pace that doesn't lose or break spectators' attention. Another way is through individual subjective experience. Boorstin [13] states that we don't watch films in one way but in three ways and as we watch a film the three compete in us. He identifies these as, 'voyeuristic', 'vicarious', and 'visceral':

i. Voyeuristic: the voyeur is the "prying observer" and the voyeur's pleasure is the joy of seeing the new and the wonderful. Boorstin [13] draws an analogy with turning the pages of a storybook to find out what happens next; (cited in [13]) what E. M. Forster describes as 'and then, and then, and then…'. If there is nothing to provoke our curiosity and interest, then simply we get bored, and thus, *breaks* our interest and attention.

ii. Vicarious: this is experience through empathy (see: [4]), that is, experienced imaginatively through another person, being or object. All interaction within VR is performed vicariously through either a first or third person perspective. This puts us in the 3D VE (as well as the visceral point-of-view, see below). Without the vicarious experience we wouldn't be there. At present, we have simple vicarious experiences. For example, traversing the VE provides users with the transfer of spatial knowledge and object manipulation/interaction such as, opening/closing windows and doors and selecting buttons, etc. As technological and artistic innovations are developed, the vicarious experience will become more complex. Inducing emotions through either our own interactions or through that of other beings or objects (e.g. agents and avatars). Within film (and theatre), the vicarious experience is induced through, for example, an actor's ability to convey honest emotion. *Breaks* in the vicarious are the unbelievable, emotionally untrue or simply 'he wouldn't do that' [13].

iii. Visceral: the instinctive base sensations and thrills; these are gut reactions rather than emotions. For example, the Helter Skelter type effect, the sensation of movement (e.g. vection) and feelings of fear, disgust and nausea. "Point-of-view (POV) is the gateway to the visceral". Like vicarious experiences, POV puts us in the scene, for example in VR this occurs through a first person perspective (although, we can also experience visceral thrills through a third person perspective, e.g. driving a racing car in a computer game from behind the car). More complex emotions require the empathic process of the vicarious. The *breakdown* in the visceral is simply, if it's not a thrill (it isn't visceral) and its main criticism is 'it doesn't get me'. This is either because we have acquired an increase in threshold for the visceral effect to kick-in or simply the design of the visceral effect is inadequate.

It is anticipated that the responses (3Vs) that are triggered in spectators of film could also be triggered in users of VR (or other new and emerging media). Breaks in users' individual subjective experiences (e.g. as identified above) could be used to inform guidelines for the evaluation of VEs. This may inspire the making of VEs of 'increasing complexity and power' [14], grabbing and holding users' attention, maintaining the illusion of interacting in 3D virtual space [12] and hence, design for increased experience.

Conclusion

In recent years, the VR, media and broadcasting communities have been increasingly interested with the concept of presence. See for example, [2]. Presence has been seen as a primary driver for design and evaluation and consequently, there has been concern for how its subjective and

objective components might be measured or assessed [1]. In this paper we have argued for an alternative view, a view that we feel subsumes this concept of presence. Our view is that presence is best defined as 'perceptual illusion of non-mediation' [2]. But if we search for an explanation for such a phenomenon one must shift to the arena of an experiential psychology. Interestingly, within HCI we have recently seen a turn away from cognitive and representational accounts of interaction to a more experiential perspective. For example, Laurel's [4] concern to re-frame HCI as theatre, Nardi's [18] concern to relate context to consciousness, and also, Winograd and Flores [3] attempt to subvert the cognitive/representational agenda for HCI.

In terms of evaluation techniques for VR, this paper has argued for the concept of 'breakdown' and 'transparency' as a means of analysing the experience of VR usability. In a way, this is renewing an old agenda laid out by Winograd and Flores [3] but we feel that this approach is so obviously relevant to VR and yet, besides similar empirical work of Slater and Steed's [24] 'virtual presence counter', has received little attention in that community. But a full turn to the experiential must go further than an analysis of the experiences of breakdown. Work in cinema has already begun to explore new concepts relevant to VR. In particular, we have adopted the three broad categories: voyeuristic, vicarious, and visceral (3Vs) [12][13], whose power lays in their potential to describe core universal human emotions, such as, happiness, sadness, disgust, surprise, anger and fear. We anticipate that this can be used to inform the design and evaluation of user experience of interacting within the content of VR. Our future work will aim to apply the 3Vs and other experiential analyses to provide an even better understanding of the constituents of experience in VR and other new and emerging media.

Acknowledgements
This work was carried out in-part at the Human Interface Technology Laboratory (HITL), University of Washington, Seattle, WA. Thanks to Professor Thomas A. Furness III, Dr. Donald E. Parker and members of the 'Presence Group', HITL. Thanks to James Willans and to the reviewers for their helpful suggestions. Funded by, UK EPSRC INQUISITIVE (Grant GR/L53199).

References

[1] IJsselsteijn WA, de Ridder H, Freeman J, Avons SE. Presence: Concept, determinates and measurement. Proceedings of the SPIE 3959; 2000, 520-529.

[2] Lombard M, Ditton T. At the Heart of It All: The Concept of Presence. Journal of Computer-Mediated Communication 1997; 3 (2).

[3] Winograd, T. Flores F. (1986). *Understanding Computers and Cognition: A New Foundation for Design.* Norwood, NJ: Ablex Publishing Corporation.

[4] Laurel, B. (1993). *Computers as Theatre*. Reading, MA: Addison-Wesley.

[5] Bodker, S. (1990). *Through the Interface – A Human Activity Approach to User Interface Design.* Hillsdale, NJ: Lawrence Erlbaum.

[6] Norman DA. (1991) Cognitive artifacts. In: J. Carroll, ed. *Designing Interaction: Psychology at the Human Computer Interface.* New York: Cambridge University Press.

[7] Holtzblatt KA, Jones S, Good M. Articulating the Experience of Transparency: An Example of Field Research Techniques, SIGCHI Bulletin, 20 (2), October 1988, 46-48.

[8] Malone TW. Toward a theory of intrinsically motivating instruction. Cognitive Science 1981; vol. 4, pp 333-369.

[9] Hassenzahl M, Platz A, Burmester M, Lehner, K. Hedonic and Ergonomic Quality Aspects Determine a Software's Appeal, Proceedings of CHI 2000: Human Factors in Computing Systems. NY: ACM Press, 2000; 201-208.

[10] Heeter C. (1995). Communication research on consumer VR. In: Biocca F, Levy MR, eds, *Communication in the age of virtual reality.* Hilldale, NJ: Lawrence Erlbaum Associates, pp 191-218.

[11] ISO. (1996). 9241: *Ergonomic requirements for office work with visual display terminals. Part 11: Guidance on usability.* International Organization for Standardization.

[12] Marsh T, Wright P. Maintaining the Illusion of Interacting Within 3D Virtual Space. Presence 2000: 3rd International Workshop on Presence; 2000, Delft, The Netherlands.

[13] Boorstin, J. (1995). *Making Movies Work: Thinking Like a Filmmaker,* Beverley Hills: Silman-James Press.

[14] Laurel B, Strickland R, Tow R. Placeholder: Landscape and Narrative in Virtual Environments, Computer Graphics: ACM SIGGRAPH 1994; vol. 28, no. 2.

[15] Marsh T, Wright P, Smith S, Duke D. A Shared Framework of Virtual Reality. UKVRSIG; 1998, Exeter, UK.

[16] Bodker, S. A human activity approach to user interfaces. Human-Computer Interaction 1989; 4:171-195.

[17] Bodker S. (1997). Applying Activity Theory to Video Analysis: How to Make Sense of Video Data in Human-Computer Interaction. In: Nardi B, ed., *Context and Consciousness: Activity Theory and Human-Computer Interaction,* Cambridge, Massachusetts, MIT Press, pp. 147-174.

[18] Nardi, B. (1997). *Context and Consciousness: Activity Theory and Human-Computer Interaction.* Nardi B, ed. Cambridge, Massachusetts: MIT Press.

[19] Nardi B. (1997) Studying Context: A Comparison of Activity Theory, Situated Action Models, and Distributed Cognition. In: Nardi B, ed. *Context and Consciousness: Activity Theory and Human-Computer Interaction.* Cambridge, Massachusetts: MIT Press, pp. 69-102.

[20] Leont'ev A. The problem of activity in psychology. Soviet Psychology 1974;13(2):4-33.

[21] Heidegger, M. (1962). *Being and Time (translated by John Macquarrie and Edward Robinson).* New York: Harper & Row.

[22] Wright P, Monk AF. Evaluation for Design. In: Sutcliffe A, Macaulay L, eds. Proceedings of the 5th Conference of the British Computer Society HCI Specialist Group, People and Computers V 1989; 345-358.

[23] Marsh T, Wright P, Smith S, Sastry L, Boyd D. Usability and Spatial Evaluation of a Stereoscopic Head-Mounted Display Virtual Reality System. 2001 (unpublished report).

[24] Slater M, Steed A. A Virtual Presence Counter, Presence: Teleoperators and Virtual Environments 2000; vol. 9 Issue 5, MIT Press, 413-434.

[25] McKendree J, Mateer J. Film Techniques Applied to the Design and Use of Interfaces, Proc. IEEE 24th Hawaii Int. Conf. on System Sciences 1991; NY: IEEE, 32-41.

[26] May J, Barnard P. Cinematography and interface design. Human Computer Interaction: Interact 1995; London: Chapman and Hall, 26-31.

[27] Marsh T, Wright P. Using Cinematography Conventions to Inform the Design and Evaluation of Virtual Off-Screen Space, AAAI 2000 Spring Symposium "Smart Graphics", Menlo Park: AAAI Press, 2000; 123-127.

[28] Marsh T, Smith S. Guiding user navigation in virtual environments using awareness of virtual off-screen space, Guiding Users through Interactive Experiences: Usability Centred Design and Evaluation of Virtual 3D Environments, Germany: Springer-Verlag, 2001.

[29] Parkinson, D. (1995) *History of Film*. London: Thames and Hudson.

[30] Messaris, P. (1994). *Visual "Literacy": Image, Mind and Reality*, San Francisco: Westview Press.

[31] Burch, N. (1983). *Theory of Film Practice*, London: Praeger Publishers Inc.

[32] Rosenblum, R, Karen R. (1979). *When the shooting stops the cutting begins.* Canada Limited: Penguin Books.

[33] Freeman J, Avons SE, Davidoff J, Pearson DE. Effects of stereo and mono manipulations on measured presence in stereoscopic displays, Perception 1997; 26 *(suppl),* 42.

[34] IJsselsteijn WA, Freeman J, Avons SE, Davidoff J, de Ridder H, Hamberg R. Continuous assessment of presence. Perception 1997; 26 *(suppl),* 42-43.

[35] IJsselsteijn WA, de Ridder H, Hamberg R, Bouwhuis D. Freeman J. Perceived depth and the feeling of presence in 3DTV. Displays 1998; 18, 207-214.

[36] Russo JE, Johnson EJ, Stephens DL. The validity of verbal protocols. Memory and Cognition 1989; 17: 759-769.