Kungl Tekniska Högskolan
Royal Institute of Technology
Numerical Analysis and Computing Science

CID-84, KTH, Stockholm, Sweden February 1999

Pushing Mixed Reality Boundaries

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Title: Pushing Mixed Reality Boundaries Report number: CID-84

ISSN number: ISSN 1403-0721

Publication date: February 1999

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eRENA

Deliverable 7b.1
Pushing Mixed Reality Boundaries

ABSTRACT

We report on task 7b.1, the eRENA workshop on pushing mixed reality boundaries. We introduce the concept of a mixed reality boundary that distinguishes our approach to mixed reality from other approaches such as augmented reality and augmented virtuality. We then review the history of boundaries in theatre in order to raise new requirements for mixed reality boundaries.

We extend the concept of mixed reality boundaries in two ways. First, we define the generic boundary properties of permeability, situation, dynamics, symmetry and representation that allow boundaries to be configured for different purposes. Second, we describe how multiple mixed reality boundaries can be used to join together many physical and virtual spaces into an integrated environment called a tessellated mixed reality.

We describe a practical experience of using a mixed reality boundary to create a performance. This culminated in a public demonstration of a rain curtain, a novel mixed reality boundary whose interesting properties include a lack of solidity, thereby allowing performers, props and audience to pass through it.

We evaluate this experience from artistic, technical and social science perspectives. We consider the implications of this work for the design of mixed reality technology in general. This involves exploring how dry versions of the rain curtain might be realised and speculating on how they might be used to create new kinds interface to virtual environments.

Document	eRENA–D7b.1–1
Type	Deliverable report with video material
Status	Final
Version	1.0
Date	February 1999
Author(s)	Steve Benford, Sally Jane Norman, John Bowers, Matt Adams, Ju Row–Farr, Boriana Koleva, Ian Taylor, Marie–Louise Rinman, Katja Martin, Holger Schnädelbach and Chris Greenhalgh
Task	7b.1

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1. Introduction

This deliverable reports on eRENA task 7b.1, the workshop on pushing mixed reality boundaries, under workpackage 7b, mixed reality environments.

The eRENA project is developing the idea of electronic arenas – inhabited information spaces that allow citizens to experience new forms of art, entertainment, performance and culture. Workpackage 7b of eRENA is exploring how emerging mixed reality technologies can support new kinds of performance within electronic arenas with a particular focus on reconfiguring traditional relationships between performers and audience and creating new kinds of stage that extend narrative possibilities. In return, this work aims to contribute to the more general development of mixed reality technology, with potential benefits for other classes of application beyond performance or indeed, beyond electronic arenas.

Workpackage 7 (b) was started in September 1998 at the beginning of the second year of eRENA. It is scheduled to run throughout the remainder of the project and will include two major public experiments between September 1999 and May 2000. The early stages of this work involve a series of practical workshops to explore different aspects of mixed reality performance so as to contribute to the full-scale experiments. The particular workshop described in this deliverable was an intensive two week practical exploration of using a novel mixed reality boundary, a rain curtain, to create a performance environment. The lessons learned from this workshop will inform the development of a major experiment called *Virtual Rain* that we intend to stage at ZKM, Nottingham and possibly Bristol and Liverpool in the autumn of this year. They will also inform the development of the underlying technology of mixed reality boundaries that is taking place in eRENA workpackage 6 and are providing inspiration for the design of new styles of interface to collaborative virtual environments. Indeed, this deliverable also contains a significant amount of background material from workpackage 6. This is included here so that the document can be read as an integrated whole and so that the Pushing Mixed Reality Boundaries workshop can be seen in the context of other eRENA activities, especially with regard to the relationship between demonstrators and underlying research challenges.

1.1. Structure of the deliverable

This deliverable is divided into the following sections.

- Section 2 introduces the background to our technical work. It begins by defining the fundamental concept of a *mixed reality boundary* that distinguishes our approach to mixed reality from other approaches such as augmented reality and augmented virtuality.
- Section 3 introduces the artistic foundations of work. It reviews the history of boundaries in performance and draws out the key artistic issues to be explored in our work as well as requirements for the further development of the mixed reality boundary approach.
- Building on the observations from section 3, section 4 extends the technique of mixed reality boundaries in two ways. The first introduces the generic boundary properties of permeability, situation, dynamics, symmetry and representation that allow a boundary to be configured for

different purposes. The second is the idea of using multiple mixed reality boundaries to join together many physical and virtual spaces into an integrated environment – a tessellated mixed reality.

- Section 5 describes an early practical experience with using a mixed reality boundary to create a performance. This took the form of an intensive two–week development session at ZKM in January 1999 – the Pushing Mixed Reality boundaries workshop. This culminated in a public demonstration of a rain curtain, a novel mixed reality boundary whose interesting properties include a lack of solidity, thereby allowing performers, props and audience to pass through it and raising new possibilities for performance. The section provides an initial evaluation of the workshop from technical, social science and artistic perspectives. This section also considers how the lessons learned from this initial experience will inform the design of a full performance that is planned to tour several European cities late in 1999. This will provide eRENA with an opportunity to evaluate this work as a "product" that is experienced directly by its intended "users".
- Finally, section Section 6 considers the implications of this work for the design of mixed reality technology in general. This involves exploring how dry versions of the rain curtain might be realised, i.e., mixed reality boundaries with similar properties of permeability but without the characteristic of wetness. It then explores how such boundaries might be used in the creation of new kinds interface to collaborative virtual environments.

1.2. How this deliverable has reacted to the first year review

The first year project review for eRENA made the following recommendations as to how the project might be improved:

- Artistic performances must be carefully chosen and cannot constitute and end in themselves. More emphasis should be placed on systematic evaluations of these performances (i.e. discussion of concepts to be tested by artist, evaluation of results, extraction of relevant conclusions from the experiments and performances, etc.). Spelling out explicitly which research challenges are addressed by an application and what the particular approach entails, as well as gathering feedback from the artistic experiences, is absolutely essential to eRENA.
- A feedback loop from user to researcher must be put in place in order to crosscheck the validity of the chosen approach. System evaluation and careful presentation and analysis of user reactions (feedback on the perception / acceptance / participation) should be carried out more strongly in the future work of eRENA.
- A stronger cross-partner co-operation and a better specific collaboration across professions should take place in the second year of the project.

The work reported in this deliverable has reacted to these recommendations in the following ways:

The decision to work with the performance company Blast Theory and their rain curtain technology was carefully made in order to demonstrate and inform the development of mixed reality boundaries in workpackage 6. Sections 2 through 4 of this deliverable include considerable background material from WP 6 in order to show how our work with the rain curtain draws on and contributes to this idea of mixed reality boundaries in general. Section 5.2 further justifies our decision to construct an experiment around the rain curtain by drawing out its interesting properties as a boundary, especially its lack of solidity, its variable transparency and its asymmetry. Finally, section 6 begins an exploration of how the rain curtain can inspire the design of dry technologies with similar properties that could be used as part of general interfaces to virtual environments. Thus, we hope to demonstrate a cycle of development that moves from a general technical innovation to its use in performance and back again.

Blast Theory were also carefully chosen as a professional performance company that was both respected in the artistic community and that could work with computer scientists in the development of new technology (building on prior links with Nottingham). In this way we aim to produce work that is artistically credible and yet makes a clear contribution to the development of general collaborative technologies. They were also introduced into to project to strengthen the link between the ZKM and Nottingham. With the additional introduction of KTH to carry out ethnographic evaluation of the workshop, we believe that we have succeeded in improving both cross partner collaboration and collaboration across professions.

Finally, we have devoted considerable effort to evaluation. Section five of the deliverable provides an initial evaluation of the workshop from artistic, technical and social science perspectives. Only one month has elapsed between the workshop and finalising this deliverable and we anticipate that reflection and evaluation activities will continue beyond this point. We have ensured as much as was possible that the workshop included demonstration to the public and that the opinions of the public were taken into account in our evaluation.

1.3. Publications arising from this work

The eRENA work on mixed reality boundaries has resulted in the following publications or submissions, all of which acknowledge the support of the project:

Reynard, G., Benford, S., and Greenhalgh, C. (1998): “Awareness Driven Video Quality of Service in Collaborative Virtual Environments”, *Proc CHI’98*, ACM Press, pp. 464-471.

Benford, S. D., Greenhalgh, C. M., Reynard, G. T., Brown, C. C. and Koleva, B. N., Understanding and Constructing Shared Spaces with Mixed Reality Boundaries, accepted to appear in Acm Transactions on Computer Human Interaction (ToCHI).

Koleva, B, N., Benford, S. D. and Greenhalgh, C. M., The Properties of Mixed Reality Boundaries, submitted to ECSCW’97.

2. Mixed reality and mixed reality boundaries

To set the scene, we begin with a brief introduction to the idea of mixed reality and the specific approach of mixed reality boundaries that is explored in this deliverable.

2.1. Creating a simple mixed reality boundary

This focus of this deliverable is on the fourth of the approaches outlined above – mixed reality boundaries. Its departure point is the idea of a simple mixed reality boundary as described in (Benford, 1996). Figure 1 shows how such a boundary can be established. On the left of the figure is a physical environment into which are projected graphics and audio from the virtual environment on the right. A group of people in this environment would have a shared view of the contents of the virtual environment, including its occupants who would typically be represented as avatars. In turn, a video camera and microphone capture video and audio from the physical environment and this is transmitted back to the collaborative virtual environment over a computer network. The live video image is then displayed as a dynamic texture map within the virtual environment. A group of people in the virtual environment would have a shared view of the contents of the physical environment. The net result is the creation of a transparent bi–directional window between the physical and virtual environments.

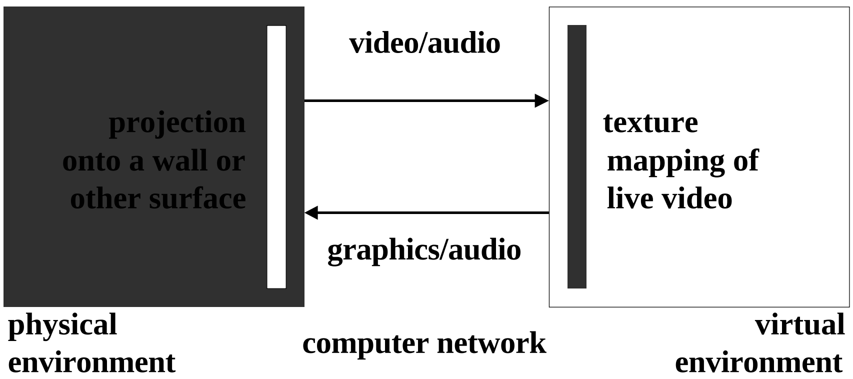

Figure 1: a simple mixed reality boundary

This approach to mixed reality was initially demonstrated by an application called the *Internet Foyer*. This involved a visualisation of an organisation's home pages on the World Wide Web, complete with representations of their visitors (this could be envisaged as a kind of virtual foyer) being joined to its physical foyer using a mixed reality boundary. The aim was to create a unified entry point into an organisation that spanned it physical and virtual manifestations and that allowed for awareness and communication between the two. In other words, visitors entering the virtual representation of the organisation (i.e., its web pages) would be aware of those in its physical reception and those entering its physical reception would be aware of those accessing its web pages.

Figures 2 and 3 show an overview of the *Internet Foyer* as it appeared to someone in the collaborative virtual environment. Figure 2 shows a visualisation of several inter–linked WWW pages (spheres connected by arrows) with the video window into the physical foyer in the background. Figure 3 shows a view from the same person when they have homed in on a specific part of the WWW visualisation. This image shows how the presence of the Web browser users is represented in more detail. Selecting one of the spheres or one of these user representations would result in a Web browser being launched in order to display its contents (a WWW page).

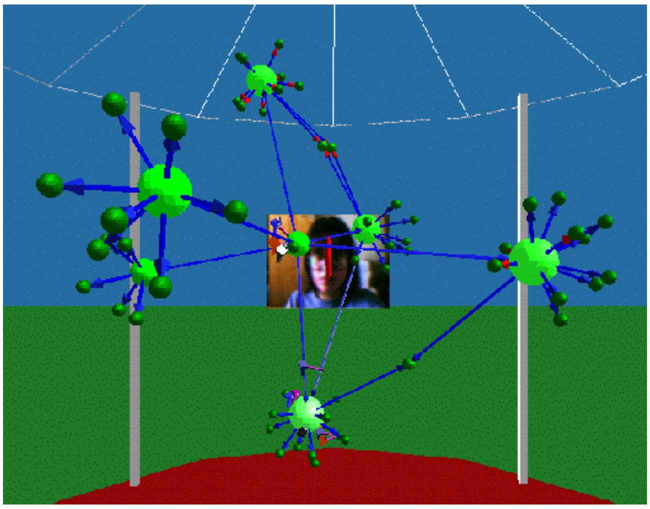

Figure 2: The Internet Foyer as seen by someone in the virtual environment

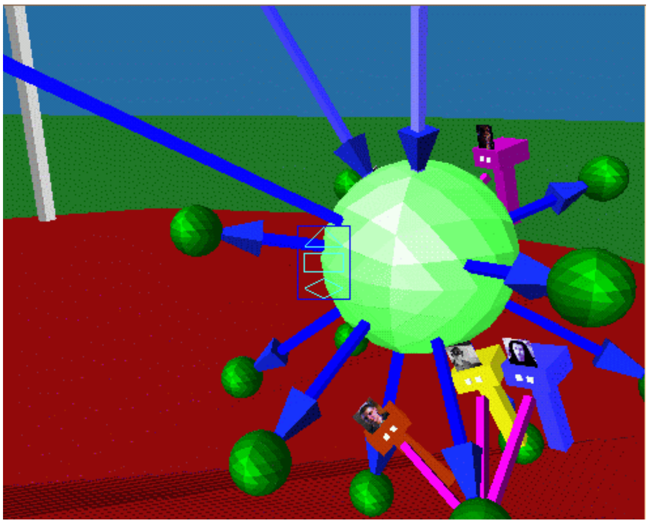

Figure 3: Close up to a Web page in the virtual environment

Figure 4 shows how the Internet Foyer appeared on a projected display to visitors in the physical foyer.

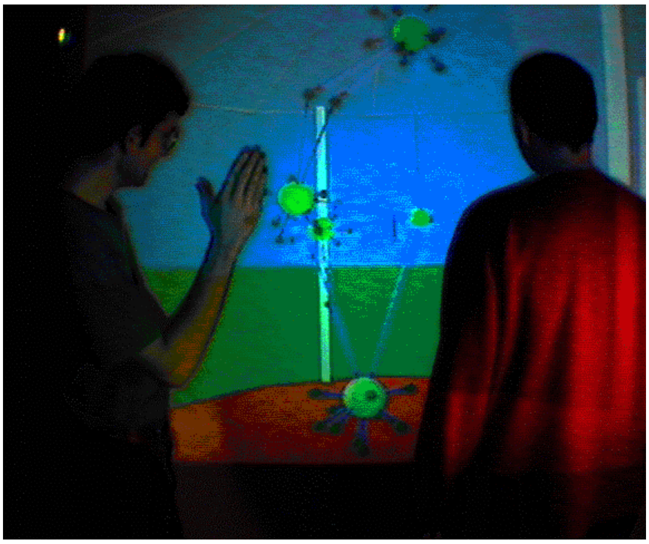

Figure 4: The Internet Foyer seen from the physical foyer

2.2. How this deliverable extends mixed reality boundaries

This deliverable extends the idea of mixed reality boundaries it in the following ways:

First, it develops a set of properties that can be associated with mixed reality boundaries. These properties are intended to support the design of mixed reality boundaries for a broad range of potential collaborative applications. For example, applications as diverse as distributed meetings, performances, media spaces, document editing and 3–D design will have varying requirements for managing awareness and privacy; for positioning a boundary and aligning it to different participants; and for scheduling its appearance. The set of boundary properties is also intended to provide an analytic framework for reasoning about how different boundary configurations (e.g., based on different combinations of projection and camera technologies) might afford different styles of co–operative activity.

Second, it considers how multiple mixed reality boundaries might be used to join together many physical and virtual spaces into a larger structure that we call a tessellated mixed reality. For example, a virtual environment might be used to join together many separate physical locations or a single physical space might have boundaries to different virtual environments projected its walls, floor or ceiling.

Third, it explores how mixed reality boundaries might be used to create new performance spaces with the potential to reconfigure traditional relationships between performers and audience and to enable new narrative possibilities. Specifically, it explores how a novel boundary material, a rain curtain – a curtain of water into which images may be projected, can be used to establish new kinds of mixed reality boundary with varying degrees of permeability through which performers, audience members and objects can move. It considers how several such boundaries might enable an audience and performers to undertake a journey through different layers of physical and virtual space. In turn, the rain curtain demonstrates a form of mixed reality boundary that might have uses beyond performance, perhaps being used for information displays in public space or in entertainment, or even providing more general interfaces to virtual environments, if its properties could be realised with a dry technology.

Now that we have introduced our technical, the following section completes our setting of the scene by reviewing the role of boundary technologies in the history of theatre.

3. Mixed reality boundaries as a founding principle of theatre

Given our goal of developing the technology of mixed reality boundaries to support new forms of performance, it is important that we first appreciate the nature of boundaries in traditional and current performance environments. This section therefore presents a brief review of boundaries in the history of theatre. Its aim is to capture the general properties that such boundaries have and to understand the ways in which these have established different relationships between performers and spectators or have enabled various dramatic effects.

3.1. Boundaries and codes

Theatre as art is hinged on an essential boundary, namely the division between actor and spectator. This boundary is used to separate two realities: reality of the performance artefact, with its aesthetically contrived space and time, and reality of so-called everyday activity, where space and time obey other (often very complex, intricately layered) sets of codes. The relationships implemented between these realities by the constitutive boundary of theatre, i.e. the actor/ spectator dividing line, show immense variability, throughout history and in different geographical and sociocultural contexts (Izenour, notably figure 2.1, "Principal Western Theater Form Outline Plans & Chronology", p.33). These relationships are today becoming a keen point of interest for developers of shared virtual environments, who are striving to elaborate paradigms for vivacious interaction between networked individuals and groups. Processes of identification and degrees of involvement sought in virtual worlds can be usefully inspired by those at work in "the virtual reality of theatre", so named by Antonin Artaud in Le Théâtre alchimique (1932). Theatre possesses a rich repertory of codes which govern symmetry and dissymmetry between viewing and acting participants in a shared virtual world (namely, the aesthetic construct that is the theatre experience), along with derivative codes that govern the degrees of overlap, permeability and interaction between these two categories of participants.

In addition to this essential generic boundary, an individual theatre work is wrought from multiple media, which may be considered as having and emanating their own respective "reality boundaries": solid three-dimensional objects, two-dimensional painted or projected images, light, sound, and live actors are all the bearers of specific existential realities or registers of presence, that converge in an aesthetically structured relationship within the staged world (see erena 1998 deliverable, chapter 2.3). Their coexistence is therefore not incidental or accidental as in everyday life (unless incidental or accidental occurrences are themselves an explicit part of the aesthetic project, as in much performance work of and since the sixties; Kostelanetz, 1967), but is planned and organised as a function of artistic design. This means that the usual, casual relationships humans have to light, sound, objects and other persons are here made subservient to a theatrical endeavour, which overrides and often creatively counters the codes governing normal interaction between these phenomena.

The codes governing theatrical reality may imbue an inert object with life, as in puppetry. They may imbue an empty space with responsive presence, as in mime. They may make us see obscurity where in fact there is light (e.g. the candle-bearing Elizabethan actor who thereby signifies darkness), or render manifest events that are in fact invisible (e.g. characters who vividly comment ongoing battles that they alone can “see”). They may dramatically conjure up an absent protagonist, as in use of a musical leitmotiv. An actor’s word or gesture may command a sudden change in lighting or sound, in ways that are only credible in the theatrical realm of suspension of disbelief. Theatre employs a multitude of resources to postulate many different kinds of reality and registers of presence, which may furthermore be mixed and remixed in the course of the dramatic action. Coherence of a performance work is basically a function of cohesion of the codes ruling the given reality or created world. Insofar as theatre proposes an environment where participants can interact with physical and non-physical information in an integrated way, it can be construed as a generator of mixed realities, in keeping with current computer science terminology.

3.2. Doors and curtains

“All the world's a stage, /And all the men and women merely players: /They have their exits and their entrances...”

(Shakespeare, As you like it, Act II, scene vii)

Performing arts have always been deeply embedded in sites, whether manifestly contrived as architecture or implicitly represented through consensual symbolic codes. Regardless of how patent it is, the boundary between observers and actors generates crucial tension on which dramatic impact depends; the performance area thus defined is sublimated and transformed with respect to its surroundings. Technical means used to implement the boundary that contains and thereby defines theatre, as a discrete artistically hewn reality, are extremely varied, historically and as a function of cultural geographies and social groups.

Many theatre conventions exploit the notion of the boundary and rites of passage by simply reproducing physical devices used to allow or prohibit passage in the real world. The most elementary of these devices is the door, which either forms part of an impenetrable occluding surface called a wall, or is opened to allow passage from one space to another. The Elizabethan stage with its two doors located back left and back right (reminiscent of Tudor manor hall architecture) indeed facilitates exits and entrances, as do many other theater configurations employing the door (hence the wall in which this opening is practised) as an effective boundary mechanism. But the Elizabethan stage is also endowed with mechanisms for aerial descents, and trapdoors for entrances by characters from the underworld (these stage entrances and exits date back to the ancient Greek mekhane or crane used to fly the gods in on the action – Deus ex Machina – and to the underground stairway employed by apparitions from Hades). These various examples demonstrate the use of boundaries that can be physically traversed and the use of multiple boundaries with various orientations and locations with respect to performers and audiences to create different stage environments.

One of the earliest dedicated, closed theatres recorded in history is Palladio’s Olympic Academy of Vicenza, inspired by the architect’s reading of Vitruvius’s (mis-) interpretation of Ancient Greek amphitheatre design, built in 1585. Palladio´s stage, constructed on a carefully calculated gradient to accentuate perspective effects, and foregrounded by an architectural facade with three main practicable doors or entrances, strongly influenced Renaissance theatre: these doors readily accommodated new dramatic forms revolving around urban intrigue and palaver. Sebastiano Serlio's design and description for the "comic scene" (Architettura, 1545) , insists that this specifically urban setting must contain a "brawthell or bawdy house, and a great Inne, and a Church". Smaller houses should be set in front of larger buildings, with subtle backlighting of windows to reinforce the sense of volumetry and spatial cohesion ("The windowes which stand before, were good to be made of Glasse or Paper, with light behind them…" Nagler, 1952). This use of windows shows that boundaries that offer varying degrees of transparency can be used for dramatic effect.

The two curtained doors in most Chinese theatre traditions are respectively termed "the door of birth" for entrances (located on the spectator's stage left) and "the door of death" for exits (stage right). This spatial distinction undergoes subtle coding within the dramatic structure: an arrival via the right-hand door indicates that the character is entering the action from another room inside the same house, whereas conventional arrivals on the left indicate that the character is coming from outdoors. Use of these entrances can also conveniently be read as a translation of rank: in court drama, dignitaries arrive on the left, whereas servants, employed inside the apartments, arrive through the door on the right.

Japanese Kabuki theatre employs a bridge for entrances. Characters who embark on this hanamichi (path of flowers), which runs along one side of the auditorium, from the rear of the house up to the stage, trigger boisterous response from spectators who welcome their favourite performers. As an actor/ spectator boundary, the hanamichi is thus endowed with its own, highly specific function in that it still resides partially within the public sphere, outside the context of the actual drama being performed (the actor is acclaimed nominally), yet at the same time hosts a kind of theatrical parade. Its significance as a boundary is therefore in the particular spatial relationship that it establishes between the performers, the spectators and the stage

In Noh theatre, the stage is also accessed by a bridge (hashigakari), in front of which three small pines are planted at regular intervals, acting as reference points for the actors as they progress along the bridge – these markers are important because Noh masks severely restrict the wearer's field of view. Here we can make a direct link to the use of headmounted displays (HMDs) for performances in virtual environments (see the poetry performance in section 4 and also the performer interfaces from the *Out of this World* Inhabited TV demonstrator from eRENA WP 7a). Like Noh masks, HMDs provide the performer with a restricted field of view (of a virtual world), typically about 60 degrees horizontally. Use of codified, readily recognisable staging elements might facilitate navigation of virtual performers in immersive environments, just as Noh spatial conventions allow traditional actors to overcome the visual limitations imposed by their headdress.

A stairway joins the centre-front of the raised Noh stage to the tatamis on which the spectators are seated (in the early days of Noh representations, winning actors in dramatic contests would descend these stairs to claim their reward). Noh theatre architecture boasts an ingenious acoustic boundary, in that the stage floor is positioned on large, empty barrels which raise it above ground level, and the actors' deft footwork elicits distinctly differentiated, resonant rhythms from this "sounding board". This emphasises the importance of considering the acoustic as well as visual properties of boundaries.

These are but a few examples of exits, entrances, and thresholds, i.e. boundary mechanisms, encountered in stage architectures. All such mechanisms metaphorically and physically instantiate the performance arena in highly specific ways. Curtains have been long used as boundary devices in performing arts, whether as painted set supports like the "scena versilis" and "scena ductilis" of Ancient Roman amphitheatres (respectively dropped and hoisted back-cloths), orchestrated by complex pulleys using the latest engineering technologies, or as screens used to conceal and reveal dramatic action at the appropriate moments. While the latter function is a relatively recent development in full-fledged stage architecture, fairground theatre booths with their curtains can be traced back to a much earlier period.

The history of curtains is a well researched area of theatre scholarship (*L'Avventura del Sipario*,1984). One recognised starting point is the tent covering that Thespis, founder of the first Athenian troupe, used to conceal the props and costumes on his wagon stationed on the agora. More recent history espouses the extremely complex mixes of new materials and lights developed by theatre technology wizards like Josef Svoboda, to restructure and dramatically requalify stage zones during live performance (Bablet, 1976). The plush red curtains of nineteenth century bourgeois stages, raised to reveal inconceivable worlds, have remained a strong indicator of performing arts rituals for many people, even though the dramas they disclose have often changed radically, content-wise, compared with their forebears. The late nineteenth century symbolists made ample use of tulle and gauze curtains, and even translucent cloths with metallic sheens, to dissolve and dematerialise staged worlds in the course of the action, rather than simply to conceal and reveal them in a more functionalist manner. Slow-motion, hieratic gesture was often employed by symbolist actors in mysteriously veiled stage space, to accentuate its other-worldliness (Norman, 1993).

Picasso's curtains for *Parade* (Ballets Russes, 1917) evoke certain aspects of this complex history of curtains, in their cunning reiteration of a theatre within a theatre: the first "Rideau rouge", disclosed during Satie's prelude, is a painted curtain showing a backstage circus troupe. This is then raised to reveal the actual set for the ballet, with its backcloth featuring yet another curtained theatre booth. Meyerhold's production of Lermontov's Masked Ball (Saint Petersburg Imperial Theatre, 1910) employs luxuriously draped curtains to ostensibly frame the stage throughout the drama, containing and emphasising the artificiality of the theatrical world at a period where he is intent on defining a "theatre of convention". Picabia's curtain which greets the public of *Relache* (Ballets Suedois, 1925) is splattered with various forms of twenties graffiti, painted in keeping with ensign aesthetics in the early days of electrified cityscapes; this anti-advertisement is raised to reveal a wall of banked-up projectors that blind the spectators, as an introduction to a work that slyly denounces the flashy aesthetics it admirably employs (Norman, 1990). These theatre works have in common a deliberately staged tautological quality: part of their performance value consists of querying (and wittily undercutting) the very media they employ. Not surprisingly, radical use of the stage curtain – or reality boundary – as a device defining status of the theatre work is particularly febrile amongst early twentieth century avant-garde movements, i.e. historically at a moment where artists are beginning to query the aesthetic empowerment that ensues from framing mechanisms, from the way a given phenomenon or situation is isolated from its everyday context, and is thus defined and experienced as art. To generalise, this discussion of curtains indicates further important properties of boundaries in that they can be dynamically introduced and removed and in the case of tulle and gauze curtains, may offer varying degrees of transparency.

3.3. Ad hoc and ambivalent performance boundaries and codes

Doors and curtains are two physical boundary mechanisms frequently used to engender performance space. Alternatively, in the absence of such physical devices, the “virtual reality of theatre” may emanate or radiate from the actor. Street theatre, where banal public space is momentarily invested with inhabitual qualities, is an example of this extremely human-centred performance art. Exacerbated focus on theatre activities hosted by self-contained, closed theatrical buildings overlooks the more subtle boundaries generated in situations like this, and indeed tends to neglect the vast range of sites exploited and appropriated by performance traditions not anchored in a dedicated space. Many ad hoc theatres created in ursurped or “hijacked” spaces reveal highly conceptual boundary mechanisms. These differ radically from patent architectural demarcations like footlights and orchestra pits, but are often just as powerfully operative in the theatre context, if not more so. Architectures invested extemporaneously for theatre show a certain fragility, in that the boundaries they erect between actors and spectators are tenuously makeshift. At the same time, such places have nurtured particularly resilient kinds of theatre, perhaps precisely because the boundaries must be asserted in vivo, by the performers, rather than being instated prior to the performance as a given architectural convention or facility.

Like most theatre architectures, the Elizabethan theatre only gradually acquired and consolidated its characteristic spatial configuration: the cockpit (or bearpit), was progressively invested by human entertainers who first decked out the primitive fighting enclosure with a trestle-mounted stage (early actors rivalled with by card-playing, tobacco-chewing youths, keen to catch the public eye), before the fixed stage was eventually built. Similarly, the Spanish corral theatre was simply an interior residential courtyard requisitioned by players, but which assumed increasingly codified spatial attributes to more aptly accommodate the remarkable dramatic writings of Golden Age authors such as Calderon and Lope de Vega. Formalisation of dramatic literature is often tightly enmeshed with formalisation of the physical stage intended to host it. The conditioning influence of a vehicle or architecture on content, an issue frequently brought up with reference to today’s infocommunication technologies, is just as pervasive in earlier media and art forms.

In the context of often trial-and-error emergence of codes governing various kinds of theatre space, there are moments where these spaces and their bounding mechanisms are deliberately kept ambivalent and alterable. An example is the gradual transformation of participatory court ballets in the Louvre salons into spectacle for passive viewers, when Louis XIV sought to dazzle his subjects with virtuosity codified by the freshly founded Academies of Music and Dance. The ornate floats that traditionally graced royal receptions, and that indifferently accommodated comestible fare and humans posed in tableaux vivants, were replaced by more substantial, less mobile decors, with reserved areas for professional actors whose art was no longer a merely decorative distraction, but demanded and deserved real attention. Yet interpenetration between actors and observers persisted in these more spectatorial ballets: courtiers would intercede in the action to plead in favour of a wayward hero, to praise the clement gods (i.e. the King), and of course, to joyfully dance the collective grand finale. In this way, the actor/spectator boundary functioned as a wilfully elusive dividing line: the public was at times held at bay from the staged action and intimidated with displays of artful splendour, and at other times welded, together with the actors, round the monarch for the ultimate spectacle of centralised royal power and unisson (McGowan, 1978). The examples in this section are especially interesting because they draw on two further properties of boundaries: the extent to which they are explicitly represented to performers and spectators, and the extent to which they are fixed or can be mobile and continually shifting.

3.4. Spectator/actor dis/symmetries

Some theatre artists and traditions prone stark opposition between the realities that fuse at the actor/ spectator boundary, pretexting an almost mathematical equation whereby the greater the perceptible difference between the two worlds, the more powerful the theatrical art thus engendered. At the other extreme, "slice of life" approaches maintain that effective spectator identification with staged action depends on recognisability and familiarity of the theatrical reality – be it the gilded realm of Versailles Sun King ballets, or grim realities of 19th century naturalism and 20th century "kitchen sink drama". To further confound these issues of alienation or rapprochement of staged as opposed to everyday reality, views of what constitute points of divergence or similarity between two worlds are extremely labile. A theatre work deemed divinely other-worldly by one spectator might seem excruciatingly banal to another.

Apart from questions of individual taste and sensibility, such differences in opinion may result from different cultural backgrounds and experience, and from the sheer distancing effect granted by time. 17th and 18th century aristocrats transported by the theatrical exoticism of anacreontic allegories or baroque orientalism were doubtless too immersed in their own cultural scenes to be able to recognise their reflections in the sophisticated forms of mimicry such spectacles offered. With hindsight, however, we can easily spot the resemblance between the actors and spectators located on each side of the performance boundary. Lessons like this might well be brought to bear in today's design of shared virtual worlds and of the mixed reality boundaries that govern them, since avatar appearance and behavioural codes currently judged foreign and alienating may appear to future generations as a barely twisted mirror image of their makers.

Mechanisms ensuring actor/spectator separations, (dis-)symmetries, and processes of identification and self-recognition, bear strong ideological connotations. How stage architectures are implemented, how they focus audience perception, how they grant or deny comparable viewing conditions to all, are basically questions of power and empowerment, as is the question of how much overlap between viewing and doing they admit, and how such overlap is orchestrated. A key property of boundaries is therefore their possibly different relationships, e.g., spatial locations, with respect to different participants. Indirectly, such architectures seem to offer some interesting tacks for current debate about enabling and engaging users in IT systems and processes, to promote more participatory cultural mores. The dangers of simplistic equations, such as "participation = equality", are well evidenced in theatre history, as seen with the forementioned court ballet example. By the same token, architectures guaranteeing comparable viewing conditions for theatre-goers do not necessarily testify to egalitarian ideologies: the Greek amphitheatre, a stunningly well-designed venue in terms of spectator equality, was established by the tyrant Pisistratus, who rigorously ordained the format of the annual cycles of tragedies (Nagler, 1952). From this standpoint, the Greek arena offers some curious analogies to the performance "venue" that today is often hailed as epitomising cultural accessibility and equality: the television set is a ubiquitous instrument which disseminates tightly dictated content.

Here again, a crucial point seems to be the conditioning influence of a media vehicle on content: theatre architectures (concrete or makeshift) can be loosely construed as "operating systems", regulated by more-or-less hard and fast rules. The organisational levels of these architectures, the rigidity of their task compartmentalisation and hierarchisation, and manoeuverability between operating functions and levels (i.e. boundary dynamics) reflect strongly on the actual works they accommodate. Theatre technologies imply and impose distinct actor/spectator relations. Apart from the actual spatial configurations and materials employed by theatre buildings, there are technologies which are borne by and constitute a corporeally integral part of the artist's stage presence: audio amplifiers (including the buccal amplifiers used in Greek tragedy) are technical devices that extend performance space by pushing back the boundaries of the normal vocal range. Amplifiers at work in the visual field, such as cothurns and the onkos (the tragic mask with its elevated crown piece), augment the performers' visible range and impact. HF mikes and fine-tuned spotlighting today ensure similar functions, heightening perceptibility of staged events and performers. These technologies clearly impact content. These examples show that boundaries, considered in a general sense, can serve to amplify or transform the information that passes through them as well as attenuating it, an important property that allows performers to address large numbers of spectators.

3.5. Identifying the properties of boundaries for performance

Our review has shown that performance boundaries have taken a variety of forms throughout the history of theatre. To generalise, we argue that these forms can be thought of in terms of the *properties* that boundaries can have and the ways in which these enable different relationships between performers, spectators and the spaces that they occupy. Key properties of boundaries include:

- *The ability to cross boundaries and so pass from one space to another:* in theatrical terms, this traversal may serve to signify a readily understandable "real-world" transition between two domains, as when a character closes a door in a built-up stage set, and visibly enters another room or space. Traditional vaudeville, with its guilty maids hiding in wardrobes, and jealous husbands listening at salon keyholes, fully exploits this transposition of a coherent bourgeois environment to the stage. At the other extreme, passing from one space to another may entail highly symbolic transformations in character and dramatic proceedings. In mediaeval mystery plays, which staged simultaneously visible locations aligned in keeping with the biblical east-west axis, corresponding to heaven, the earth, and hell, movement between these spaces engendered spectacular changes in events and tone. A character's deambulations from the temptations of hell through to celestial redemption (or vice versa) occasioned highly stylised dramatic changes, emphasising the autonomy of these three discrete realms, while drawing dramatic interest from their potential links.
- *The ability to locate boundaries in different positions*: various kinds of theatrical boundaries may be incorporated within the depicted stage space, and/or reside in the cleavage between the audience and the performers. Wagner's orchestra pit at Bayreuth was meant to reinforce the latter kind of boundary: this was a "mystical chasm" whence light and music arose, to enthrall spectators in the Ring cycle. Steam was used to emphasise the vaporous other-worldliness of the Wagnerian Gesamtkunstwerk (Bertolt Brecht condemned what he saw as an unhealthy attempt at hypnosis, while George Bernard Shaw complained that the Bayreuth

opera smelled like a laundry). The way boundaries are positioned may be gauged to elicit a specific emotional response or type of involvement from the spectators. Grotowski placed his spectators in a voyeuristic situation for *The Constant Prince* (1965): the fact that they had to peer over the wall which enclosed the rectangular performance space reinforced their sensation of witnessing forbidden acts. Most of Grotowski's works sought to restructure actor/ spectator boundaries through staging that dispensed with conventional proscenium-type confrontations.

- *The ability to use multiple boundaries to create several linkages between two spaces or to link many spaces together to form a larger structure:* this property is obviously at work in the mediaeval mystery sets, where traversal of and roaming between the three simultaneously staged, discrete worlds in itself constitutes the essence of biblical drama. More recently, and particularly with the introduction of powerful lighting and projection techniques, pioneering directors like Erwin Piscator have created modern equivalents of such multiple, potentially linked spaces by selectively revealing and concealing different stage "compartments" at specific moments of a performance (cf. Ernst Toller's *Hoppla, wir leben!*, 1927; Bablet, 1976). In a rigorously architectural orchestration of spectator/ actor space, Ariane Mnouchkine's production called *1789* (1970) used a series of stages and bridges located round and through the space occupied by the public, exposing the spectators to disturbing proximity with the actors, and constant, unpredictable changes in the acting locus.
- *The ability to dynamically introduce and remove boundaries*: since the late 19th century, lighting has immensely facilitated the dynamic reconfiguration of boundaries, since this dispenses with heavy, physical maneuvers. Readily controllable fixed and chase spots allow fluent, fluid segmentation and restructuring of visible stage space. But earlier theatrical boundaries characterised by their dynamics include the Ancient Greek *ekkyklema*, a chariot on which spectacular, often gory *tableaux vivants* would be fastidiously and secretly prepared (e.g. Media devouring her children), then the chariot would be suddenly wheeled from its hiding place beneath the proscenium towards the spectators, and just as swiftly wheeled back, as the public recovered from the shock of this primitive zoom. In one of the heydays of theatre machinists, 17th and 18th century pulley and rail systems allowed swift, spectacular transformations to be commanded before the spectators' very eyes (the uproar of the machines often being drowned out by a vigorous musical fanfare, which thus served both a theatrical and utilitarian purpose). The 18th century Carriage-and-Frame system at the Swedish Drottningholm Theatre still bears more than thirty sets of scenery which allow stage transformations in just a few seconds. Large-scale mechanisation breakthroughs in late 19th century theatres led to swiftly transformable revolving and superposable scenes, thereby introducing new kinds of boundaries which remained tightly contained within an autonomous performance space, making the stage itself a powerful living machine.
- *The ability for boundaries to be mobile or fixed:* architectural fixtures, painted sets, and ephemeral boundaries devised from effectively localised and piloted lighting are an indication of how very different materials actively contribute towards implementing and orchestrating a wide array of theatrical boundaries. Theatre history testifies to the continued use of primitive boundary solutions, which tend to be integrated into a constantly growing panoply of tools for reconfiguring performance space. Thus, ancient machine strategies like the ekkyklema, trap doors, and flying platforms are frequently combined with the latest laser projection technologies and use of new synthetic materials to occlude, reveal, and transform the stage.

Spectacular rock concerts and much music video, as evidenced by MTV, avidly exploit the modern counterparts of baroque theatre machinery, which are intimately mixed in performances integrating the latest computer graphics special effects.

- *The ability for boundaries to offer varying degrees of visual and acoustic transparency, or possibly even amplification*: today's use of HF mikes and the possibility to "ventriloquise" and acoustically adorn an actor's voice by dispatching it through a mixer and speaker system introduces a new arena for dramatic experimentation. David Warrilow's formidable rendition of Pinget's *Hypothèse* (1986) was a chillingly pervasive theatre work, where his amplified voice was "choreographed" to exploit a complex battery of speakers located all around the theatre, as though belying the actor's unaltered frontal station before a public trapped in the web of surrounding sound and mesmerised by Warrilow's steely monologue. But acoustically defined and differentiated performance spaces can also be discerned in theatre conventions of pre-electronic days: the simultaneously visible mediaeval realms described above functioned coherently because of respect for acoustic properties, set by convention. If an action was being staged in heaven, then angelic singing and celestial music made this apparent, while a grotesque din and heinous sound effects accompanied action performed in hell. Only the current focal point in the dramatic narrative was "sonified" at any one moment: characters stationed in the other realms could follow the action in the active world and mime their reactions to it, but were on no account allowed to make any noise. In this way, passive performers visibly accompanied and corroborated the dramatic process but remained mute (under mediaeval theatre guilds, actor errors like speaking out of turn could be heavily and dissuasively penalised).
- *The ability for boundaries to be explicitly or implicitly represented to spectators*: this last feature is broadly a matter of theatrical convention, and a matter of how far this convention consists of importing familiar boundary mechanisms from everyday life, or alternatively, of establishing codes to make unfamiliar boundary mechanisms recognisable, thus operational, within the creative context of performance.

3.6. Summary: using the properties of performance boundaries as design input for mixed reality environments

The ideas of boundary properties and of using multiple boundaries to structure performance spaces form the central thread of this deliverable. Our aim is to see how approaches to boundary principles operative in an artistic (performance) context can be usefully fed in to the elaboration of mixed reality environments, to enrich the types of interaction they accommodate. The above-listed properties, identified within the context of theatre practice, offer general qualities apt to be taken into account for CVE design. Amongst other issues raised by this extrapolation, it implies the necessity to determine how the attributes of a physical configuration can be translated and transposed to a homogeneous digital medium.

The wealth of boundary mechanisms available and operative in performance largely derives from the physical anchorage of theatre in real world materials – physical spaces and human performers in real time. But the effectiveness of theatrical boundaries is not a function of their sheer abundance, since theatre does not aim to duplicate or replicate the abundance and quiddity of the real world, but rather to extract, create, and offer events for aesthetic contemplation. More than in their intrinsic properties, the effectiveness that characterises theatrical boundaries is entrenched in their correlative differences, their disparities and their tensions, in short, in the degree of heterogeneity they are capable of dramatically conveying and upholding. What determines the aesthetic coherence of a given set of theatrical boundary mechanisms is how they interrelate, how each demarcates a specific moment or aspect of performance with respect to the others.

This would seem to be a generic principle: by the same token, the effectiveness of boundary mechanisms in collaborative virtual environments could be seen to reside in their interrelationship, and in how their respective demarcations are made operative within a given system, be it built to aesthetic or functionalist ends. Like theatre, CVEs present their own intrinsic panoply of "mixed media", and even the apparently homogeneous digital world conveys a host of heterogeneous kinds of images, with very different qualities and propensities to occupy, share, and demarcate screen space. By first identifying a taxonomy of images proper to digital space, hence their respective boundary mechanisms, one can then proceed to experiment with these various species of images, in order to derive fluency in the manipulation of their differences and boundary mechanisms.

To take just one example of an image "genre" employed in the computer world context, live video feed into digital displays manifests a highly distinctive iconicity, which contrasts sharply with other forms of digital imaging. The redeeming, humanising quality of video streaming into otherwise alienating displays has often been observed in "mixed reality" works, as is evidenced by art installations such as Bill Seaman's *World Generator* (erena project, year 1) or Masaki Fujihata's *Nuzzle Afar* (escape project, year 2), where filmed visitor portraits appear as avatars in the CG field. Similarly, Ken Feingold's ongoing erena project, *Seance box no.1*, designed to exploit the theatrical skidding and discrepancies between different, variously mediated media (human actors performing live at the physical installation site, physical robot-puppet being driven via the internet, avatars integrated into the digital image field, etc), uses live video feed of the audience to ensure this grist of immediacy, with its unique affective overtones.

Beyond strictly artist-driven projects, this technique has also been used in the i3 context for entertainment experiments in inhabited television such as *Heaven and Hell Live* and *Out Of This World*, and is drawing increasing interest in the realm of teleconferencing, where video-derived avatars of participants are integrated into a predefined virtual set. Visuals gleaned from real film or scans, however crude their quality, seem to convey an instant recognisability, and be loaded with powerful affective connotations lacking in strictly computer-generated imagery. In the section dealing with Blast Theory's rain curtain (cf. infra, chapter 5), integration of a "live" television set into projected computer graphics bears out the same principle: even within the homogenising setting of the digital display, this embedded element has a clear, specific impact, contrasting starkly with the heavily outlined, wire-frame furniture, the photorealistic landscape picture affixed to the wall, and glimpses of the highly stylised outside desert. All these displayed elements manifest their own dimensionality and demarcate quite visible terrain within the overall digital image field.

To conclude, multidisciplinary analysis of various types of boundary properties, in performance, in "real-life" ergonomics (e.g. office situations, as described below in section 4), and in developing CVEs, would seem to constitute particularly valuable input for the design of new kinds of virtual social space. The following section builds on these ideas by revisiting the basic mixed reality boundary mechanism from section 2 and extending it to consider the range of properties that mixed reality boundaries might have and the ways in which multiple boundaries might be used to create tessellated mixed realities. As part of this work we introduce a general taxonomy of boundaries based upon a classification of their properties. We argue that this taxonomy might serve as an analytic tool for the design of mixed reality environments.

4. Extending mixed reality boundaries – properties and tessellation

This section introduces two key extensions to the technology of mixed reality boundaries as described in section 1. The first, described in section 4.1, is to identify a set of general properties of mixed reality boundaries that might allow them to be configured to support different social situations, including different styles of performance. The second is the idea of using multiple mixed reality boundaries to join together many different physical and virtual spaces into an integrated whole. In each case, the concepts are further explained through a series of demonstrators, in the domains of performance and more general co–operative work.

4.1. The properties of mixed reality boundaries

We propose that mixed reality boundaries might be designed and analysed in terms of a set of generic properties. Our proposed properties are grouped into three general categories: *permeability*, properties that define how information passes through a boundary; *situation*, the spatial properties of the boundary; and *dynamics*, the temporal properties of the boundary. We also introduce the meta–properties of *symmetry* and *representation* that apply to the other properties.

4.1.1. Permeability

Permeability describes how the boundary affects sensory information passing between the linked spaces. We break down permeability into visibility, audibility and solidity, based on the three primary types of information that can pass through the boundary. Our discussion focuses on vision, sound and touch because most current interfaces between the physical and the virtual are based on a combination of these. However, we note that smell and taste information might also be "transmitted" through mixed reality boundaries in the future.

Visibility – considers what visual information is permitted through the boundary and consists of two components: visual resolution and field of view. Visual resolution concerns the amount of visual information obtained through the boundary and is affected by factors such as the resolution of capture and display technologies and graphical level of detail. Field of view describes the volume of the connected space that is made visible through the boundary and is determined by factors such as the field of view/projection of (physical and virtual) cameras and projectors.

Audibility – considers what audio information is permitted through the boundary and is determined by factors such as the positioning and sensitivity of microphones as well as sampling rates.

Drawing on previous work on virtual boundaries and crowd representations (Benford, 1997a), we propose that visibility and audibility can be further described in terms of the combination of four effects:

- *attenuation* – for example, reducing video resolution or audio volume;

- *amplification* – for example, projecting audio in the manner of a public address system;
- *transformation* – for example, distorting audio and video to establish anonymity; and
- *aggregation* – summarising what lies beyond the boundary. For example, showing only the number of remote participants instead of each individual.

Solidity – refers to the ability to traverse the boundary. This includes metaphorically extending a limb through the boundary to manipulate or feel a remote object; pushing an object through the boundary so that it becomes available on the other side; and stepping through the boundary and assuming control of an avatar or physical proxy on the other side. Strictly speaking, this last case establishes a second mobile boundary between the spaces (see below) as the participant may not actually leave their local physical space behind. However, metaphorically, there is a sense of stepping through the boundary.

Traversal from the physical to the virtual can be realised using 3–D interaction devices and tracking technologies to manipulate virtual objects that appear on a projected display or to track local physical objects and update their virtual counterparts. Allowing the user to sense virtual objects is achieved through haptic devices such as those described by Fogg (1998) and Colwell (1998). Traversal from the virtual to the physical involves remote control of physical proxies such as mobile cameras and robots as in the *GestureCam* system (Kuzuoka, 1995)). Digital documents can be pushed through the boundary by projecting them onto a desktop in the manner of the *Digital Desk* (Wellner, 1993) or by placing them directly on the boundary itself in the style of *Clearboard* (Ishii, 1992).

The potential for combining different visibility and audibility effects with varying degrees of solidity allows the definition of a wide range of boundary types. These include analogies of familiar everyday physical boundaries such as windows, walls, curtains, fences, one–way mirrors and even lines on the ground, as well as new kinds of boundary that have no common physical counterpart. Furthermore, a systematic exploration of all possible combinations of visibility, audibility and solidity might identify the fundamental building materials that can be used to join together physical and virtual spaces.

4.1.2. Situation

Situation concerns the spatial relationships between the mixed reality boundary, the physical and virtual spaces that it connects and the participants and objects that these contain. This includes the location of the boundary, whether this location is fixed, whether the boundary is segmented and the extent to which it joins the two spaces in a spatially consistent way. Between them, these properties determine the spatial understanding that the participants in one space have of the connected space.

Location – describes the placement of the boundary within the connected spaces. A vertical location involving projection onto a physical wall or screen or texturing onto a virtual wall or screen will establish the boundary as a window between the two spaces. Given a large enough display, the remote space might even be presented as a direct extension of the local space. A horizontal location involving projection onto a physical or virtual desk or board will establish the boundary as a shared drawing surface. The use of ambient display media as proposed in (Ishii, 1997), could establish a more peripheral connection between the spaces.

Alignment – concerns the orientation of the boundary with respect to the different participants and objects and may establish different possibilities for turn taking and access to other participants. For example, the triangular alignment of figure 5 allows a physical performer to simultaneously address a physical and a virtual audience while allowing the two audiences to address one another.

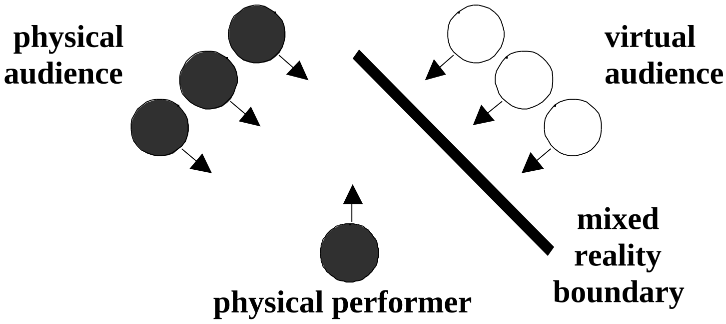

Figure 5: a triangular boundary alignment

Mobility – describes whether the boundary assumes a static situation, thus offering connection between two fixed sections of the linked spaces, or whether the boundary can join different parts of the spaces over time. A mobile boundary is one that the participants can steer through the linked spaces or which follows a pre–programmed trajectory. In practical terms, mobility requires that the boundary components (e.g., physical or virtual cameras and microphones) can themselves be moved. There can be various restrictions on the movement of the boundary. For example, participants may only be able to rotate the boundary around a fixed point without translating its position.

Segmentation – a boundary can be segmented in terms of its properties and spatial location. The former refers to when a boundary is made up of one or more segments with distinct property sets. A spatially segmented boundary, on the other hand, links the two spaces through multiple non–adjacent segments (these can themselves be property segmented).

Spatial consistency – describes how the spatial co–ordinate system of one space is related to that of the other. More specifically, it concerns the extent to which the connected spaces provide a unified frame of reference across which position, distance, orientation and perspective are consistent. This establishes the level of detail to which participants on opposite sides can establish mutual orientation, a reciprocity of perspective and can use spatial language and gesture.

There are two problems in establishing detailed spatial consistency. First, the use of a single fixed camera (physical or virtual) on any side will only provide an accurate perspective from one viewing position. A participant may move along the boundary or change their viewing angle, but will still retain the same view of the connected space. The use of multiple cameras, mobile cameras and even stereo cameras may overcome this problem to some degree, but only for one participant at a time. Second, it may be necessary to locate audio information in a spatially consistent manner. This may require the use of multiple or mobile microphones and spatialised audio rendering.

Combining these situation properties with the permeability properties described previously, defines the regions of each space that are public (i.e., accessible from the connected space) versus those that remain private to each space (i.e., are out of camera shot or microphone range).

4.1.3. Dynamics

Dynamics concern the temporal properties of the boundary, including its lifetime and its degree of configurability.

Lifetime – refers to when and for how long the boundary is in existence. Boundaries may be scheduled to appear at specific, even periodic, times to support the pre–planned nature of many activities (e.g., performances and meetings) or may be created on the fly. The potential duration of a boundary can be considered in the light of previous research into media spaces that distinguished different services ranging from persistent “office share” connections through to short–term “glance” facilities lasting for just a few seconds (Gaver, 1992).

Configurability – describes how dynamically the various boundary properties can be changed. Permeability might be adjusted in order to reflect changing privacy requirements. Configuring situation involves being able to move cameras and projectors and re–positioning furniture and other aspects of the connected spaces, for example in order to accommodate new participants. Finally, dynamic properties such as lifetime might also be directly configurable.

So far, we have established the fundamental boundary properties of permeability, situation and dynamics. We now discuss the two meta–properties of symmetry and representation that relate to each of these.

4.1.4. Symmetry

Symmetry refers to the extent that the properties of a mixed reality boundary are configured to be the same on both of its sides (i.e., from the physical to the virtual and vice versa). A degree of asymmetry may often be imposed as a result of the technologies used (e.g., where cameras and projectors differ in the their field of view). In other cases, it may be desirable to deliberately create asymmetric boundaries in order to meet a specific communication need (e.g., using a one way boundary to unobtrusively observe activity). Mixed reality boundaries may be asymmetric with respect to permeability, situation and dynamics.

Asymmetry introduces an additional dimension to the configurability of boundaries. We propose that participants should be able to configure their own side of the boundary and also set limits on the potential configuration of the other side as it affects them. For example, a participant may wish to set an upper limit on what the other side can see of them. To generalise, each control for configuring a boundary property might combine the ability to set the property in one direction and limit the property in the reverse direction.

4.1.5. Representation

Mixed reality boundaries are potentially complex technologies that may take many different forms. We argue that, in order to successfully use a boundary, participants will need to understand both the current and potential settings of its properties. In other words, the properties of mixed reality boundaries should be made visible (and possibly audible), be it explicitly through controls and labels, or implicitly through metaphor, interior design or architecture.

Considering permeability, a boundary should indicate the current and potential settings for visibility, audibility and solidity at each side. Considering situation, the separation of public from private space should be clearly marked so that participants know how to position themselves in order to communicate or avoid those on the other side. For example, the view frustra of physical and virtual cameras could be made explicitly visible by marking them on the floor. Considering dynamics, participants might be notified in advance when a boundary is going to appear or disappear so as they may adjust their behaviour and/or appearance appropriately.

This concludes our introduction to the properties of mixed reality boundaries. The following sections present two demonstrations of how these properties might be configured to meet different application requirements. The first is a performance in which a performer on a virtual stage engages an audience in a physical theatre through a mixed reality boundary. The second looks beyond performance to consider an “office door” that establishes an open connection between a public virtual world and a private physical office. This necessitates the management of virtual visitors in relation to local physical activity, especially with regard to shifting privacy requirements.

For each demonstration we state its goals, describe its design and offer some initial reflections. We then compare the two in terms of the property configurations of their boundaries.

4.1.6. First Demonstration – a Mixed Reality Performance

Our performance demonstrator extends our previous experience of staging a poetry performance simultaneously in physical and virtual theatres as reported in (Benford, Greenhalgh, Snowdon and Bullock, 1997). This previous attempt involved poets performing in a conventional physical theatre and at the same time, appearing as avatars on a virtual stage in front of an on–line audience in a virtual environment. A view of the virtual environment was then projected as back drop to the physical stage. A key observation from this previous performance is that the event became fragmented into two parts – a conventional performance and a social–chat virtual environment. We have argued in (Benford, Greenhalgh, Snowdon and Bullock, 1997) that the nature of the projection of the virtual space into the theatre may have been a key factor in these problems. In particular:

- the projection created a one way boundary between the two spaces – the physical audience and performer could see their virtual counterparts, but not vice versa;
- for aesthetic reasons, the projection was rendered from a moving viewpoint. Consequently, there was no stable spatial relationship between the two spaces and it would have been difficult for the participants in the physical theatre to establish any consistent reference or orientation to those in the virtual theatre.

The current demonstrator has therefore focused on the issue of whether effective social engagement can be established between real and virtual theatres. In this case, the performer, a poet, appeared on a virtual stage and attempted to engage the attention of an audience who were located in a remote physical theatre. The poet attempted to persuade the audience to join in the performance by answering questions, standing up and chanting as part of an improvised poem – essentially a test of whether they could exert sufficient social pressure on the audience. A key design goal was therefore that the boundary should be as invisible as possible, especially to the audience. Specific differences to the previous performance were that:

- the physical and virtual worlds were linked through a mixed reality boundary that allowed the audience to see and hear the virtual poet and vice versa;
- the boundary had a fixed spatial location with the intention that the virtual stage would appear to the audience as a conventional physical stage would;
- the poet was physically separated from the audience and was immersed in the CVE using a head–mounted display. As a result, their only option for communicating with the audience was via the mixed reality boundary.

Technical Realisation of the Performance

Figure 6 summarises the realisation of the performance.

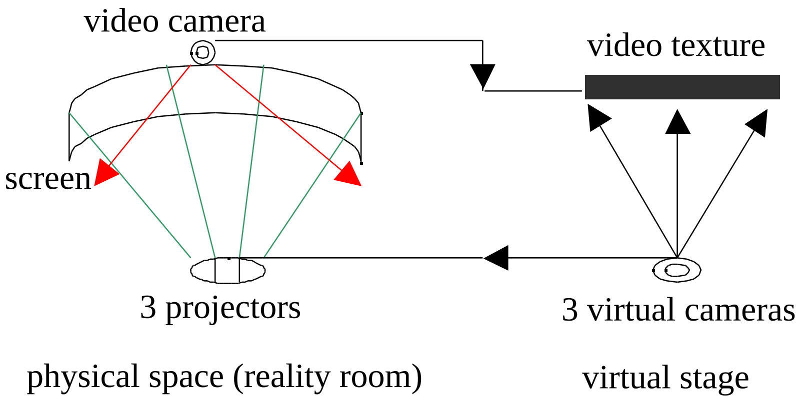

Figure 6: the design of the mixed reality performance

The physical audience were located in a Reality Room, a facility that allows the output of a high–performance computer (Silicon Graphics Infinite Reality Engine) to be projected onto a wide angle curved screen (using three separate projectors whose output is blended together). The poet was located in a separate physical room and used an Eyegen 3 head–mounted display to become immersed in the virtual stage. Their view of the virtual stage included a video texture looking back out into the audience space taken from a video camera mounted at the top and centre of the projection screen. A separate analogue circuit provided an audio link between the two spaces. By positioning a microphone in the audience space at the focal point of the curved screen we could easily pick up any noise made by the physical audience, a useful additional feature of placing a curved screen in a shared space. Finally, in order to introduce an extra element to the performance, an additional virtual actor was able to enter the virtual stage using a workstation that was located in the audience space.

Experience from the Performance

Our initial performance lasted for half an hour and involved one of the poets from the previous performance (Dave “stickman” Higgins). The stage and poet’s avatar were designed by the artist Derek Richards who also joined in the end of the performance as a supplementary actor. The performance began with the virtual poet entering from the wings and improvising a poem while the audience watched. After five minutes the poet directly addressed the audience for the first time, requesting that they stand up and asking them a series of questions. After picking on several other individuals in the audience, he then persuaded them all to rise and to clap and chant along with the poem. Figure 7 is taken from the audience space and shows the poet avatar on the virtual stage addressing an audience member.

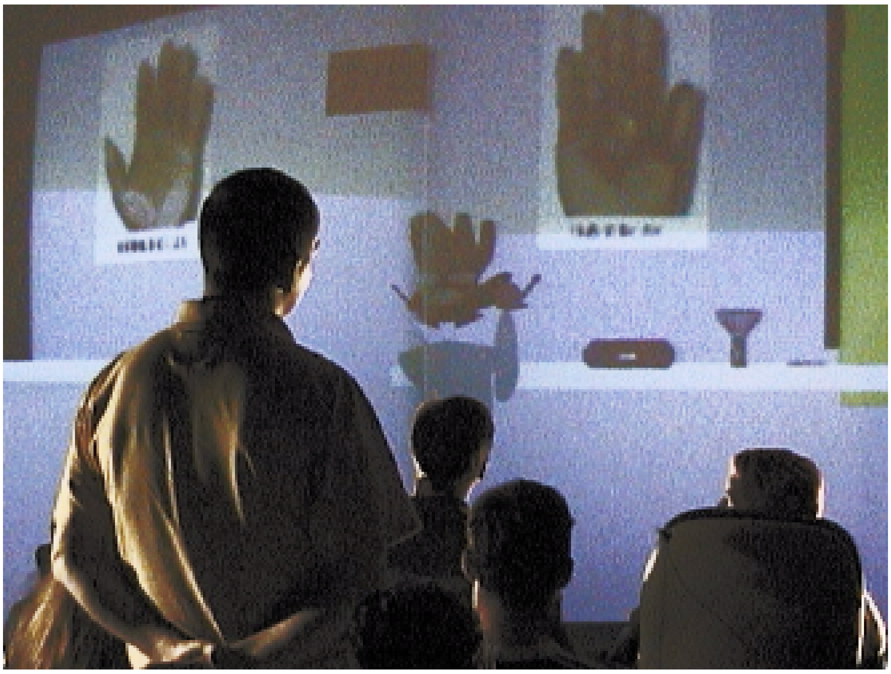

Figure 7: the poet interrogates an audience member

This initial test suggested to us that the poet was able to engage the audience to some degree. They did respond to his requests, although on some occasions (e.g., on first asking them all to stand up) this took several attempts, emphasising the importance of visibility through the boundary (it was clear that he could see when they had not responded to his request). The resolution of the textured video made it impossible for the poet to pick out details such as facial expression, but he was able to pick out gross physical features such as clothing and to spot large gestures. There were several problems with the performance, especially with the poet becoming disorientated. However, we argue that this simple test demonstrated a level of engagement between the real and virtual that was not achieved in our earlier performance.

In some ways, these observations reflect the current successful use of virtual actors to engage physical audiences through large screens at entertainment events and installations, see for example, (SimGraphics, 1999). However, in these events the human actor typically adopts an out of body view and sees the remote audience on a separate video monitor. Our experiment involved full–immersion with a textured video view of the remote audience being presented as a window in the virtual world.

4.1.7. Second Demonstration – the ”Office Door“

Our second demonstration moves outside of the domain of performance in order to demonstrate how the notion of boundary properties might be useful for the design of more general mixed reality applications. This demonstration is called the office door. Its aim is to connect a private physical office to a public virtual corridor to enable remote visitors to drop by over a computer network. This has been inspired by previous work on media–spaces that introduced the ideas of “glancing” into remote offices and establishing long–term “office–share” relationships (Gaver, 1992). However, in this case, one of the connected spaces is a collaborative virtual environment. An important aspect of this demonstrator is that, in contrast to the performance, it raises the issues of dynamically managing and representing availability and privacy when using open and persistent mixed reality boundaries.

Technical realisation of the office door

To create the office door boundary, we have projected a view of a virtual corridor onto the wall of a private office. At the same time, we have texture mapped the reverse video view of the office into the virtual corridor. By using a workstation on their desk, the occupant of the office can also step into the corridor, taking on the form of an avatar. Thus, the physical side of the boundary is not solid. Two potential views of the corridor are therefore available to the occupants, a permanent view looking out of their office (wall projection) and sometimes a mobile view from within the virtual corridor (using a workstation).

We have extended the basic mixed reality boundary design to offer varying degrees of visibility and audibility. On the virtual side, the volume of audio from the physical can be adjusted as can the resolution of video (down to no audibility or visibility). On the physical side, audio volume can also be adjusted as can the level of detail of the graphical view of the virtual corridor. For the latter, the current demonstrator supports four levels of detail: no visual information, an aggregate count of how many people are beyond the boundary, indication of the positions of these people (they are represented as simple blocks) and finally a full view of individual avatars. These levels of audibility and visibility are directly configurable at each side of the boundary through a series of interface controls that also indicate their current settings. Specifically:

- each side of the boundary provides a control for setting and indicating the visibility of the other side. A parallel control is provided for audibility.
- each side of the boundary provides a separate control for limiting the maximum visibility of this side to the other. Using this control, participants can set an upper limit on how visible they wish to be, including reducing their visibility to zero. A parallel control is provided for audio.

By using these controls, participants can dynamically negotiate degrees of privacy. It is important to note that levels of visibility and audibility need not be symmetric across the boundary.

Figure 8 offers a screenshot of these controls as seen from the virtual corridor. The two sliders at the side of the video texture set the desired audibility and visibility of the other side. The two sliders above the texture limit the ability of the other side to see and hear this side. We can see two avatars in the virtual corridor looking into the physical office and one person looking back at them. The part of the corridor that is visible from the physical office is shaded a different colour to the part that is not (although this is difficult to see in the greyscale image).

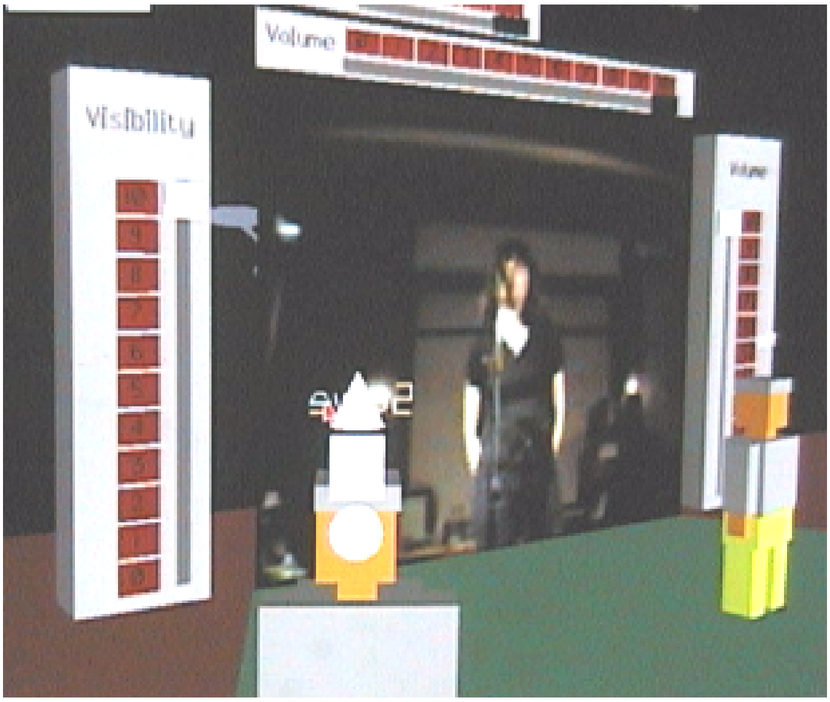

Figure 8: Controls for visibility and audibility

Experience of the Office Door

We installed the office door boundary in two offices within our laboratory, one that was shared by four researchers and a second that was the private office of our laboratory manager. The boundary was established as an open–connection between these spaces and the virtual corridor. It was also used during regular weekly laboratory meetings. The latter involved three or four members of the laboratory attending these meetings remotely and appearing in the virtual corridor, with the remaining participants (between five and eight) being physically present in the office. For the shared office, the boundary was placed diagonally across a corner of the room so that the participants could arrange themselves in a circle when seated. For the private office, it was placed at the end of an existing meeting table.

Our initial reflections have raised a number of issues for further exploration. First, although virtual visitors appeared visually on a large projection and could be heard as soon as they spoke, the silent nature of movement in the virtual corridor was potentially disconcerting for those in the physical space. Sensing presence and movement near the boundary and indicating these through additional audio cues may prove useful, especially on the virtual side of the boundary. Second, several different avatars were tested for the virtual visitors. Those featuring a live video face seemed best suited to this particular application, perhaps because they offered a degree of symmetry in terms of providing a reverse video view back into their user's own physical space. In particular, they would make it possible for occupants of a physical office to tell when several remote people were looking at them through a single shared avatar. Third, the circular arrangement of participants worked adequately for the laboratory meetings. Participants in the virtual space claimed that, at least some of the time, they could tell when they were being looked at and could identify individuals in the physical space (although, unlike the performance, the participants knew each other well). We suspect that swapping turns across the boundary as opposed to our usual progression around the circle may have promoted communication between the physical and virtual spaces.

4.1.8. Analysing the demonstrators in terms of boundary properties

We conclude our presentation of the two boundary demonstrations by directly comparing and discussing their properties. Our aim is to show how their different configurations reflect their intended uses. The table below summarises this comparison.

We begin with permeability. Visibility and audibility were fixed for the performance boundary with the aim of achieving the best possible visual and audio experience for both sides. In contrast, they were defined to be dynamically configurable for the office door boundary, allowing the participants to select a configuration best suited to their current requirements for awareness and privacy. In terms of solidity, both demonstrators allow one person to metaphorically step through the boundary from the physical to the virtual by controlling an avatar. In both cases, the boundaries were solid from the virtual to physical, due to a lack of locally available tele–presence technology (e.g., remote controlled robots).

There were also differences between the two boundaries in terms of their situation properties, especially alignment and location. With the performance, the aim was to link the whole physical room with all of its audience members to the virtual stage, making the two spaces appear to be direct extensions of each other. In other words, the boundary was intended to be as transparent as possible. This was facilitated by the use of a wide screen projection facility housed in a purpose built room. Indeed, a key element of the performance was the moment of surprise when it was revealed that the performer could actually see the audience through the projection screen! In contrast, an important aspect of the office door alignment was the desire to deliberately keep one area of the office out of view of the boundary so as to retain a private area. The office door alignment was also limited by the physical shapes of the existing offices. This severely constrained the location of screens and projectors.

Property	Performance		Office door	
	Virtual	Physical	Virtual	Physical
Visual resolution	Video resolution 120 x 120 pixels	Projector resolution 3556 x 1024 pixels	Configurable video resolution from 120 x 120 to 0 x 0 pixels	configurable graphical level of detail (4 levels)
Field of view	60°	175°	60°	65°
Audibility	Amplified		Variable – volume can be adjusted at both sides	
Solidity	Solid	one person can step through	Solid	one person can step through
Location	Vertical – establishes boundary as window	Vertical – establishes boundary as extension of space	Vertical – establishes boundary as window	

Alignment	Facing seats	Facing stage	Into part of office	onto corridor
Mobility	Static		Static	
Segmentation	Property segmented		Not segmented	
Spatial consistency	Horizontal and near vertical	Horizontal and vertical	Horizontal and near vertical	Horizontal and vertical
Lifetime	half hour		Persistent	
Configurability	None		Visibility, audibility	

Considering spatial consistency, there was slight vertical misalignment at the virtual side of the boundary in both demonstrators. This is due to the video camera being located at the top of the projection screen for the performance and at the bottom for the office door as opposed to at its vertical midpoint.

Positioning the camera at the vertical midpoint behind the projection would have been ideal, but would have required a special screen that was transparent from the rear. In both cases, the correct alignment was achieved at the virtual side because the video texture was defined to be a one sided polygon through which the virtual camera could see.

The performance boundary raises an additional issue, that of property segmentation. As the table shows, there is a difference between the field of view offered by the projection (175 degrees) and by the video texture (60 degrees). In effect, this created a property segmented boundary consisting of a central segment which was roughly symmetrical with respect to visibility and audibility and two outer segments that were asymmetric (the audience could see the performer, but there was no reverse video texture by which the performer could see them). This segmentation was an accidental side–effect of the locally available camera and projection technologies. However, it could have had significant effects on social interaction, as it created areas of the boundary that were in effect one–way mirrors. We anticipate that such situations might arise regularly where boundaries exploit existing local facilities. Furthermore, we propose that our boundary properties provide a useful analytic framework for predicting when such accidental effects are likely to occur.

A key difference between the two boundaries concerns their dynamics. In the case of the performance, the boundary was created at a specific time for a pre–planned event, it had a set duration and its properties remained static throughout its lifetime. The office door boundary, on the other hand, had an open–ended lifetime. The connection of a public space to a private space in which different activities could occur (including private consultations), necessitated the dynamically configurable nature of the boundary as was realised through the controls mentioned above.

Considering their symmetry, the performance boundary was intended to be symmetrical and any asymmetries were side effects of the technologies that were used. In contrast, the potential for asymmetry was deliberately designed into the office door. For example, the occupant of the office might have closed down their side of the boundary during a private meeting while retaining a view into the virtual corridor to see if any potential visitors were waiting.

Finally, issues of representation of properties were particularly significant with the office door due to its configurability (i.e., it was necessary to convey the current and potential state of both sides of the boundary) and also due to the need to mark the distinction between public and private space. In contrast, the intended transparency of the performance boundary led to its properties not being directly represented.

In summary, we have presented two contrasting demonstrations of mixed reality boundaries that exploit different configurations of boundary properties in order to achieve their goals. The performance seeks to establish from scratch a boundary that is invisible to its users and that exists for a fixed period of time. In contrast, the office door requires that the boundary be integrated in an existing working environment and so must be visible, understandable and configurable. A further key point concerns the way in which purely technological factors (such as differences in the field of view of available cameras and projection equipment) can result in accidental asymmetries and segmentation of boundaries. We argue that our notion of boundary properties provides a framework for understanding when these might occur and how they might affect participants.

4.2. Tesselating boundaries

This section introduces our second major extension to the basic mechanism of mixed reality boundaries – the idea that multiple boundaries might be used to join together many different physical and virtual spaces into a larger integrated structure called a tessellated mixed reality. We propose that this ability to join together many spaces is a powerful and distinguishing feature of the boundary–based approach to mixed reality.

The idea of using technology to join many spaces together is a familiar one. In the case where all of the spaces are physical, the result would be a form of media space. In the case where they were all virtual, the result would be a collaborative virtual environment that was structured as a set of regions (as many CVEs are). The hybrid case where some spaces are physical and some are virtual, however, raises some interesting new possibilities and leads to the idea of tessellated mixed realities.

From the point of view of a virtual space, different video views could be texture mapped into different locations. For example, a new form of navigable 3–D media space might be created by linking several video views into a navigable synthetic corridor (i.e., one could navigate through a 3–D structure in order to access different video views into people's physical offices). We shall demonstrate this example later in this section. Alternatively, a single synthetic space such as an information visualisation might be used as a central linking point for several physical spaces. A team of distributed software engineers might link their offices through a common visualisation of a software structure or a series of separate Air Traffic Control Rooms might be linked through a common 3–D visualisation of air–space.

These possibilities are briefly summarised in figure 9, where 9 (a) shows the possible use of a 3–D corridor in a media space and figure 9 (b) shows the use of a shared 3–D visualisation to link physical control rooms.

From the point of view of a physical space, multiple linkages might involve locating different boundaries on different surfaces of a room. In this case, a new form of navigation might be achieved by dynamically switching some of these views to portray new scenes.

Given a consistently defined overall topology of tessellated cells linked by mixed reality boundaries, a local physical room could become a vehicle to be navigated through a tessellated mixed reality. Figure 10 depicts a mixed reality constructed from square cells, each of which is linked to its neighbours by an appropriate mixed reality boundary. A physical room might logically be located in any one of these cells and given an orientation. This would determine the projected views to be shown on each of its four walls. Thus, in figure 10, the user's physical room (vehicle) is currently located in cell E, facing cell A, thereby causing views into cells A, B, C and D to be projected onto its walls.

The ability to occupy a given cell would be subject to various constraints, such as there being a match between the properties of the boundaries of the cell and the available equipment within the particular room.

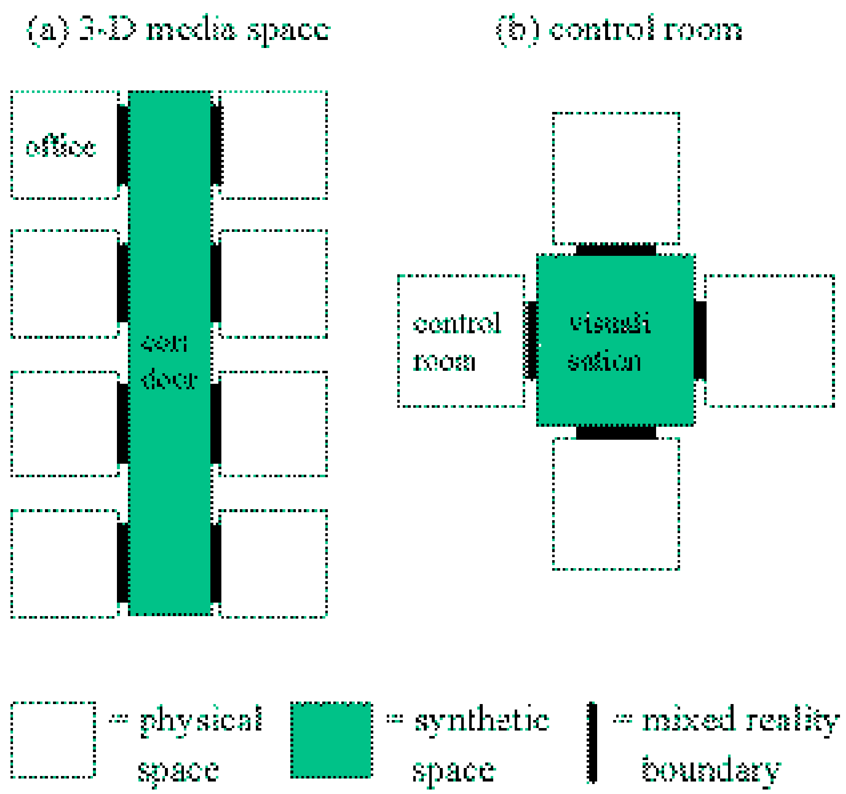

Figure 9: Synthetic spaces linking multiple physical spaces

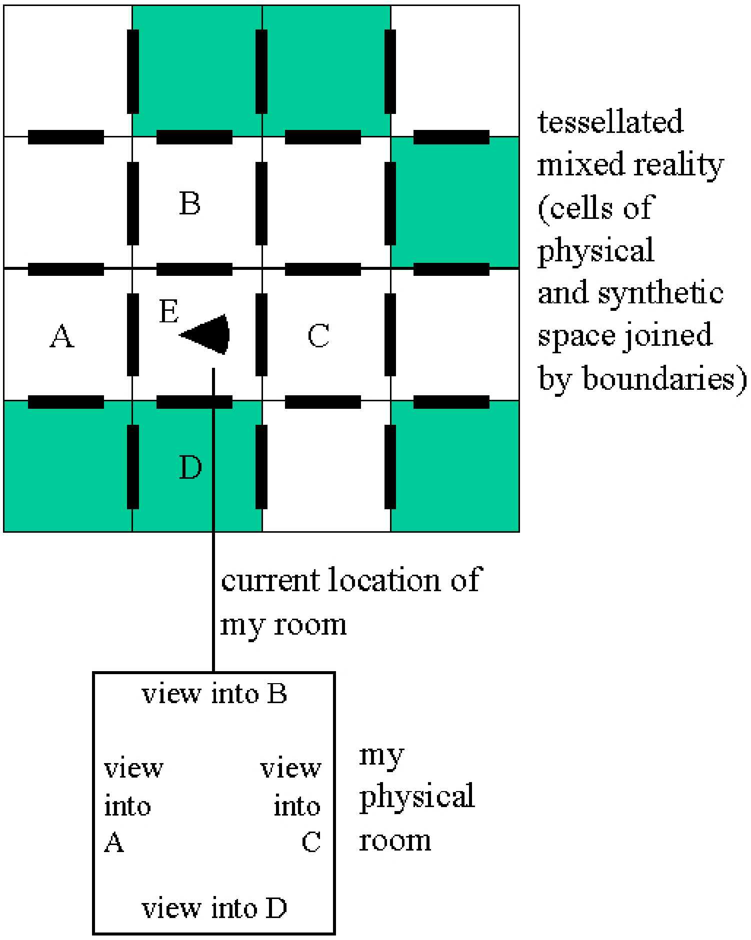

Figure 10: using a physical room as a vehicle to move through a tessellated mixed reality

Given that a room can occupy a cell, it may be possible to move the room through the overall structure. For example, the room in cell E might be moved into one of the adjacent cells A, B, C or D; might be rotated to face another cell; might take a guided tour through several cells; or might jump to some other location altogether. We propose that these ideas of structured and tessellated mixed realities open up new possibilities for a general merging of the physical and synthetic worlds and represent a key direction for future research into mixed realities.

Whatever the design, the net result is a structured environment of inter–linked physical and virtual spaces. In terms of performance, such an environment might be used to take an audience on a journey through multiple layers or scenes of physical and digital information, an idea that we shall return to later in this deliverable. In the meantime, we demonstrate the idea of a tessellated mixed reality through a more conventional example that directly extends the office door demonstrator from the previous section – a 3–D media space.

4.2.1. Third demonstrator – 3–D media space

Our demonstration of tessellated mixed reality combines the functions of traditional conferencing tools with those of media spaces. The result is an integrated environment that supports personal communication between multiple participants as well as general awareness of the presence and activities of others in both the virtual environment and in local physical environments.

The starting point of the application is an office–door as described above, a persistent mixed reality boundary that joins a physical office to a collaborative virtual environment. We extend this scenario by allowing multiple physical offices to be linked to a common virtual environment. Each physical office is mirrored by a virtual office in the virtual world and the virtual offices are arranged into a navigable 3–D structure, such as the circular configuration as shown in figure 11.

Two video windows, each showing the same overview of its owner's physical office, are texture mapped onto each virtual office. One is located on the roof and this offers what is termed a *porthole* style service – a low frame–rate video image that is intended only to give a general sense of the likely occupancy of the office. A user who levitates above the virtual offices and looks down (to obtain the viewpoint in figure 11) will therefore see the equivalent of a 2–D portholes style interface to a media space (Dourish and Bly, 1992). The second video window is located on the front of the virtual office. Most of the time this will also offer a porthole service that can be seen from ground level. However, when someone who is browsing the environment stands directly in front of this window and looks in, this is upgraded to a *glance* service – a medium frame–rate video window at one frame a second that is intended to give a general sense of on–going activity within the office. Thus, users can browse through the environment to obtain a general awareness of who is present in their physical offices or can approach a specific office for a more detailed look inside.

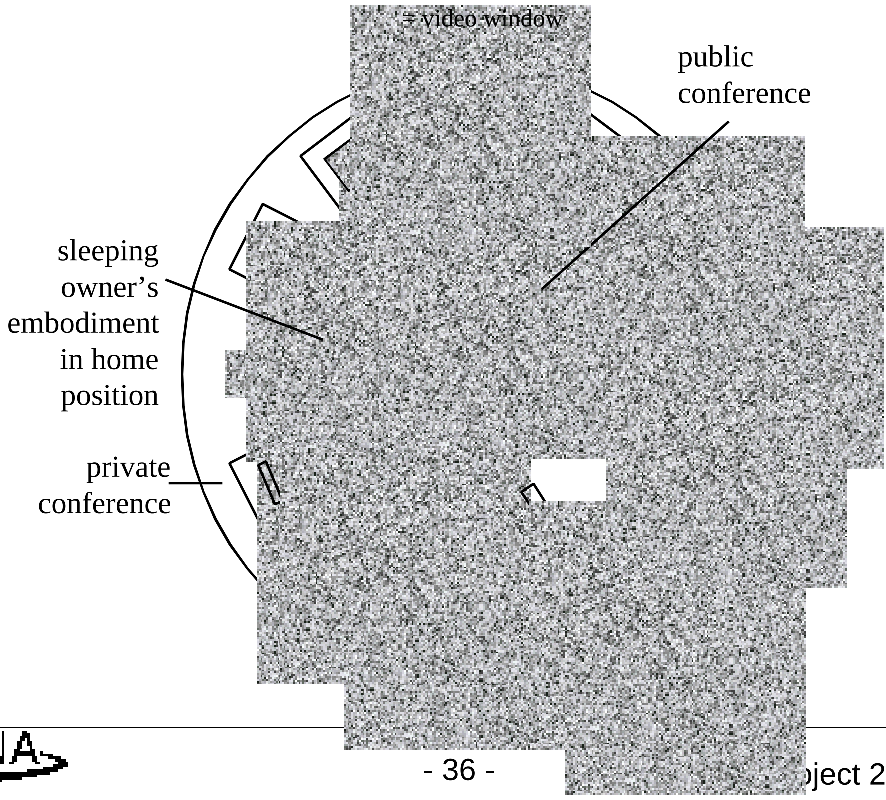

Figure 11: The structure of the virtual environment

Each occupant of the virtual environment is given a graphical embodiment that they move through the virtual world in order to look into different virtual offices or to meet and talk with other users (either by chance or by design). Each embodiment is also assigned a home position, directly in front of its owner's virtual office. Home positions are the default resting place for an embodiment when its owner is not actively browsing the media space or engaged in a private conversation inside their virtual office. When its owner is not even logged on to the application, the embodiment assumes a sleeping position to explicitly show their absence and all video views associated with that user can be switched off.

An important aspect of embodiments is that they enable mutuality of awareness. In particular, in order to glance into an office, a user must position their embodiment directly in front of it, making their action directly visible to the occupants of the office via the physical half of the associated mixed reality boundary. In other words, someone glancing into your office would appear as an avatar on the projected display on your office wall. We anticipate that this will result in social control over the use of glances, without the need for technical mechanisms to limit their availability (e.g. time–limited glancing or explicit notifications (Dourish, 1996)). Just as in the real world, where it could be impolite to hang around someone's open door for a long time without taking any further action, so it could be in the virtual world.

Figures 12 and 13 are screenshots from our application. Figure 12 shows four virtual offices, embodiments and associated video windows. Note the two sleeping embodiments, one whose owner is not logged in (in front of the unoccupied office) and the other whose owner is logged in but is not currently active. Figure 13 shows an embodiment glancing into a virtual office (note – we are looking at the back of their head) with another nearby embodiment facing us. Crossing the "glance line" on the floor activates the glance service.

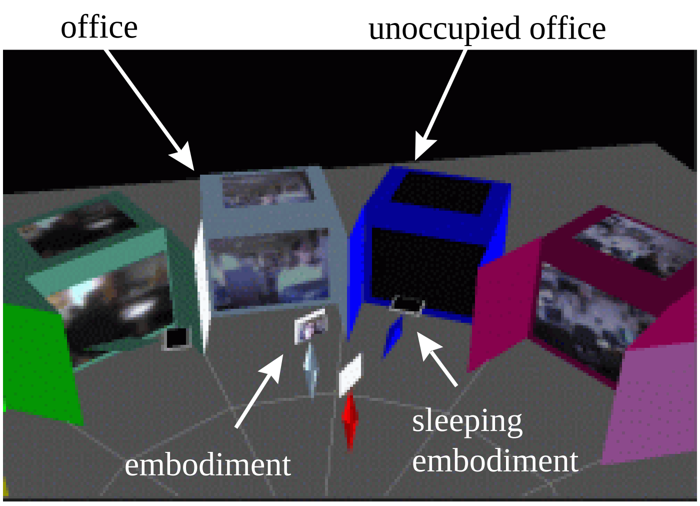

Figure 12: Four virtual offices and embodiments

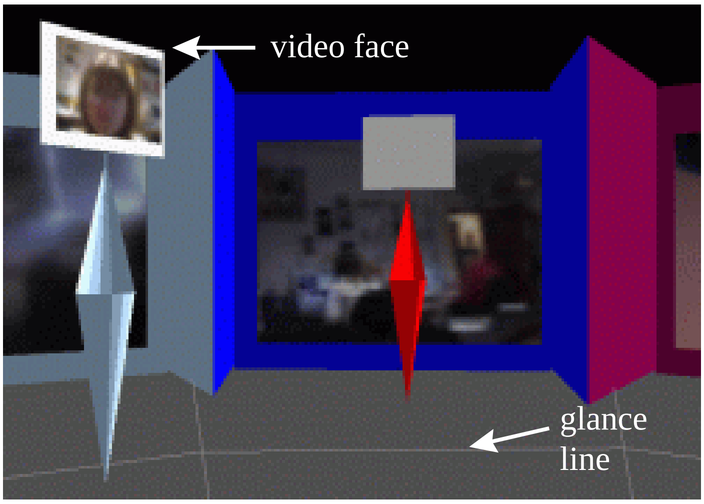

Figure 13: Glancing into a virtual office

In summary, the 3–D media space demonstrator presents a simple example of a tessellated mixed reality. In this case, multiple mixed reality boundaries are used to join together a number of physically separated rooms through a common shared virtual environment. Later in this deliverable we shall consider how this approach could be used to create new forms of performance space. However, before passing on, the following section undertakes a brief digression in order to reflect on some of the underlying software techniques that supported this demonstrator and that would be used in future examples.

Notes on the implementation of the 3–D media space

Our demonstrator makes use of the technique of awareness driven video QoS as previously described in eRENA deliverable 4.1. With this technique, participants movements in a shared virtual world are used to compute levels of mutual awareness which in turn, trigger different levels of video quality of service. Thus, by moving up to, turning towards or focussing hard on a video object, a participant could view it with a higher level of QoS. Before this, previous research into media spaces had proposed the idea of the *service* as the basic unit of interaction. For example, the *Goddard* interface to the RAVE media space introduced four main services: the *glance*, a time limited one way view into a physical office; the *v–phone*, a two way video phone call; an *office–share*, a long term connection between offices; and *background*, the equivalent of the view out of an office door or window (Dourish, 1993). To these can be added the *751porthole*s service which provided slowly updated frame–grabs from a camera in an office so as to promote background awareness of availability (Dourish, 1992).

Our design builds on this approach. We define three distinct levels of service: *porthole*, *glance,* and *communication*, which can be triggered by actions within the virtual world. In our interpretation, a porthole provides background awareness of activity; a glance provides a moderately detailed view of this activity; and communication is used for facial expressions on our avatars. In terms of QoS, these services are distinguished by their frame–rate. A porthole corresponds to one frame every five minutes; a glance to one frame a second; and communication to twenty or more frames a second. We have chosen frame–rate because it is relatively easy to manipulate, it has a major impact on underlying bandwidth and hence scalability; and it reflects privacy requirements in that a low–frame rate view provides some awareness of presence but without details of specific activities.

As described above, three video textures are associated with each occupant of the virtual world: the face on their embodiment and the front and roof of their virtual office. Spatial awareness is configured so that the roof can only ever display the porthole service and the front of the office can display the porthole or the glance service, with the latter only being enabled when the observer is standing directly in front of the office looking in. Faces, on the other hand, can be associated with all three video services: portholes for distant views, glances for close–up and communication for very close–up and face–to–face (so that an observer could only ever access one communication service at a time).

Table 2 summarises the different video services that are defined by our application, their uses, their relations to awareness, and their associated frame–rates.

	use	awareness	QoS
porthole	offices and faces	low	1 frame in 5 mins
glance	offices and faces	peripheral	1 frame a second
commun–ication	faces only	high	20 frames a second

Table 2: Conferencing/media space video service

Although full details of the implementation of our application are beyond the scope of this paper, we do offer a brief glimpse of how awareness driven video QoS is realised in the network before passing on.

Our application has been implemented using MASSIVE–2, a CVE application development platform. Like other recent CVEs, MASSIVE–2 utilises network multicasting to enhance scalability. Multicasting is a technique which allows a single message to be efficiently sent to any number of recipients such that the message never crosses any network link more than once (Deering, 1989). Video integration within MASSIVE–2 exploits network multicasting as follows. Each source of video is associated with its own separate multicast group for each level of video service that is offered for this particular application (three in our case). The source continually transmits video via all of these groups. A recipient of video (a sink) *automatically* joins the appropriate multicast group according to its current level of awareness of the source as determined by MASSIVE–2‘s implementation of the spatial model of interaction. Figure 14 shows how this operates between a single source and a single sink. The source is transmitting video to three multicast groups corresponding to our three levels of service. The sink currently has full awareness of the source and has joined the highest QoS group in order to receive video at the highest frame–rate. We can see that both the source and sink monitor local processing load and the volume of network traffic and adjust awareness accordingly.

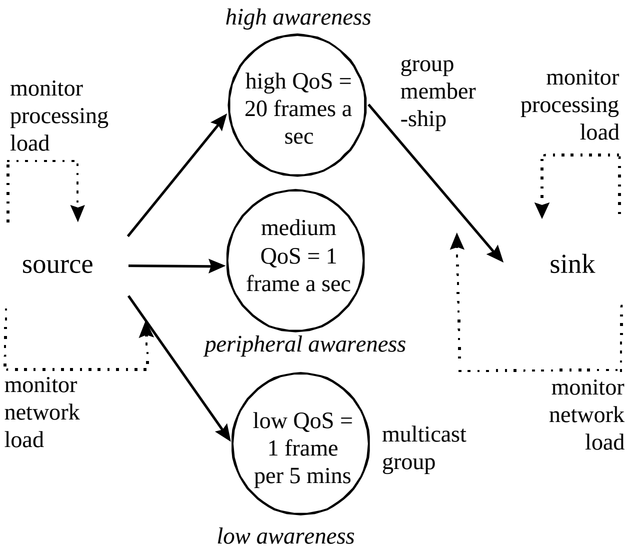

Figure 14: Multicast groups and different levels of QoS

4.3. Summary

This section has introduced two major extensions to the basic mechanism of mixed reality boundaries. The first of these has been to consider how an individual boundary might be defined in terms of the properties of permeability, situation, dynamics, symmetry and representation. The second has been to consider how multiple mixed reality boundaries might be used to create tessellated mixed realities. We have demonstrated these ideas through three demonstrations that include a performance as well as two more conventional applications for co–operative working. The next section of this deliverable describes how these ideas were carried forward in a workshop and experimental performance that was staged at the ZKM in January 1999.

5. An early practical experience and demonstration of using a permeable mixed reality boundary in a performance

During January 1999 a team of computer scientists, performers and social scientists spent a two week period at the ZKM experimenting with a rain curtain, a curtain of water into which images could be projected, as a mixed reality boundary to support performance. The broad objectives of the workshop were:

- to assess the potential and limitations of the rain curtain as a novel material for creating a mixed reality boundary. The rain curtain has a number of interesting properties, especially with regard to permeability, dynamics and symmetry.
- to assess the potential use of the rain curtain in creating performances that establish new relationships between performers and audience.
- to create a fully permeable mixed reality boundary, i.e., one that was not solid and through which performers, audience members and objects could pass. Our research to date had not created a mixed reality boundary that could be physically traversed.
- to develop an appropriate style of interaction with the rain curtain.

The workshop culminated in a full day of public demonstration followed by an evening panel discussion and feedback session. Our evaluation of the workshop as reported later on focussed on the following specific questions:

- What technical issues were raised by the demonstration, especially with regard to public interaction with the rain curtain technology?
- What work was involved in creating the demonstration, what technical options were explored on the way to the final demonstration and what everyday practical issues are involved in working with this technology?
- To what extent was our initial public demonstration of the rain curtain successful in artistic terms and why?

It should also be noted that the workshop has been the first step in creating a larger scale public performance that we intend to tour several cities in Europe in the autumn of 1999. The final performance will involve the coordinated use of several rain curtains by audience members as they undertake a journey through a collaborative virtual environment, interacting with the performers on the way. However, the initial workshop described in this section focused on interaction with a single rain curtain as part of a more limited experimental scenario.

In addition to ZKM, Nottingham and KTH as eRENA partners, the workshop also involved performers from the company Blast Theory. Blast Theory is a group of five inter–disciplinary artists based in London. Since 1991 the group has created theatre performances, installations, videos and new media works. A common thread running through almost all their work is the fusion of video, computers and live elements, often with some kind of interaction with the audience/visitor. For example, *Stampede* in 1994 used a system of pressure sensitive mats during a promenade performance to allow both audience and performers to trigger audio and video events. An ongoing focus on the siting and thus framing of their work has lead the group to use unusual spaces such as film studios, shopping centres and a bank for the presentation of their work. This approach has extended to making work specifically for night-clubs and a 45 second film which toured European cinemas in 1997.

The group has been recognised as being at the forefront of interdisciplinary practice within the UK and beyond. Their work has been shown at the Institute of Contemporary Art, at the South Bank Centre and at venues throughout Britain. In 1997 the group spent 9 months in residence at the Kunstlerhaus Bethanien in Berlin and since then Blast Theory has shown work in Amman, Utrecht, Hannover, Hildesheim among others.

In addition to their experience with new media performance, Blast Theory also introduced the technology of the rain curtain to the project. They had first begun experimenting with the rain curtain in 1997 while on a research placement funded by the Arts Council of England. During this time they met with researchers from Nottingham who were developing the mixed reality boundary approach described above and the idea of using the rain curtain as a boundary material was first borne.

Having introduced both Blast Theory and the goals of the workshop, the remainder of this section describes our experimental performance and the technology development behind it, beginning with an introduction to the rain curtain as a material for creating mixed reality boundaries in section 5.2. Following this section 5.3 describes the design and structure of the public demonstration and section 5.4 presents an initial evaluation from artistic, technical and social science perspectives. Finally, section 5.5 outlines our plans for moving forward to a full-scale public performance.

5.2. The rain curtain as a material for mixed reality boundaries

The term *rain curtain* refers to the projection screen used in the workshop. Each curtain uses four sprinkler heads mounted on a brass tube to deliver a fine sheet of water spray that is two to three metres high, two metres wide and approximately half a metre deep. The sprinkler heads used are designed for use in horticulture. The system used was developed by an irrigation specialist in the Netherlands. An image, for example an image of a collaborative virtual environment, can then be back projected into the curtain.

The boundary properties of the rain curtain

As a material for constructing mixed reality boundaries, the rain curtain has several interesting properties, especially with regard to its permeability.

Visibility – by adjusting the light levels on either side of the rain curtain its opacity/transparency can be varied allowing it to move the viewer from a high involvement to a low involvement in the projected image. At the same time, more or less detail of the physical space beyond the curtain becomes visible. Thus the curtain can overlay a projected image onto a physical scene with varying degrees of balance between the two.

Audibility – the rain curtain makes a gentle noise and so partially masks sound from the physical environment beyond it or from a virtual world if the latter is projected into the local environment.*Permeability* – the rain curtain is not physically solid so that it is possible to pass through it into the physical space beyond. Of course, the solidity of a mixed reality boundary as defined above refers to the ability to pass through it *from the physical to the virtual* or vice versa. However, the ability to step through the curtain and so disappear from the local physical environment, opens up the possibility of creating mixed reality boundaries that give the illusion of passage between physical and virtual space, an illusion that might be exploited in performances. For example, to appear as an avatar in a virtual world, one might have to step through the curtain in order to access the appropriate interface technology. Similarly, objects or people might be seen to materialise from the connected virtual environment into the local physical environment.

In terms of its situation, the current rain curtain requires a vertical location, is fixed in position and consists of a single segment. However, it can potentially be dynamically reshaped or moved. This could be achieved either by controlling the individual valves that combine to make the curtain or by physically obstructing a part of the falling water. For example, it would be possible to make holes in the curtain by by holding objects within the water flow or turning some nozzles off while leaving others on. A sophisticated spray system could add mobility to the curtain by projecting water in different directions under computer control. The alignment of the viewer to the boundary is significant as their position relative to the projector beyond the screen determines to a great extent the way in which they perceive the projected image in relation to the flow of the water itself or the physical environment beyond. Also, because the projector is placed behind the curtain and pointed at the viewer, the image cannot be seen from an angle.

The dynamics of the curtain are interesting, as it can be switched on and off, causing it to appear and disappear at will. Furthermore, it takes a short but noticeable period of time for the curtain to establish itself or die away. Finally, it should be possible to change the properties of the curtain either by adjusting the lighting on either side or by altering the rate of water flow or operation of the nozzles.

Another key feature of the rain curtain is its asymmetry. It is possible to project different images into different sides of the curtain without interference. This might be used to offer different views of a virtual environment at each side.

Finally, considering the property of representation, the rain curtain does naturally represent its presence or absence through the sound of the water spray.

The aesthetic qualities of the rain curtain

Beyond its properties as a mixed reality boundary, the rain curtain also has a number of key aesthetic qualities that make it an interesting medium for art and performance. In terms of interfacing with a screen it has a unique feel; one that incorporates an ethereal, elusive atmosphere in which the data projected onto it seems to be in constant motion as well as having a three dimensional quality. This clearly connects with ideas of elusiveness, intangibility and a world in which everything is shifting or dissolving. The depth of the water (approximately 0.5m) also gives a two dimensional image a disconcertingly three dimensional feel.

By allowing people or objects to pass through it, the curtain conjures ideas of travelling, entering/exiting and cleansing with an almost religious quality. It also holds an image in a very unusual way because the projector is placed behind the curtain and pointed at the viewer. The sensitivity of the curtain to viewing angle combined with the asymmetry noted above raises the idea that information shifts according to where one looks from.

The curtain also has interesting acoustic aesthetics. The system generates three distinct kinds of noise: a rapid 'whoosh' when starting up, a steady sound of falling spray during operation and a loud, intermittent dripping as it comes to rest which isolates the visitor in a cocoon of rain or white noise.

Finally the wetness of the curtain generates humidity and coolness providing a strong physical response to approaching it.

Summary

In summary, the rain curtain is an interesting material from which to build a mixed reality boundary due to its lack of solidity, its variable visual permeability, its dynamics and its asymmetry. In a broader sense, the rain curtain therefore allows us to experiment with a new class of mixed reality boundary. How we might realise a version of the rain curtain suitable for use in the home and workplace using dry technologies is considered later in this deliverable. In addition, the curtain has interesting aesthetic qualities that suit the development of interactive performance and art. These qualities might also make it suitable, even in its wet form, for use in public space (e.g., for displaying public information) or in entertainment (e.g., in rides).

5.3. A description of ”pushing mixed reality boundaries“

The section presents the overall design of our public demonstration, including the design of the virtual environment and also the physical infrastructure within which it was located and through which interaction was made possible. It should be remembered that this design is just one stage on the way to creating the final Virtual Rain performance, the plans for which are presented in the next section. The final performance will involve several simultaneous participants using multiple rain curtains to undertake a journey through a shared virtual environment during which they will interact with performers.

The first stage described here focused on testing the interface technology and took the form of a single–user experience involving a single rain curtain. Each participant was encouraged to navigate through a simple virtual environment consisting of a number of rooms and regions. This environment was displayed on a rain curtain that was located in a darkened and physically isolated environment. Navigation was via a footpad device and sounds from the world were heard over headphones. The main interaction with the performers occurred at the end of the experience when one of them stepped through the rain curtain in order to give the participant a physical object. However, the performers also spoke to participants via the headphones in order to assist them if they appeared to be experiencing difficulty.

5.3.1. World design

The virtual environment consisted of three main areas. The first was a reproduction of a American motel room, including a television set that displayed a fragment of CNN's gulf war coverage, presented as an embedded video and audio image. The walls of the motel room were solid and the only exit was through a door, leading to an undulating desert landscape. While in the desert area, music would be heard over the headphones. A large bunker could then be seen in the distance behind a semi–transparent fence. The participant could cross the fence in order to approach to bunker and enter it through a small door. Once inside they would encounter a large white screen. The act of facing the screen was the cue for a performer to approach the rain curtain from behind, appearing as a black shadow on the image of the virtual environment. They then crossed through the boundary, physically materializing in front of the audience member, and gave them a physical object. This event marked the end of the experience. Figures 15, 16 and 17 are taken from the virtual environment. Figure 15 shows a view from inside the motel room, looking out through the door and window to the desert beyond. Figure 16 shows a view from the desert of the fence and bunker beyond. Figure 17 shows a close up view of the bunker.

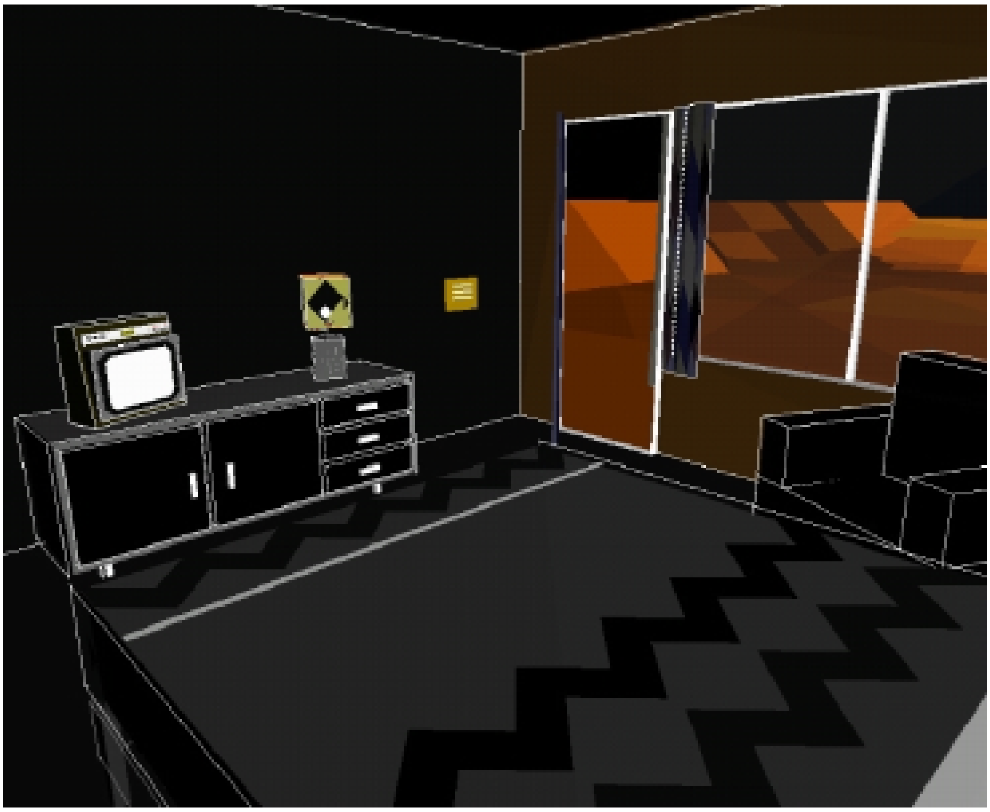

Figure 15: the view from inside the motel room

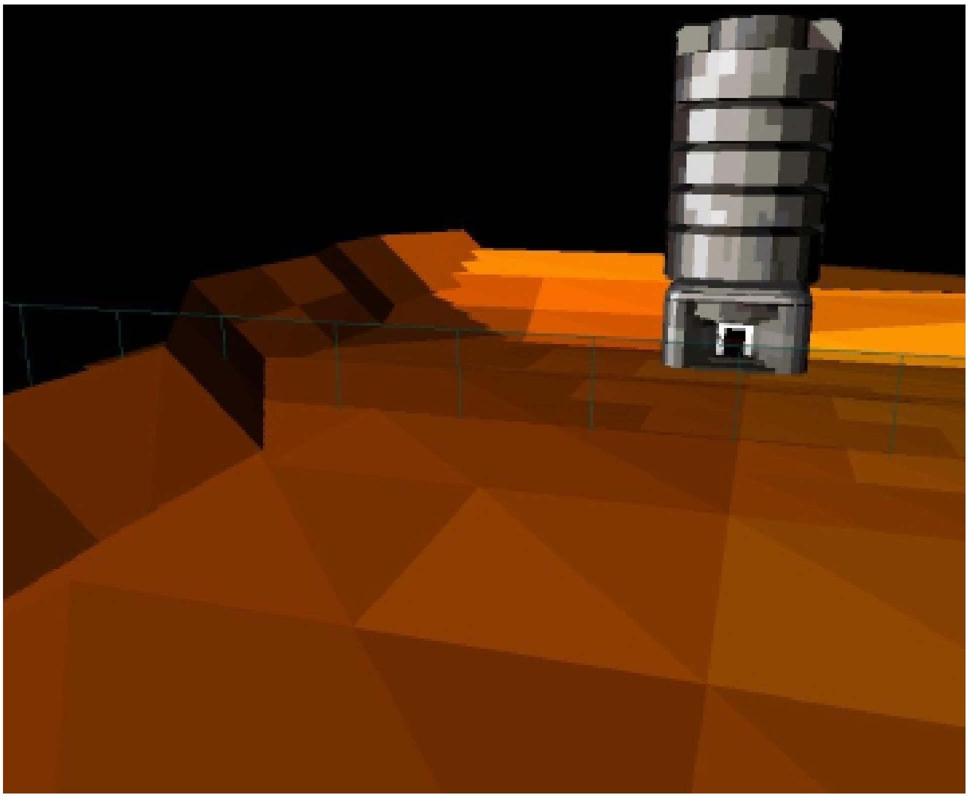

Figure 16: a view from the desert

Figure 17: a close up view of the bunker

The virtual environment was created in the MASSIVE–2 system. A facility for terrain following was added especially for this event.

5.3.2. Physical infrastructure

Our performance was staged in the ZKM's Medientheatre, a large open space with a high ceiling. Figure 18 summarises the infrastructure that was established.

The rain curtain was produced from a single brass pipe with four nozzles what was suspended from a large wooden frame in the shape of a triangle. The participant stood at the apex of the triangle, looking out at the curtain. The wooden frame was covered in black drapes and the lighting in the theatre was darkened in order to isolate them from external distractions. The eventual performance will involve six such triangles arranged as the slices of a large circular pie.

The participant used a footpad to navigate through the virtual world. This was a small wooden platform on which the user stood that could be gently titled by the act of shifting their weight. This tilting was measured by three contact sensors and transmitted back to a PC. A second computer, a Silicon Graphics O2 was used to host and render the virtual world. This received input data from the footpad PC over an Ethernet connection and was also connected to a video projector that back–projected the image of the virtual environment into the rain curtain. An external microphone was connected to the system to enable the performers to directly talk to the participant if necessary.

Water was pumped to the pipe from a distant tank and was caught in a shallow plastic pool on the ground from which it was returned to the tank.

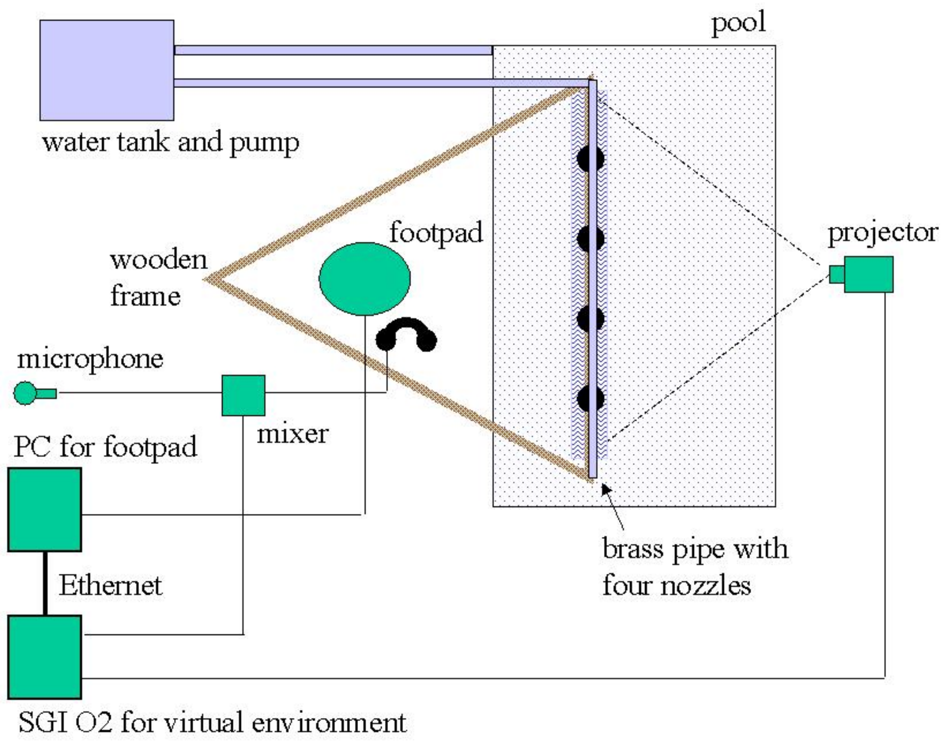

Figure 18: technical infrastructure

Figures 19 to 25 show various aspects of this physical infrastructure.

Figure 19 shows the sketon framework for the raincurtain and the two computers in the Medientheatre.

Figure 20 shows a participant in the pie–slice.

Figure 21 shows the pipework, nozzles, waterspray and pool.

Figure 22 shows a view of the virtual world as seen through the rain curtain. This image is subject to extra blurring due to the use of long exposure times in the photography.

Figure 23 shows the footpad being tested.

Figure 24 shows several participants watching the performer approach the curtain from behind.

Finally, figure 25 shows the performer walking back through the curtain as seen from behind the curtain.

Thanks to Christof Hierholzer of the ZKM for these photographs.

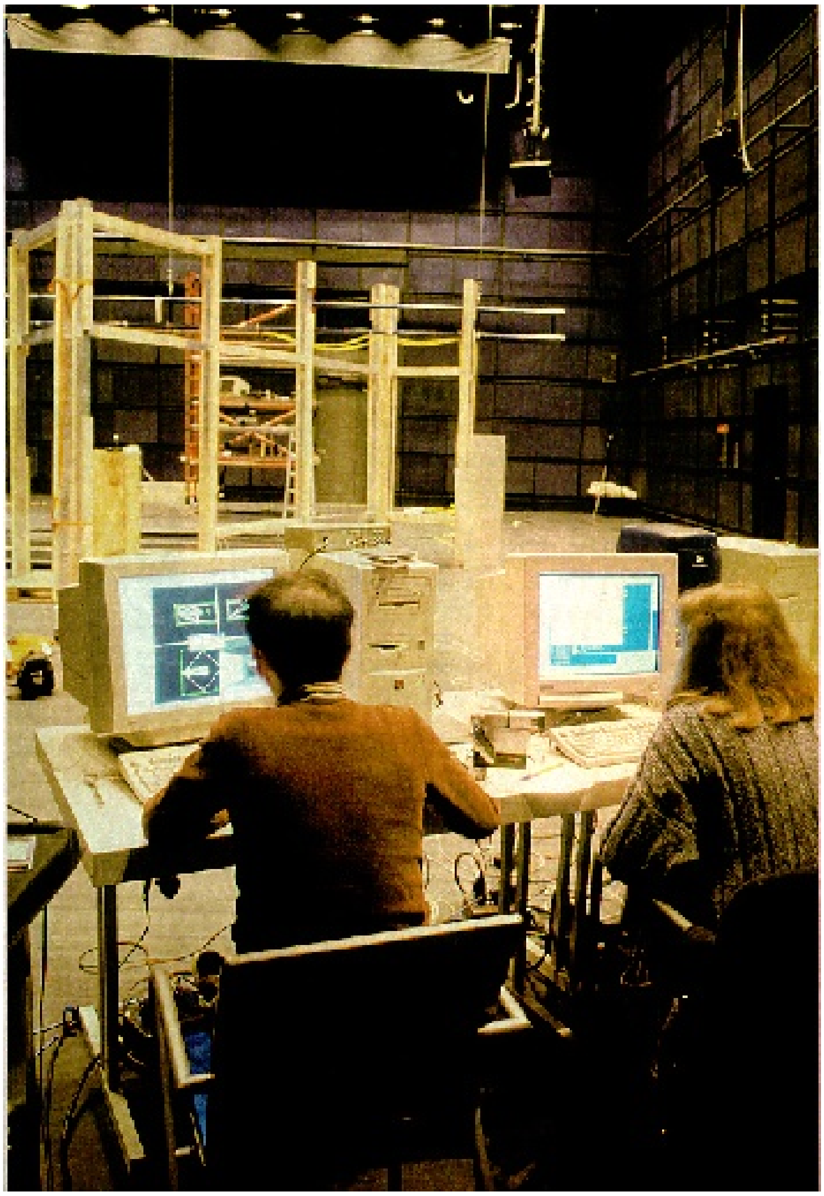

Figure 19: the rain curtain framework and computers in the Medientheatre

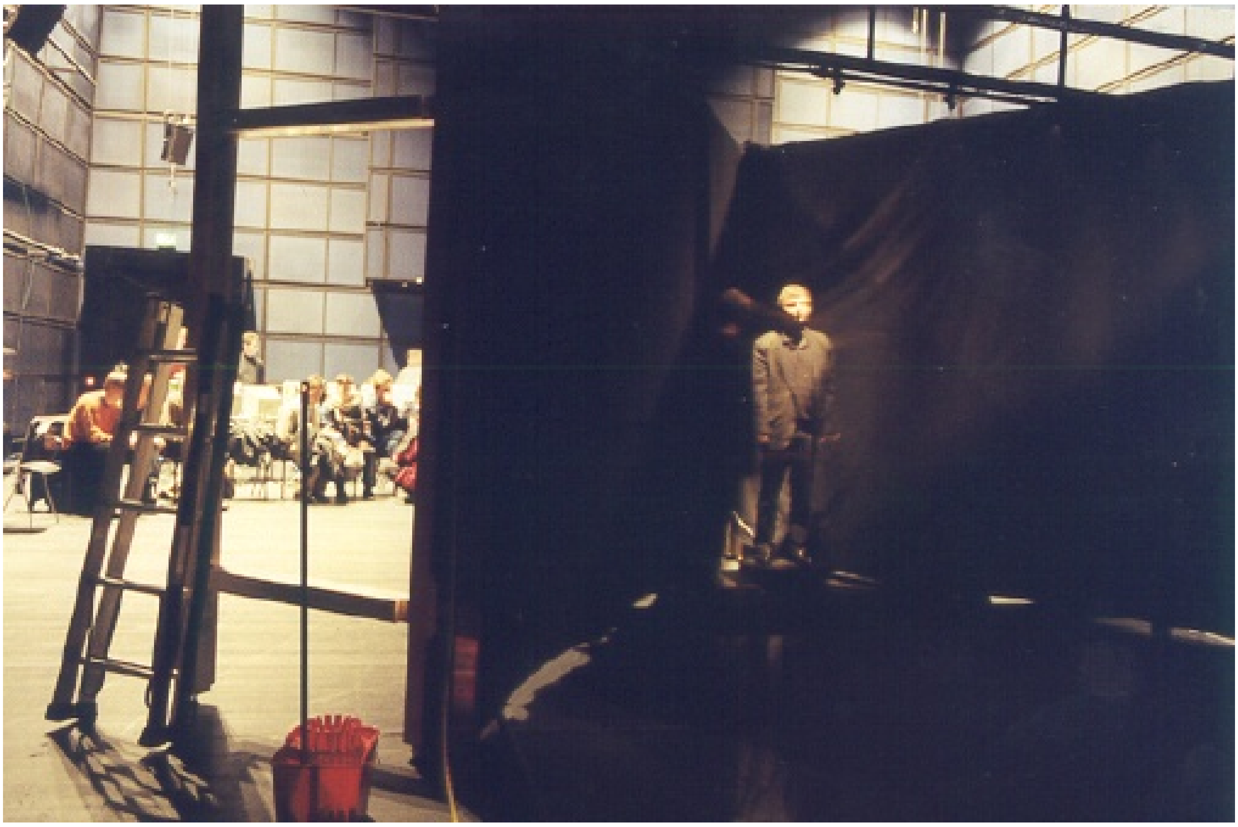

Figure 20: a participant standing in the pie–slice

Figure 21: the pipework and pool


Figure 22: a view of the virtual world as seen through the rain curtain

Figure 23: testing the footpad


Figure 24: watching the performer about to step through the curtain

Figure 25: the performer walking back through the curtain (seen from the behind)

5.3.3. Public participation

Our demonstration was opened to the public between for six hours on the afternoon of the 27th January 1999. During this time twenty seven members of the public experienced the piece for between ten and fifteen minutes each. The first four participants were not told anything about what they were meant to do. The remaining twenty three were briefed that they should find and enter the bunker. The progress of each participant was monitored and noted by a member of the production team who was able to follow their viewpoint in the virtual world on the monitor of the SGI computer. Once they had completed the experience, the participants were informally interviewed and asked for their opinions.

In the evening there was a two hour panel session to discuss the event. The panelists were Steve Benford from the University of Nottingham, Sally Jane Norman from ZKM, Matt Adams and Ju Row–Far from Blast Theory and Andrew Chetty, director of Nottingham's NOWninety9 festival who is involved in commissioning Virtual Rain. There were approximately 20 people in the audience, many of whom were from the ZKM, but not directly involved in this project. Each panel member made a brief statement and then the audience was invited to ask questions and make comments.

5.4. Initial evaluation and reflection

This section presents an initial evaluation of the Pushing Mixed Reality Boundaries workshop. This evaluation addresses the following questions:

- What technical issues were raised by the demonstration, especially with regard to public interaction with the rain curtain technology? (section 5.4.1).
- What work was involved in creating the demonstration, what technical options were explored on the way to the final demonstration and what everyday practical issues are involved in working with this technology? (section 5.4.2)
- To what extent was our initial public demonstration of the rain curtain successful in artistic terms and why? (section 5.4.3)

In answering these questions we have drawn on a number of sources including:

- comments from the public after their experience and at the public panel discussion.
- an ethnographic study of the production process by researchers from KTH that captured the event as it happened.
- our own reflections as art and computer science researchers that, in contrast to the ethnographic study, were raised after the event.

These perspectives were brought together at a post-event debriefing in February 1999. We would stress the preliminary nature of this evaluation, occurring as it does at the end of February 1999 – only one month after the workshop. We hope to gain further and deeper insights over the next few months and expect these to contribute to work on production technologies (WP4) and mixed reality boundaries (WP6) as well as to the full-scale public performance planned for the Autumn of 1999.

5.4.1. Technical evaluation

What technical issues were raised by the demonstration, especially with regard to public interaction with the rain curtain technology?

Graphics and projection

A focus for technical evaluation was the quality of the image of the virtual environment in the rain curtain. The nature of the image as held by the falling water was commented upon by several observers. In particular, it was felt that, depending on the image and the viewer's position relative to the projector, the viewer's attention could move between the image, the water itself or even the light of the projector behind.

Several experiments were made in order to try to strengthen the image. One successful technique was to *reduce* the resolution of the projected image to 640 x 480 pixels. An unsuccessful attempt involved adding milk to the water supply in order to whiten the surface of the water curtain. These issues are discussed in greater detail in section 5.4.2.

The rendering of the virtual world was a cause for concern and it was generally felt that the frame rate was unacceptably low. Part of the problem may have been that the world was created as one large object as opposed to being split into separate regions as encouraged by MASSIVE–2. Rendering bottlenecks are currently being tested at Nottingham. However, it does seem that, as with Out of this World, graphic design will have to proceed to a tightly defined budget in terms of polygons and textures. This raises a requirement for the production tools that are being considered in eRENA WP 4. It would be useful if 3-D modeling tools would allow for both the definition of complexity budgets for different 3-D objects and regions and also provided facilities to monitor and report on them as the objects were being constructed.

Navigation and the footpad

The question of whether the public would be able to successfully navigate the virtual world using a combination of the footpad and rain curtain was a central concern to the workshop. Our experience was mixed. Of the twenty-seven participants, eighteen completed the whole route (i.e., explored and left the motel room, crossed the fence, entered the bunker and then entered the box within). The fasted completion time was 30 seconds, set by a female participant with no previous experience. On the other hand, five participants only partially completed the route and of these, three were from the group that had not been briefed and the other one did not realise what the footpad was for. One visitor found it difficult to navigate and never managed to leave the motel room. Finally, one visitor left after two minutes, also saying that they had difficulties navigating and found the whole experience to be frustrating. Overall then, there was the sense that the footpad can be used as a navigation device, but that a number of problems need to be addressed. We felt that calibration of the footpad is a key concern, especially to take account of variation in the weight of participants. Wear and tear on the tennis balls the support the footpad platform was also a subject for concern – how robust will the footpad be if the final performance work tours several venues over a period of several weeks?

Audience feedback at the panel session raised the issue of training. What opportunities would be provided for learning to use the footpad before the performance?

These observations served to hi-light a more general HCI issue. To what extent should the limitations of interface technology be made transparent to the user as opposed to being made directly visible? A common approach in VR is to create transparent interfaces – the user may be standing on a footpad, using a mouse or wearing a head-mounted display, but in each case, they are meant to experience the idea that they are flying freely. An alternative approach would be to embody the interface device including all of its limitations within the content of the world. Would users have accepted the limitations of the footpad as being part of the experience if they had seen it as an object to be wrestled with on the desert sand – for example, if it had been presented as a vehicle that kept getting stuck? This issue is revisited from an artistic perspective in section 5.4.3.

Constraint versus encouragement

Of course, navigation is a familiar problem in the design of virtual environments. However, the extension of the current experience into the final *Virtual Rain* performance where several participants will need to co–ordinate their journeys, exacerbates this problem. It also raises the further issue of how to support participants, especially whether to constrain them or encourage them. The *Out of this World* Inhabited TV show (see companion deliverable 7a.1) introduced movement constraints in order to produce coordinated and scripted action involving members of the public in a shared virtual environment. In that case, each participant was placed inside an invisible box in the virtual world that limited their scope of movement. The size and trajectory of this box could be varied according to the phase of the event so that at some times they were relatively free to explore, but at others they were rooted to the spot. In addition, a member of the production team called the world manager was able to select phases of the event in order to force all of the participants to move to new locations in a coordinated way.

Although the introduction of system enforced constraints may have been appropriate in a TV show, it is questionable whether the same technique would transfer to an artistic experience that is more concerned a process of discovery and that does not attempt to produce action for a separate viewing audience. As a result, our workshop followed the alternative approach of encouraging participants. Although the world did introduce movement constraints in the form of solid virtual boundaries such as the walls of the motel room, these were less tightly defined. For example, at no point was the participant rooted to the spot. Furthermore, no use was made of the ability to force movement by triggering phases. Instead, the performers chose to speak to the participants through their headphones in order to assist them when they were in difficulty and to encourage them to move on if they appeared to be spending too long in one location.

The asymmetric properties of the rain curtain played a key role in this process as the performer was able to see the participant through the rain curtain, without being visible in return. As a result, they could monitor their reaction to the experience. An additional monitoring capability was provided by a computer monitor on the production desk that showed the participant's view of the virtual world.

This approach of monitoring and encouragement seemed to work well enough for the single participant experience of the workshop. However, it is not clear how effective it would be in a multiple participant situation, especially where there are tight timing constraints and where the progression of the participants may depend upon all of their members keeping up with the pace. In our initial experience more than one in four people experienced difficulties in navigating. Given that we currently plan to coordinate teams of six participants, it would appear that we should anticipate situations where groups regularly leave members behind. This raises the questions of whether we can improve the footpad sufficiently to ease navigation, whether verbal encouragement is sufficient to ensure that the performance progresses, whether enforced constraints would ever be appropriate or whether the performance should be designed so that some participants can be left behind? However, the collaborative situation also raises new opportunities for helping people. For example, on spotting someone in difficulties the performers might intervene by asking another team member who is coping well to give assistance. This might potentially slow the front person down and speed the trailing person up, thus keeping the participants grouped together.

To generalise, the issue of coordinating and timing collaborative activity in on-line events is one that spans all aspects of eRENA. The performance work form WP7b and the inhabited TV work from WP7a adopt different solutions to this problem – systems constraints versus monitoring and encouragement. The further generalisation of these approaches is then a further issue for the production and management work in WP4.

5.4.2. Working with mixed reality boundaries – reflection on the production process

What work was involved in creating the demonstration, what technical options were explored on the way to the final demonstration and what everyday practical issues are involved in working with this technology?

The previous two sections reflected on the success of the final demonstration of the rain curtain. During the two weeks of the workshop, however, several alternative designs were experimented with, many interesting problems encountered and ingenious solutions devised. That is, it must be appreciated that the creation and implementation of a novel mixed reality boundary is the product of concerted work and improvisation, very little of which could be fully anticipated and planned for in advance. Behind the above description lies much creative work of interest in its own right. The documentation of this work forms part of the ongoing ethnographic research being conducted within eRENA at KTH. In this section, we highlight some of the themes of this research. In particular, we describe:

- the work which went into making the rain curtain function adequately as a mixed reality boundary.
- some of the contingencies surrounding the use of the footpad and the experimentation which was required to make it usable.
- how the virtual world was designed and the practical problems which were confronted in the process.

Plumbing – The Rain Curtain as a Mixed Reality Boundary

To achieve the desired effects for the rain curtain several problems needed to be addressed. Many of these stem from the fact that the curtain itself is part of a water supply system that has to be carefully controlled. Water from the curtain needs to pass into an appropriately designed “basin” and water on its way to the curtain has to be drawn from a tank, itself filled from a public water supply. Each of these recepticles needed careful consideration in their selection or design, and often required someone to oversee them and the flows between them.

A rectangular basin, a wooden frame, was made of battens and planks, approximately 4.90 by 4.50 meters across and one decimetre high. This wooden construction had no bottom surface itself. This was first provided by a light, thin grey waterproof mat bought in London a couple of days before the workshop. However, after the curtain's first trial, it was found that this mat had leaked and had to be replaced with a black rubber mat sourced from ZKM. This substitute worked better-its blackness also giving an impression of an endless void instead of the floor surface that was clearly and distractingly seen through the rain curtain initially.

To enable the rain curtain to be worked with for long enough before the basin required emptying or the supply tank required refilling (either by pumping water back from the basin to the tank or sourcing fresh water), a tank of approximately 1000 litres was required. This mass of water could be safely used without overflowing the basin and would enable several days of intermittent usage of the curtain itself. An open plastic container, brought by the ZKM's manager of the Medientheatre, was used as a water tank and placed out of sight in a closed area outside the theatre. Filling the tank demanded some consideration. For the first trials, it took more than an hour before a satisfactory method was found to make the water flow at a steady pace from the lavatory in the dressing room outside the theatre into the tank. Filling the tank then took two to three hours.

Recycling the water from the basin to the supply tank was not done continuously as this would require the sustained operation of a pump that would give off distracting noise. To drain the basin and refill the tank took about 30 minutes, rather less time than filling the tank afresh. After a week of usage, though, it was all too evident that the water needed replacement. Many litres had been lost due to evaporation and occasional spillage. Algae and other “foreign bodies” had begun to noticeably grow! Indeed, some visitors to the workshop had complained about the smell.

It should be clear from this discussion, therefore, that careful consideration of the water flow system was necessary to make the rain curtain viable in hydrological terms let alone serve as a mixed reality boundary.

To create the rain curtain itself, the production team (Blast Theory and the researchers from Nottingham and the ZKM – henceforward referred to as “the team”) had ordered a sprinkler system from Holland, normally used in greenhouses. A steel pipe with nozzles was attached to a bar hanging from the ceiling. Although the team had experimented with projecting virtual worlds onto a water curtain before, they were working with this particular sprinkler system for the first time in the workshop. The system had been very carefully researched and selected, including making a personal visit to Holland. However, several fine details of its operation needed to be resolved in an improvised fashion unaided by memory or documentation. For example, it was not clear what orientation the taps should be placed in to let the water through. At the risk of mistaking “open” for “closed” and creating a disasterous flood, the team agreed: “Let’s find it out the hard way”. The taps were set, the projector was switched on, the water system worked in a controlled way, and a fairly sharp test image appeared on the moving surface. Although the correct usage of the taps had been guessed at, this did not stop mistakes on other occasions, in particular, mistaking one tap for another in darkened conditions. “The theatre's floor has never been so clean,” remarked one visitor.

Over a period of several days, even though the initial results were satisfactory, the team made several variations on the rain curtain to see if its properties could be improved. For example, the number and spacing of nozzles was experimented with. A set up with many nozzles closely spaced gives a bigger projection space than one with fewer nozzles further apart as the areas unfilled with spray between adjacent nozzles are smaller. However, such an arrangement requires higher water pressure and the team were already concerned that they were fortunate in using a very powerful pump provided by the ZKM which they couldn't count on at other venues. Additionally, it was discovered that the top area of the curtain, above where the water has fallen into droplets, is not satisfactory for projection anyway. Accordingly, although five nozzles were commonly used in testing the curtain at the ZKM, a four nozzle system is currently preferred for future use. Finally, while the team are generally satisfied with the curtain as a projection surface, they nevertheless plan another visit to the nozzle specialist in Holland to discuss potential improvements and to share experience.

Some of the most dramatic experiments conducted with the rain curtain involved trying to improve it as a projection surface. The team wondered whether a whiter surface would heighten the ability to discriminate among graphical objects. It turned out that one of the ZKM employees had a friend in Berlin, who worked with art video production, and it was recalled that in one of his videos milk had been used in order to hold a bright image. A couple of days later, contact with the Berliner had been made. Indeed, milk had been used and, even left in a basin for several days, it neither turned sour nor nasty-smelling. After some calculations it was decided that five litres of (long-lasting, low-fat) milk was to be used for the curtain. The milky water passed through the pipes, and became visible less in the curtain than as patterns in the bottom of the basin. The difference in image quality was hardly noticeable, besides making the curtain a bit dimmer perhaps. After two hours of hard work with a vacuum cleaner and a mop, the basin was dry and the water tank emptied. When the water system was tried out the next morning, a couple of the nozzles did not work, probably blocked by the fat in what had been sold to the team as low fat milk. To get rid of the blockage, to disinfect and to prevent the smell of rotting diary produce, chlorine bleach was put in the water tank. It also eliminated all further signs of algae.

The Footpad

The team, for the purposes of the workshop, were reusing a footpad interaction device which had been developed in association with the ZKM for other purposes. Adapting the device to the team's project raised a number of problems. On arrival the footpad, at that time known as the 'surfboard', appeared in bright pink hues with numerous stickers attached with logos and slogans from surf equipment manufacturers-a design aesthetic and suggested use context which could scarcely be more different to the foreboding desert setting the team wished to explore! Before being shown in its new context to the public the board was repainted black. The board also had a triangular shape perhaps suggestive of the front half of a real surfboard. It was mounted with three sensors, one at each corner of the board. In its original operation, this distribution of the three sensors should enable good responsiveness to patterns of movement reminiscent of those involved in surfing: the single sensor at the front tip yielding forwards movement, the others making for lateral shifts.

However, the team wished to physically locate this interaction device at the narrow apex of wooden framed triangular enclosure (see Figure 18). To fit the device in this location, it had to be fully reversed. Although it now fitted snugly in place, the orientation of the sensors, of course, was in turn reversed with the left and right pair now at the front and the single sensor, formerly at the tip of a 'surfboard' now at the rear. This led to extensive difficulties in reprogramming the software which interpreted sensor data (so that, e.g., forwards movement was not mistaken for reverse movement) and for some users (a surfing posture now being anomalously interpreted).

The device required calibration so that its responsiveness would be intuitively related to the movements and postural changes that the user would make. However, clearly, the sensor data in such a device are effected by the weight of the user in question. As, naturally, the team were not expecting all visitors to weigh the same, how to handle a potentially great variation in responsiveness was a taxing problem. The inventor of the footpad suggested calibrating the device in several different 'weight-bands' and switching between different settings for different users. Not only was there not enough time in the workshop to do this, the team were sceptical about the acceptability of this in actual use.

A final example of the contingencies which had to be dealt with making the interaction device work is worth noting here. The device used three tennis balls to provide physical resistance to the movements of users. It turned out that in its life as a “surfboard”, the device had experienced much wear and tear on these. Within the workshop, the tennis balls further lost their elasticity. Not only did this make the board less mobile, it may have contributed to the failure of one of the sensors which then required replacement-a matter which was itself delayed as the ZKM's supplier did not deliver another sensor in a timely fashion.

In summary, the adaptation of the interaction device required considerable effort. While this was irksome for the workshop, it had the advantage of drawing attention to important criteria for good device design for environments where a mixed reality boundary is to be worked with. For example, the device must not only work effectively in enabling appropriate interaction with a virtual world, it must also physically fit a real-world environment and mesh with the capabilities of flesh and blood users.

Virtual World Design in Practice

For the team, it was essential that the virtual worlds projected onto the curtain could be clearly recognised. The motel environment where all participants would start their exploration should be legible as such. The desert that lies outside of the motel room door should be legible as a desert. And so forth. However, designing such worlds presented several difficulties.

For example, no 3D modelling package offers a rendering window where the effects of projection onto a rain curtain are simulated. Changes to designs required not inconsiderable imagination in the face of only partially useful feedback from a conventional rendering window, when it was inconvenient to launch the rain curtain itself. This made the practice of rapid experimentation and quickly implemented changes that would normally be familiar in graphical design often somewhat problematic.

The properties of the rain curtain necessitated adaptation to other aspects of design practice. For example, high colour contrasts are required in graphical design for the perception of differences on the curtain. Patterns and other textures have to be very carefully designed to be legible at all. This is especially important if one wished to convey depth, as colour contrasts and texture gradients often give the viewer useful perceptual depth cues.

In the case of the motel room, a radical graphical design strategy was adopted to give the viewer the impression of the “boxiness” of such environments. With the exception of one textured wall and a moving image on a virtual TV set, the room's surfaces were rendered through white 'wireframes'–that is, the edges of the surfaces were suggested by thin white lines against a black background. This had the effect of not only high contrast but also clear perspective depth cues as lines converge. Interestingly, then, what is rather a crude rendition of a room when it appears on screen becomes intriguing and potentially engaging on the rain curtain. The motel room, then, exemplifies very well the challenges that exist in graphical design for a mixed reality boundary like the rain curtain – challenges that needed to be met by extensive ad hoc experimentation by the team.

The bunker presented fewer graphical design challenges of such a unique sort. The architectural structure of a bunker lends itself well to a rendition composed of polygons with large faces. High contrasts in shading also worked well in suggesting a three dimensional structure. Most participants visiting the workshop could see this as a clearly legible building even if it was not positively identified as a bunker. This, together with the motel room, give us some clues about how to develop graphical design practices which may work well for mixed reality boundaries like the rain curtain. Forms which either are (bunker) or can be made to be (motel room) angular, composed of large, flat surfaces and relatively uniform in their colour can project adequately well in the face of loss of fine detail on the rain curtain. Forms which in conventional graphical design practice are rendered through multiple small surfaces or the extensive use of textures may be problemtic. This is borne out by difficulties there were in conveying the other forms in the virtual environment: the desert and the semi-transparent fence.

As one team member put it: “if there's one property that a desert has, it is that it is undulating”. Suggesting a rolling terrain on the rain curtain, then, is of essential importance for the team. This proved to be especially difficult and, at the time of writing, no fully satisfactory solution has been adopted. There are complex dilemmas here. A smooth terrain with much curvature is highly “expensive” in polygon-count and resource intensive to render. As discussed further below (5.4), complex worlds that yield a low frame rate seem to be especially objectionable for users viewing a rain curtain projection. Furthermore, as one of the effects of the rain curtain can be to lose subtle detail in geometrical shapes, a terrain was experimented with consisting of large triangular faces and substantial colour contrast between them. However, the colours did not “mix” on the rain curtain as intended and the large shapes did not combine to suggest an undulating desert landscape. For most of the rest of the workshop, a relatively flat terrain (except for a slight downwards slope towards the entrance to the bunker) was preferred. It is, though, highly questionable whether this suggested a desert to any of the participants who visited during the workshop. Effectively suggesting a desert terrain, then, remains an outstanding problem.

Another outstanding problem of virtual world design is the semi-transparent fence between the motel and the bunker. While on screen in the 3D modelling package that the team were using this does indeed appear as a semi-transparent fence, it seems more opaque on the rain curtain. The team's intention was to portray a permeable boundary (if possible itself resembling a rain curtain) within a virtual environment that was in turn projected onto a permeable surface. Attractive though this self-referentiality might seem, in the timescale of the workshop, it was impossible to satisfactorily realise. Indeed, the relative opacity of the fence seemed to make some users turn back and return towards the motel room even though it was quite possible to move through the fence.

Making Mixed Reality Boundaries

It should be clear from our discussion of the work conducted during the two weeks of the workshop that the fascinating properties of the rain curtain come at a price. New graphical design practices have to be improvised. Interaction devices have to be carefully selected and adapated. A whole water transportation system needs to be attended to. While the boundary that is the rain curtain mixes “realities”, just as clearly, did the team and those working with them have to mix radically heterogenous forms of technology, from the computational to the hydrological. Each of these elements needed to be in place for the boundary to work as specifically a mixed reality boundary rather than a load of falling, dimly illuminated water. In short, the mixed reality boundary needed much real world work in its creation and maintenance. To properly appraise the viability of such technologies, we need to document and draw attention to this work so as to sensitise others who may follow such an experimental path in what to expect and to provide a “practical baseline” for the future. If the rain curtain becomes progressively easier to work with, if new graphical design practices can emerge, if interaction devices which seem appropriately matched to the rain curtain can be developed, then we can determine whether – as a technological innovation – he rain curtain and the ideas it expresses are on the way to a stable form that could be adopted by others or are remaining problematic. Only if we document the work to make the rain curtain work now will we be able to evaluate its viability in and for the future.

This concludes of our initial evaluation of the Pushing Mixed Reality Boundaries workshop. This evaluation has focused on a range of issues from the artistic, technical and social science perspectives. The following section briefly outlines how this work will be carried forward towards the design of a full-scale public performance.

5.4.3. Artistic evaluation

To what extent was our initial public demonstration of the rain curtain successful in artistic terms and why?

Entering the work

The rain curtain provoked extremely varied response from the public, with nevertheless a unanimous initial reaction of hushed surprise and intimidation upon entering the theatre. The actual configuration of the rain curtain in the Medientheater, with the high wooden frame shrouded in black cloth, accessed from the far side with reference to the theatre entrance, endowed the installation with mysterious qualities. The line-up of computers at the rear of the house, manned by a silent team of programmer/operators, added to this disturbing atmosphere. Visitors were escorted into the theatre individually or in twos or threes, and tended to await their turn in apprehensive silence. To a certain extent, then, they were “conditioned” before going into the actual installation and experiencing the virtual rain curtain. Immediately after penetrating into the enclosure via the manoeuverable flap of black cloth, they were hit by the unearthly sound of finely dispersed falling water, and by a moderate but perceptible change in temperature (between visits, the rear theatre door was regularly opened and closed to control the level of the external water tank; this rear door connects directly with the exterior of the building, and January temperatures were low). Obscurity surrounding the projection equipment on the other side of the water curtain, and the fact that the dazzling projection beam prevented clear vision of the space beyond the curtain, gave the space a disconcerting sense of openness and boundlessness: people felt as though they were entering an “outside” world because the installation limits were unfathomable.

Technological shortcomings versus critical aesthetics: the art of exploiting ”bugs“

Opinions concerning the navigational experience proposed through the rain curtain projections, and attitudes regarding the above-identified technological shortcomings, diverged quite strongly in ways that largely reflected preoccupations and demands which, in turn, can be characterised as a function of the visitors’ backgrounds. We were fortunate in being able to host observers from the theatre world (including certain ZKM theorists and, in particular; the theatre and stage design students from the Hochschule für Gestaltung, housed under the ZKM roof), as well as observers more versed in visual than in performance media.

Overall, these two groups manifest two distinct kinds of reactions to the proposed aesthetics: visitors fluent in computer-based, interactive visual media experienced a higher degree of frustration with the paucity of the graphics and the slowness and cumbersomeness of the navigation system. In some cases, this frustration overrode and dispelled the initial fascination with the rain curtain configuration, and the visitors left with a negative impression. In contrast to this attitude, persons attuned to performance and theatre aesthetics tended to be less irritated by the technological shortcomings of the system, and to consider the low frame rate and laborious navigation as constituting an integral part of the aesthetic project. Even though there was widespread frustration with the footpad interface amongst both these groups, persons drawn by the strange temporal qualities of the water curtain, and by the singular “pace” emanated by this constantly moving projection surface, tended to be more tolerant and even appreciative of the slow graphics. For the latter persons, the graphics pace was gauged to serve a work essentially engaged in media criticism – including self-reflexive criticism of the media used to convey the work itself. Hence, display techniques running counter to slick, seamless graphics, to video game speeds, and to smooth TV news-type editing (e.g. precisely the Desert Storm “montage” of mediated events the Virtual Rain piece seeks to denounce), were in this case considered as an appropriate, meaningful artistic choice.

Frustration with the navigation interface and with the visual reference system (or lack of) raised vigorous debate about the extent to which interface attributes – possibilities and shortcomings – can and should be written in to the aesthetics and narrative of interactive art. Indeed, if a work seeks to counter the streamlined aesthetics of today’s often bland media, and if this criticism is in part enunciated via clumsy interfaces and laborious graphic refreshment rates, then such criticism might be more effective if the glitches of the systems used were explicitly emphasised within the actual narrative framework. Reasoning along these lines, difficult manoeuverability of a footpad-type interface could be dramatically highlit, and slow graphics made even slower – at least momentarily in the course of the visit – to reveal this as a deliberate artistic strategy.

Artists who deliberately exploit the bugs and glitches of their media as chosen areas for aesthetic intervention abound throughout history – from baroque musicians who integrated flaws in music paper into their compositions, through to contemporary figures basing their works on computer viruses, pirated ascii code, or other diverted, subverted uses of technological processes (examples can be seen in Ascii Art Ensemble projects – Walter van der Cruijsen/Luka Frelih/Vuk Cosic, in “technoparasites” work by Andreas Broeckmann and Erik Hobijn, and in the I/O/D Web Stalker). In all cases, though, a delicate balance has to be struck to appropriately and redeemingly contextualise the “bug” in order to endow it with artistic meaning. Otherwise, one is stuck with a nondescript work that is simultaneously bad art and bad technology.

This issue requires careful discernment to identify which technological features are indeed an integral part of the final aesthetic project, and which are simply a passing (negative) reflection of a given moment of a work in progress. Given the nature of Blast Theory’s media critical discourse, such questions have to be weighed up carefully: to employ a truism, slow systems are not always the most apt to generate impressions of slowness, just as fast systems are not always the most apt to generate impressions of speed. In the ongoing project, choices as to allocation of computing power to image and sound functions, and further refinement and calibration of the user interface, will decisively articulate the relationship between technological means and the creative project. These longer-term choices will be crucial for the artistic strength of the final Virtual Rain piece.

Projection support / projected content: mismatching (as) aesthetics

Visitors were intrigued by the use of water as a surface for projecting images conveying an arid landscape. The resultant tension “worked” for most, though a few persons were sceptical about this forced marriage, maintaining that they would have been happier with projected images that physically and metaphorically espoused the aqueous display plane, thereby raising questions of redundancy – does one have to project dry images onto a flame surface, gritty images onto a sand surface, or wet images onto a liquid surface to optimise visual impact and coherence? The issue of whether and how far a match should be sought between the display surface and projected imagery is central in the context of ongoing mixed reality technology research, which ultimately targets use of standard computer display systems – screens, HMDs – in ways that capitalise on properties of a wide range of projection media (cf. infra, section 6).

In an artistic context, use of a given projection material to display ostensibly contradictory image content may be deliberately sought for this perceptual jarring, which effectively unleashes all kinds of associations, metaphors, and interrogations in the observer's mind. Blast Theory explicitly vindicates this technique in their art practice (Tadeusz Kantor employed the term "constructivism of the emotions" to describe this careful staging of dramatic tensions). A host of latent creative solutions to technological stalemates may be harboured by an artistic project that in purely ergonomic terms involves condemnably loose use – or abuse – of a technology. Getting back to the rain curtain, to criticise appropriateness of the match between display materials and displayed imagery on the grounds of predictable, prosaic relations is to apply misplaced criteria and miss the point of a creative undertaking. On the other hand, it is useful to question the legibility, coherence, and effectiveness of the proposed interplay between materials and imagery in specifically artistic terms. At this level, the paradox of viewing highly stylised desert visuals on a clearly wet, cold surface, and the particularity of the "mirage" generated by this constantly falling water screen, were in fact well received.

Ideological issues: (self) critical media art works

The central ideological thrust of Virtual Rain was positively identified by visitors to the installation, who spontaneously subscribed to Blast Theory's denunciation of a certain anaesthetised form of media culture, epitomised by television coverage of Gulf War events. Discussion participants conveyed their sympathy for this critical take on digital media and on so-called virtual reality, and for Blast Theory's attempt to raise and challenge the controversial issue of media neutrality. As mentioned earlier, the clumsiness of certain technological features was often construed as deliberate, even though the installation was still clearly at the early prototype stage. Spartan aesthetics running against the grain of glibly rendered, fast refreshed graphics were seen as an integral part of the final project, and as indispensable to its critical portent.

The English group's focus on theatrical, as opposed to purely technicist art, and aptness of their choice of the rain curtain to convey and provoke reflection on a potent ideological issue, were well recognised by the public, as was pertinence of the rain curtain to symbolise an information screen, filter and medium, and to serve as a vital link between different qualities of space. The visitors' situation in the installation is extremely ambivalent. They are simultaneously passive and active, closely confined in an unfamiliar physical space, and able to move in virtual space via a precarious interface and an alienating display system which literally seeps into real space. They are being observed by an unknown, unknowable number of persons on the other side of the virtual world, lurking in a space which may or may not constitute a part of that world; at the same time, their sole form of communication with others takes place inside and through the virtual world. In short, the rain-curtain boundary in Virtual Rain is an excellent metaphor for the Gulf War media experience: one is confronted with constantly merging, shifting levels of information which remain indistinguishable, in a situation where one's individual capability to act effectively is fundamentally and permanently challenged.

Blast Theory's combination of extremely pragmatic theatre expertise to underpin work that, at another level, can be seen as highly conceptual and ideologically loaded, differentiates their art from innumerable contemporary mixed media performances which offer interesting material for media boundary analysis, but do not contain the rich critical ambivalence that characterises a creation like Virtual Rain. Thus, for example, in *Jet Lag* (directed by Elizabeth Diller, Ricardo Scofidio; technical direction Marianne Weems, premiered at the Dutch Festival of Electronic Arts, Rotterdam, November 1998), scene shifts between a navigator lost in (filmed) seascapes, and broadcasters relaying his expedition, are obtained with Privalite-type booths and judicious lighting (cf infra, section 6.1.2, for an analysis of Privalite glass as a potential "dry rain curtain" material). Yet while the latter piece entails a cunning commentary on media duplicity (the lone navigator uses a panoply of special effects to fake his heroic solo journey), its perfectionist technical polish puts *Jet Lag's* critical edge at a level that might be summed up as Broadway with a bite.

A similar problem is posed by the (in-)famous performances of Emergency Broadcast Network, an American group whose aesthetics hover between *Mash* and CNN, which "works to harness the power of multimedia audio-visual technology into the most effective electronic behavior control system" (EBN's statement of purpose). Their staged events call on a bullhorn-bearing media frontman, live DJ turntable operation, video projection wall, telepodium, motorised podium equipped with color televisions and lighting and laser effects, and an Emergency Broadcast Vehicle with mobile video projection system using a rotating satellite dish as a screen. Spokesman Josh Pearson states that the EBN goal is to "enhance people's will to think for themselves by greatly exaggerating the amounts of potential information we all receive daily from television and the media." Paradoxically, though, EBN shows tend to be so luxuriously equipped and technologically careened that the media dazzle hits like fireworks, leaving no critical distance for people to think for themselves and a sometimes barely discernable satirical bite, closer indeed to CNN than to *Mash*. Alongside Virtual Rain, performances like EBN events and *Jet Lag* provoke reflection on how and how far media technologies can be pushed towards masterful, high-end spectacle, while upholding uncompromised critical stances in a very perceptible, legible fashion.

The fact that Virtual Rain is being developed on a relatively limited budget, with a view to easy dismantling and re-installation (the work uses Mac and PC computers, and a simple physical scaffolding system), was appreciated by participants in our final discussion session. Numerous regular ZKM visitors were intrigued to learn that the Medientheater was hosting a work in progress which, in its final form, targets other venues, and is not bound to ZKM equipment for its future artistic viability. Since most R&D work undertaken in the Karlsruhe premises tends to exploit high-end computer systems, and depends closely on ZKM facilities for showing subsequent artistic outcome, the Blast Theory workshop created an unusual precedent. The aura of self-sufficiency that sometimes enshrouds works built in and for a specific institutional infrastructure was happily dissolved in this situation, while the ZKM's position as vital node of a broad, actively relayed artistic network was consolidated.

Generally speaking, response to the Virtual Rain workshop indicates interesting shifts in, and maturation of, public opinion with respect to new media use in the arts. After an initial period where criteria of speed and slickness made digital media art the prerogative of a privileged few well endowed artists, and of a privileged few equally well endowed sites, the novelty of sophisticated, exclusively heavy platform based work seems to be wearing thin. Correlative to the increased presence – thus lessened impact – of high-end digital aesthetics in our everyday environments, notably via television and cinema, video and computer games, these reserves are apparently prompted by a demand for reflection and content, and for work characterised by a sharper critical edge. For many people, ingenuous, unquestioning use of powerful media technologies to convey innocuously decorative work is not the artist's task, but rather is the role of the media designer, who employs technologies in a more consensual, valorising light.

Blast Theory's careful determination of technical systems that correspond to predefined artistic goals, and that in no case override or eclipse these goals, emerges clearly from any discussion with the group, and this guiding principle was well perceived and received by a public which has become indifferent to idle technological dazzle. Virtual Rain represented a savvy blend of techniques and disciplinary competence, a primitive water screen being used to display graphics piloted by a particularly powerful software tool. The visibly very hands-on encounter of performers experienced in a wide range of theatrical interventions, and computer scientists engaged on high-end software development, itself constituted a significant, unusual, encouraging event in the eyes of the ZKM public, and would thus seem to augur well for future in-depth forms of multidisciplinary research.

This concludes our description of the pushing mixed reality boundaries workshop. This initial experience has raised a range of issues to be considered in developing a full scale, multiple participant performance. The following section briefly outlines our current plans for developing such a performance.

5.5. Future development – Virtual Rain

The Pushing Mixed Reality Boundaries workshop has been one stage in the development of a full–scale performance called Virtual Rain. This will involve six participants journeying through a shared virtual environment, using six separate rain curtains as interface devices. Consequently, Virtual Rain will allow us to explore the idea of tessellating mixed reality boundaries as well as exploring the novel properties of an individual boundary. This section presents our current plans for Virtual Rain including its artistic foundations, the proposed design of the experience and our current plans for staging it as a public work and for evaluating it.

5.5.1. Artistic concept

Virtual Rain will use a combination of virtual reality, installation and performance to problematise the boundary between the real and the virtual. It will involve participants in a collaborative virtual environment in which the real intrudes upon the virtual and vice versa. It will use the real, the imaginary, the fictional and the virtual side by side and will seek to juxtapose these elements as a means of defining them.

The piece will be influenced by Jean Baudrillard's assertion that the Gulf War did not take place because it was in fact a virtual event. Whilst remaining deeply suspicious of this kind of theoretical position we recognise that this idea touches upon a crucial shift in our perception and understanding of the world around us. It asserts that the role of the media, advertising and of the entertainment industries in the presentation of events is casually misleading at best and perniciously deceptive at worst. As Paul Patton says in an essay about Baudrillard,

> "the sense in which Baudrillard speaks of events as virtual is related to the idea that real events lose their identity when they attain the velocity of real time information, or to employ another metaphor, when they become encrusted with the information which represents them. In this sense, while televisual information claims to

provide immediate access to real events, in fact what it does is produce informational events which stand in for the real, and which “inform” public opinion which in turn affects the course of subsequent events, both real and informational. As consumers of mass media, we never experience the bare material event but only the informational coating which renders it “sticky and unintelligible” like the oil soaked sea bird.”

This reference to the “oil soaked sea bird” as an icon that stands in for the reality of an oil spill and which, in effect, distracts attention from and even masks entirely the real complexity and significance of the events surrounding an oil spill, gives a direct example of the ways in which these processes affect us every day. While these ideas form the backdrop to Virtual Rain, the piece is not intended to be a demonstration of this theory merely to accept its significance in informing our view of the relationship of the real to the virtual and especially in its assertion that the virtual has a daily presence in our lives. Indeed we also have a great interest in those who have coruscatingly attacked Baudrillard's ideas as “absurd theses” which are “ill equipped to mount any kind of effective critical resistance”.

The role of the cinema, particularly Hollywood, in this process is also important. As a vehicle for dreams, aspirations and fantasies films play a major role in affecting our self image and as a source of inspiration. The key motif of the individual overcoming all odds to triumph is a touchstone for our culture and has an impact on real life. Arnold Schwarzenegger and Norman Schwarzkopf both exemplify certain aspects of leadership, for example, and each draws on the attributes of the other. Virtual Rain will therefore attempt to bring visitors to a new understanding of the ways in which the virtual and the real are blurred and, in particular, the role of the mass media in distorting our appraisal of the world beyond our own personal experience.

5.5.2. The experience of Virtual Rain

The experience will be structured like a game in which five or six visitors enter the installation at a time. Within the virtual world the visitor gathers information, completes tasks and collects virtual objects. At certain stages in the process the visitor will need to walk through the rain curtain to leave the virtual world and enter a real environment. The real environment will parallel the virtual world in many respects but – it will gradually be revealed – will diverge significantly in certain key respects. In conjunction with the discreet intervention of performers the piece will bring the relationship of the real to the virtual into sharp focus. The following paragraphs provide a more detailed description of the experience as it is currently envisaged, although this may change radically for the final piece.

The Antechamber

Six visitors are shown into a small room. Six chairs sit opposite six coat hooks. The visitors give their coats and bags to the attendant. For 30 seconds they are shown a map of the virtual world that awaits them without being told why they are being shown it. They are given a photo of a person to take with them and told “This is you”. The visitors are then lead in total darkness into the main space by the attendant.

The virtual world

Each visitor finds themself in a triangular space, standing facing the rain screen. The virtual world – which is implemented using MASSIVE 2 – is video projected onto the rain screen about 4 metres in front of the visitor. They stand upon a footpad. By rocking the pad backwards, forwards, left and right the visitor can navigate within the virtual world, which begins in a motel room.

The description that follows uses a linear structure for simplicity but, of course, there will be many different ways of passing through the virtual world.

The motel room is broadly naturalistic (containing a bed, a chair, a table etc.) but is stylised in the manner of a Patrick Caulfield painting: bold lines, sparse forms. A television in the corner of the room is on. It is showing a trashy American cable channel (an embedded video view). The programme is interrupted with an urgent message to inform the inhabitant that due to an accident everyone must evacuate the entire area within 30 minutes.

Once the inhabitant leaves the motel room they find themselves in a desert landscape with a clock ticking down from 30 minutes. American guitar music (perhaps the theme from Paris, Texas) is heard. The only objects visible are three buildings far away on the horizon. As the visitor travels towards them they will follow the undulations of the landscape, occasionally losing site of the buildings altogether as they cross a ravine.

In one of these ravines is a fence stretching away to left and right. The fence cannot be crossed. At intervals along it are signs that read “Military Area, Access Forbidden”. Occasionally the fence contains letter box sized holes. Looking through them the inhabitant sees the world beyond the fence represented in negative: black is white, red is blue etc. Adjacent to these “windows” is a crossing point but as the inhabitant goes to cross they are hyperspaced into the middle of three buildings. All American references are now gone and day has become night.

Seen close up the buildings are, in fact, large concrete bunkers. For the first time inhabitants will be close to each other and will probably meet. Each inhabitant's avatar is a simple geometric form with a flag attached containing a photograph of “their” face (which they were given in the antechamber). As inhabitants get close enough to speak to one another their avatars will pulse to indicate speech. With the clock ticking inhabitants will need to share information as they explore the three bunkers.

The first one contains a map of the whole surface of the virtual world. It also hints at the subterranean sections to come. The locations of all six inhabitants are visible. The second bunker is a cylinder with six doors around its circumference. When opened each door reveals a live embedded video view. The six different views show the six visitors standing on their footpads in the triangular rooms, thus forming a bridge between the virtual and real worlds. Using this device allows inhabitants to communicate with one another while physically distant within the virtual world.

The third bunker will seem empty at first. A small amount of exploring however will trigger an encounter in which a bag of sand is thrown through the rain curtain and lands on the floor in front of the visitor. Attached to the bag is a magnetic swipe card.

The three bunkers are linked below ground by tunnels. Where they meet, the three tunnels combine in a gentle slope leading downwards. A doorway at the end shows brief glimpses of huge objects moving past it from right to left. As the inhabitant steps through the doorway they enter a large cross tunnel. A huge object, reminiscent of a juggernaut, is bearing down on the inhabitant. Before they can move to avoid it, it passes over them and is gone. As it does so it immerses them in a clip from a radio station or a TV station about the gulf war. Ten seconds later a second “media truck” – containing a different audio clip – hits the inhabitant. A new truck will hit them every ten seconds before they exit via a small door on the opposite wall of the cross tunnel.

The final virtual space is a vast hangar containing 100,000 numbers. Every number from 1 upwards is represented as a three dimensional form stretching away into the distance like a cemetery. As the inhabitants (either individually or collectively) push their way through the densely packed numbers they destroy them. With the clock ticking dangerously low an exit sign appears on the far side of the hangar.

As they make for the exit, one visitor at a time is grabbed by a performer who emerges through the rain curtain.

Exiting the virtual world

The visitor is facing down a narrow corridor. Blocking their exit is a 3 metre high pile of sand that fills the corridor. Having climbed up the pile and down the other side they reach the final room of the installation. The 3m x 4m room is an English hotel room. The four walls are large photographic representations of the four walls of the hotel room including pictures on the walls, chairs, bed, TV. The room contains no objects apart from a magnetic card reader and six monitors cut into the photographic walls. Each visitor swipes their card and goes to a screen.

On the screen is “their” face. The camera zooms out to reveal that person sitting in the real hotel room of which the final room is a photographic representation. Each of the six people has had their life changed by the Gulf War in some way: as a soldier, a journalist, a pilot, a medic or a passive spectator. For about five minutes they talk about their relationship to the events, their proximity to them and how “real” it felt.

The visitors collect their coats and bags and leave. At some point later they will discover a small bag of sand concealed in their coat or bag. The bag will contain approximately 100,000 grains.

5.5.3. Plans for staging and evaluating Virtual Rain

It is currently planned to stage Virtual Rain between September and November 1999. The work will tour a number of European cities, including Karlsruhe (based at the ZKM), Nottingham (the NOWninety9 festival) and others, possibly including Liverpool, Bristol and Frankfurt. Additional funding to support full–scale development and touring is currently being sought from arts funding bodies including the Arts Council of England and the NOWninety9 festival – so far over 35,000 ECU has been raised. This additional funding will allow the eRENA project to gain added value from this work by exposing it to the public as a professional touring performance. In turn, this will provide an extending opportunity for evaluating the work as directly experienced by its intended “users”. Our evaluation will include, ethnographic studies of the production of Virtual Rain by KTH, ethnographic studies of public interaction around and within Virtual Rain by Kings College London (working with Nottingham), an artistic evaluation of Virtual rain by ZKM and finally, a technical evaluation of the software by Nottingham.

6. Broader implications for CVE interfaces and mixed reality technlogy

In this final section we consider how the results of the Pushing Mixed Reality Boundaries workshop, especially the use of the rain curtain, can inform the design of more general interfaces to CVEs to be used in everyday architectural settings.

One approach would be to look for other applications where the rain curtain itself could be used without its wetness causing difficulties. An example might be in water based entertainment experiences at theme parks where the public might pass through a series of boundaries as part of a ride. Another might be in information displays in public spaces such as public buildings or foyers. For example, a rain curtain might provide an appropriate material for presenting the Internet Foyer application from section 2 as an informative and aesthetic public display.

A second approach is to consider the rain curtain as just one example of a more general class of non–solid, semi–transparent mixed reality boundaries, some of which might be realised using dry materials. These dry boundaries would be suitable for use in a typical home setting, either for telework purposes or entertainment (inhabited television possibly), or in a work environment, perhaps as part of 3–D interface to a media space as outlined in section 4. The remainder of this section explores this second approach in more detail, focusing on two key questions:

- how might these dry boundaries be created?
- how might they be used to improve on current interfaces to shared virtual worlds?

6.1. Creating a dry rain curtain

Section 3 defined the properties of a general mixed reality boundary. We argue that the rain curtain has instantiated these properties in two particularly interesting ways.

- **solidity in a physical sense –** it is possible to step through the water and access a physical space beyond. Additionally it is possible to push objects through the boundary into the area beyond. Combined with the original property of solidity the curtain now offers access to two distinct spaces 'beyond' the boundary, one physical and one virtual.
- **visibility in a physical sense –** it is possible to perceive physical objects (shadows or outlines) through the water curtain. Combined with the original property of visibility one can now see two different spaces on the boundary and beyond. One is projected on to it while the other is directly behind it. Interesting overlays are possible and have already been exploited in the performance described previously.

We are at present trying to explore materials and find designs that support these properties in a dry arrangement. We are looking at materials that have different translucency states and set–ups that permit the direct physical access to the space directly behind the mixed reality boundary.

Future work will aim to support a wider range of properties with architectural means (situation and dynamics).

Architectural context

The mixed reality boundary is designed to interface virtual and physical spaces. These spaces are distinct but appear to be adjacent, meaning that they remain readable as separate entities. These kinds of spatial relationships are issues architecture is traditionally concerned with, albeit in the area of linking a number of physical spaces in contrast to the mixed reality boundary that links virtual and physical ones.

Here an attempt is made to reintroduce some of the properties that are inherent to physical doors and windows and use them in connection with the mixed reality boundary. These are mainly the qualities of materials already used in architecture and a sense of tactile interaction on the physical side of the boundary.

It is suggested that the mixed reality at home is set up in front of a large window or door (leading outside to an external terrace for example). Two boundaries, one to the physical space outside and one to the virtual environment are now available. Both can be ‘opened’ to step through them for access to the areas on the other side.

This results in three distinct spaces. The public exterior space in front of the window, the semi-private interior, which in this context is a living room and the private space between the two housing projection and immersion equipment. These will be discussed in more detail in section 6.2. To access any of these spaces the user has to interact with the physical boundary in some way just as he would using a door or window. This interaction is tactile in contrast to most of the interaction inside virtual environments, which will emphasize the material and physical qualities of the mixed reality boundary.

The following two sections will demonstrate a number of suitable designs and materials.

6.1.1. Variations of designs for non–solidity

We begin by proposing various set–ups that might achieve the key property of non–solidity, i.e., that are designed to allow users to step through the mixed reality boundary.

Rotating door elements

Three screen elements are arranged as rotating segments. Projection is possible from both sides. To step through the boundary the user rotates the elements out of the way (either manually or automatically). The boundary can then be closed again if continued use is required by either the person that has stepped through or the people staying behind. Finally the screen can be pushed out of the way to the side of the room if there is no use for it for a while. The gaps between the segments will be of some concern, but as the number of elements is not even, the centre of the projection will not be affected by that. Interaction with the boundary is very similar to a conventional door and detailed design will incorporate elements that make its use intuitive (indicate clearly that and how the boundary can be opened).

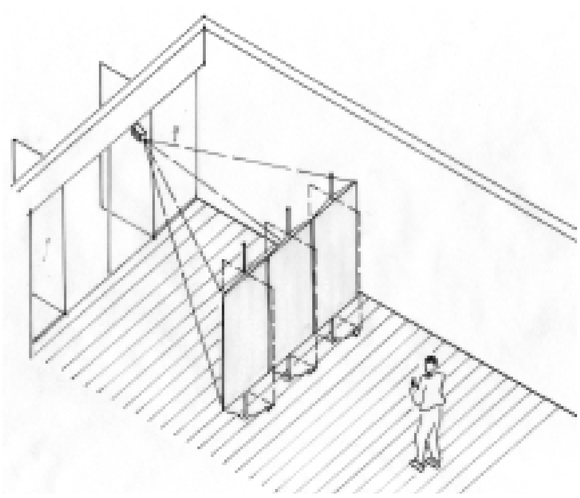

Figure 26: rotating door elements

Lift up screen

Here the mixed reality boundary has been integrated into one object as all the necessary technology is incorporated within the frame so that the unit is ready for use without the need to complex rewiring. If the user wants to step through the boundary, the whole element is folded upwards to the ceiling and if desired closed again behind the user. This mechanism can be handled manually or automatically. As above it can now be used by an individual in the private space between the exterior and the interior or by other people occupying the interior space. In the ceiling position the mixed reality boundary additionally acts as a display for ambient media, for example suggesting to the user to fold it down to follow something up in the virtual environment. This is achieved by using the original projector now projecting images on to the screen via a mirror and by means of the audio equipment integrated into the frame.

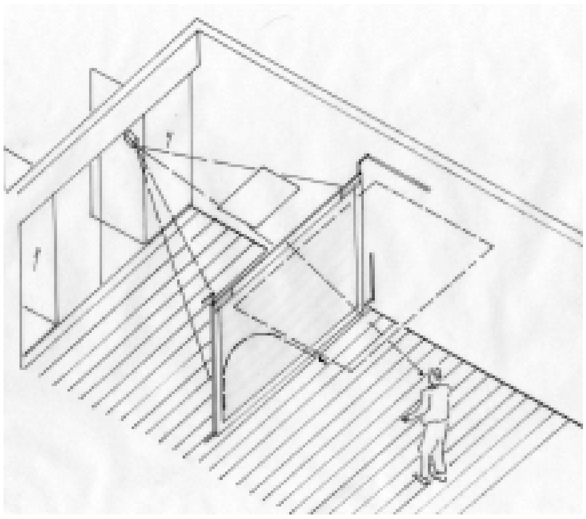

Figure 27: lift up screen

Curtains

This set–up plays with the idea of a curtain to achieve the desired permeability. The design might employ a range of materials from glass beads, an arrangement of plastic pieces as shown in the illustration to conventional cloths divided into convenient segments. To step through the boundary is as simple as pushing the curtains out of the way. Gravity will close the gap again behind the user. Again it can be used from both sides depending on the projector set–up either using front or rear projection. Interaction is expected to be straight forward as curtain are familiar elements of everyday life.

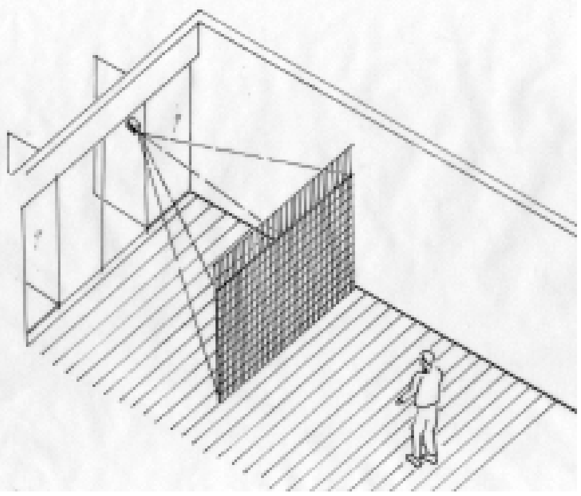

Figure 28: curtains

Tensile element

This element was inspired by the availability of a flexible projection material and the rather widespread use of tensile structures in architecture.

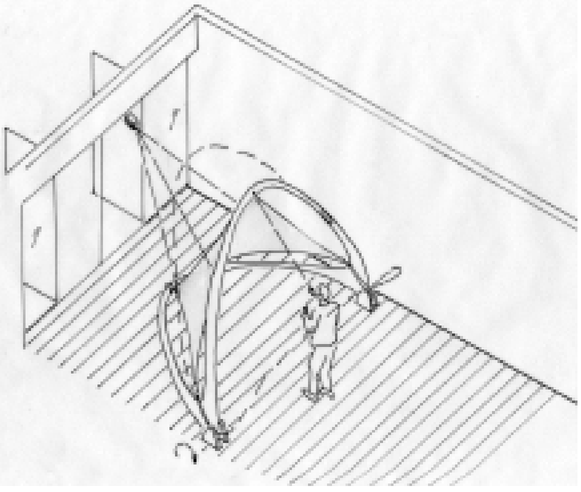

Figure 29: tensile element

A piece of flexible fabric (this could potentially be the material used for professional cinema screens) is fixed to a rigid frame made from fibre reinforced plastic. As the screen element can achieve a small curvature the sense of immersion is expected to be stronger than with flat screens (peripheral vision will be covered also) although this curvature also creates technical problems for the projection of the image. The element like the lift up screen is self contained and flips up over the user as a whole, to allow access to the area behind it. Use as an additional element for ambient media is possible while the use from two sides seems rather restricted, as the curvature faces then the wrong way for one viewing direction.

All of these set–ups allow the application of the newly defined boundary property of physical solidity derived from the experiment with the water curtain. This means that all permit the physical penetration of the mixed reality boundary by people and objects, although this happens in quite different ways.

6.1.2. Projection materials to support variable visibility and assymetry

In this section we now proceed to look at the second property of interest: visibility. Here we have been looking at different materials offering differing properties of translucency. The table in appendix A offers a condensed overview of the materials considered so far. Of these, four stand out as offering special advantages over the others.

Priavlite glass

This material has been developed and is now produced by Solaglas, a manufacturer of a wide range of glass products. Its state of transparency can be changed from transparent to translucent by applying electricity to an LCD layer sandwiched between two panes of float glass. This change is virtually instant. *Privalite* therefore allows visual permeability and the projection of images (rear projection). In principle these two uses will have to be alternating, while *Privalite* even in its translucent state allows the perception of outline figures and shadows behind. This makes it very interesting for the mixed reality boundary, as the property of visibility (see above) can be adjusted. While the glass does not allow physical permeability without moving it out of the way, it allows visual permeability to the physical area behind the screen, if desired. When set up in front of a conventional window, it at one time is used as interface to the virtual world displayed on it and at the next time it becomes a visual interface to the physical world directly behind it. Another interesting point is that as the switch between the two states of transparency is controlled by electricity, which allows for easy synchronization with events in physical or the virtual environments.

We have not yet been able to conduct our own projection tests as the material is too expensive to obtain samples from the manufacturer. However it is used at least in one occasion for rear projection (the TV studio of the BBC used for the *Grandstand* programme).

Privalite can be used for the lift up screen and possibly the rotating door also.

Acrylic Plastic

This material is a very clear plastic most commonly known under its trade name *Perspex*. The most interesting property of this material is the fact that it allows the projection of two different images on to the same screen without them interfering. Early experiments have shown that this can be achieved by treating both surfaces (using sandpaper for example) and the right lighting conditions. This might find interesting applications in the mixed reality boundary as it now can be used from both sides at the same time (see the following section). A change of the surrounding light conditions additionally allows the same image to be seen from both sides, although the image appears in reverse on one. As the material is translucent it permits the perception of figures through the boundary, so that areas or objects of a virtual environment can be referred to from both sides.

Acrylic plastic can be used as material for the rotating doors, the lift up screen and the curtain.

Flexible film screens

This material is most prominently used for projection purposes in cinemas. What is most interesting in this context is its flexibility. Therefore rather complex and aesthetically interesting shapes can be achieved that ‘wrap’ around the user. This might increase the sense of immersion. Its flexible shape might even allow the change of the physical shape of the boundary to for example accommodate it for varying numbers of users or simply different projection requirements. Its light weight might allow a variety of other uses also as it can be moved around easily and it might find different positions in the home. Up to now we have only had the chance to experiment with the image quality, which is very good due to the fact that it is a material professionally used in the film industry. Future work will have to explore its exact properties concerning the use in tensile structure (structural properties and durability for example)

Flexible film screens will most prominently be used in the tensile structure and the curtain.

Beads

Made from glass or plastics, beads can be either fully transparent or translucent depending on the surface treatment. Most interesting here is the small size of the elements that allows beads to be used in curtains made from transparent strings. This allows the direct access to a physical area behind the curtain without the need to move large elements out of the way. In that respect it is very close to the interactivity of the water curtain. However, initial experiments with a very small sample have shown that image quality is rather limited. The transparent beads only display a hint of colours while the translucent version allows the perception of some details also. In the future we will try out different sizes of bead or even different sizes of rectangular pieces of plastic. Beads are used in the curtain.

The combination of the designs and materials discussed above allows us to introduce the qualities of the rain curtain namely its permeability and quality of visibility into a more practical design. The remainder of this section considers how this might be used as part of a general interface to CVEs.

6.2. An interface to CVEs for use in everyday environments

An important characteristic of even the most immersive of VR displays is that participants do not leave their local physical space behind them when they step into a virtual environment. Ethnographic accounts of the use of CVEs with desktop interfaces have highlighted the way in which distractions in a participant’s local environment that are not visible to other participants in the virtual environment may cause misunderstandings and breakdowns in communication (Bowers, 1996). In an extreme case, participants may even stop using the virtual environment altogether, but leave their unoccupied avatar behind them indicating apparent presence. Anyone who has used a head–mounted display will know that it is difficult to ignore one's local physical environment for long. It is all to easy to bump into objects, trip over cables or be disturbed by local noise. This is especially true if the technology is used in a shared environment that is also used for other activities.

Given these observations, this section speculates on an interface to a CVE that involves stepping into a virtual environment and appearing to de–materialise from one's local physical environment. Inspired by previous work on media spaces that has focused on using video and audio technologies to establish open and long–term connections between existing physical spaces, we propose that a general interface to a CVE should consist of two main components:

1. a persistent and open connection between the participant's physical environment, the semi-private space, and the part of the virtual environment that represents their location in the network (i.e., their home territory in cyberspace). This would take the form of a bi–directional mixed reality boundary between the two spaces that would be generally fixed in its location in both the physical and virtual spaces. Often this part of the boundary is used by a group of people.
2. a mobile viewpoint within the connected virtual environment that is associated with the participant's avatar whenever they become active within it. This viewpoint would be accessed using appropriate VR technology such as a head–mounted display, projected interface or conventional monitor. The virtual world would also contain an embedded video view looking back out into the public space of (1). Generally this part of the boundary is used by an individual.

Both of these components can be seen in the 3–D media space interface described in section 4 above.

We propose that in order to enter the virtual environment, the participant should have to physically pass through the fixed mixed reality boundary that connects their public space to the virtual environment into a further private space beyond. We call this the VE access space as this is where the participant gains access to the technology required to control their avatar. This requires that the mixed reality boundary is non–solid. It is also necessary that both the persistent and avatar's viewpoints are available simultaneously as many physical environments are shared, implying that some participants will typically remain in the public space while others have passed through into the access space in order to become active within the virtual world.

The use of a non–solid boundary in this way has the following key properties:

· participants appear to "dematerialise" from their local physical space when they enter the virtual world.

· provision of a separate access space means that participants may be less subject to external distractions while they are inside the virtual environment.

· participants who remain on the public space can still access the virtual world through the open connection.

· the technology for accessing the virtual world can be protected from interference, either physical or possibly optical or electromagnetic.

The degree of visual permeability of the boundary might also be significant in this design. A semi–transparent boundary such as the rain curtain would allow participants to maintain a background awareness of those on the other side of the boundary. For example, people entering the public space might be aware that someone was accessing the virtual world beyond the boundary and vice versa. Advance warning might also be given when people were going to cross the boundary through the appearance and growth of shadows on the projected image.

Finally, the use of boundaries that could hold a different image on each side could bring a further advantage. First, participants in both the public and protected spaces could use the same screen, one side showing a fixed view of the virtual world and the other a mobile view from the perspective of an avatar. This might potentially reduce space requirements. Second, such an arrangement aligns the participants so that they are facing one another through the boundary. Both sides can therefore make use of its visual permeability as proposed above. This use of a non–solid, semi–transparent and asymmetric mixed reality boundary is summarised in figure 30.

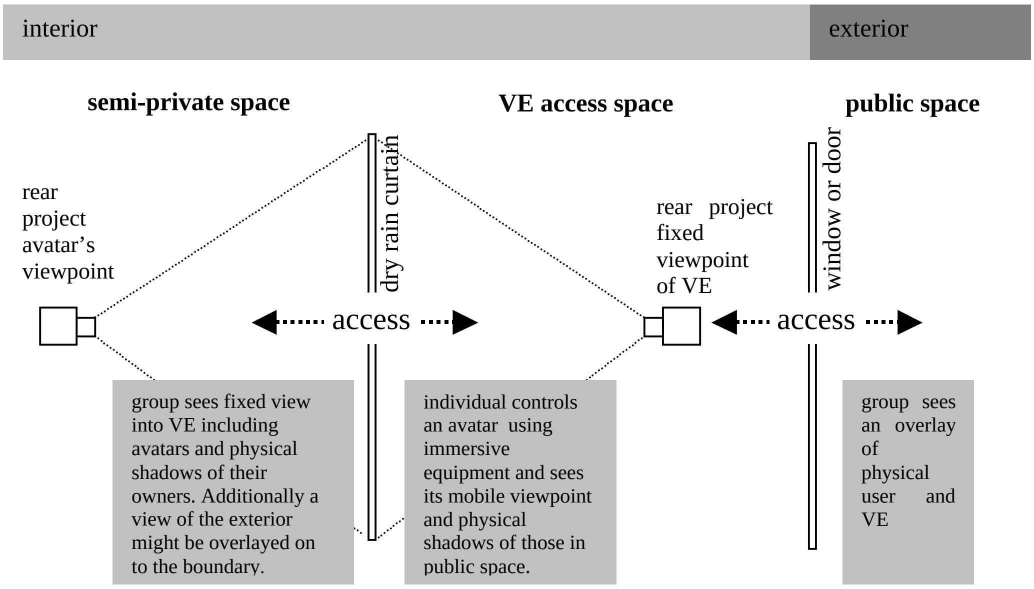

Figure 30: providing fixed and moving viewpoints on a virtual world

The graphic above shows that the VE access space is sandwiched between the semi-private space in the living room and the public space outside. This could potentially allow interesting overlays of virtual and physical environments on the screen and beyond. A number of architectural techniques like blinds and variations of lighting will potentially allow the flexible adjustment these overlays according to the requirements of any of the set-ups.

In summary, we speculate that a mixed reality boundary with the properties of non–solidity, visual permeability and asymmetry (i.e., those of a rain curtain) can provide shared access to a virtual environment that involves both a fixed and persistent connection between physical and virtual space as well as movement of avatars through a virtual world. Such a boundary might be created using a range of projection materials of varying visibility configured so that participants could step through them or could temporarily remove them.

Final word

This concludes deliverable D7b.1, our report on the Pushing Mixed Reality Boundaries workshop that was staged at the ZKM in January 1999. Our goal was to explore the use of a novel mixed reality boundary, a rain curtain, in the creation of a performance. At the same time, we have tried to show how the rain curtain represents a particular class of mixed reality boundary and have suggested how "dry" boundaries with similar properties might be created and used in more everyday settings.

This workshop has been one informative part of the process of developing a full public performance that will involve multiple participants interacting with performers. The issues raised by the workshop will inform both the technical and artistic design of this public performance in the remainder of workpackage 7b. They will also continue to inform the development of the underlying technology of mixed reality boundaries in workpackage 6.

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Appendix A – variable visibility projection materials for dry mixed reality boundaries

materials	Features	Shapes/ Curvature	Max. Dimension	Projection Requirements	Light transmission	Weight/m^2 (appropriate thickness)
Privalite	Instant switch between transparent and translucent states by applying electricity. Power on switches to transparent state. No intermediate.	Rectangular, possible to cut edges off to create rounded or angled corners, can be curved in one direction (very expensive)	2800x1000 MM, there can be larger sizes this will be very costly (Solaglas)	Rear projection possible	75% high	~ 25–35
Translucent Glass	Translucent Distributing light evenly Constant quality of transparency	Can be curved in two directions (domes) with diametre constraints, optically true surfaces can not be obtained with rough cast process	Standard stock 3210x1500 M^2 (Solaglas) Max. 6000x3210 M^2 (Solaglas)	Projection seems reasonably clear, no definite data available angle of view limited gain reasonable	75 % high	~ 25–35 depending on thickness
Rigid film screens	High image quality on a purpose made material. Optical systems Diffusion systems	More or less any shape Can be curved in one direction (cylinder segment)	Standard stock ~ 2740MM x 3650MM at 4:3 ratio (Stewart) larger sizes possible	Gains up to 5 are possible (Stewart). Viewing angle reduces with higher gains Different versions for different daylight conditions	medium	~ 8 kg
Acrylic plastic	Acrylic plastic, sanded down on one side	More or less any shape Can be curved in one direction (cylinder segment) Can be curved in two directions (domes etc.)	3000 MM x 2000 MM (Amari Plastics Plc. Nottingham)	Projection seems reasonably clear, no definite data available angle of view limited gain reasonable	medium	~ 8 kg
Flexible Film Screens	Flexible material custom made for projection purposes Different types for front and rear projection	More or less any shape, can be flexibly curved to create complex curvatures	Standard sizes up to 3650MM x 2740 MM (Stewart) Maximum size 13200MM x 29200MM (Stewart)	Gains up to 2 possible (Stewart). Viewing angle reduces with higher gains Versions for different daylight conditions	medium–low.	info not available yet

Curtain	Beads or small flat pieces of plastic arranged in a curtain	Flat, rectangular	Any size possible	Unclear image on beads Image on plastic sheets dependent on size and gaps	medium	dependent on size of beads or plastic elements

Cost/ m^2 +	Maintenance	Durability	Manufacture	Advantages	Disadvantges	materials
£ 1500	Simple, cleaning like normal window	durable under normal circumstances, does not scratch easily	LCD element is layered between two sheets of float glass	Change of Transparency Synchronization of this with performance Complete visual permeability, if desired Window metaphor strong light transmission Light transmission	Cost Weight Availability only from one company Fixing and handling complex Limited view angle	Privalite
~ £ 81 for sandblasted ~ £ 108 for acid etched	Simple, cleaning like normal window	durable under normal circumstances, does not scratch easily	Float glass is acid etched (very smooth surface) or sand blasted (interesting rough patterns)	Cost Availability Light transmission Frame less fixture	State of transparency fixed Does not allow clear visual access to the area behind the screen Weight Limited view angle	Translucent Glass
~£1375 for optical systems ~£625 for diffusion type	Relatively simple, avoid scratching. Attracts dust due to electrostatic charges.	Abrasion is higher than with glass, more easily scratched	The optical system is edged into either side of the surface The diffusion type is made by treating chemically	Optical quality Simple fixing and handling Light weight Frame less fixture Expertise readily available	Cost State of transparency fixed Does not allow clear visual access to the area behind the screen Thermal movement Electrostatic charge	Rigid film screens
~ £ 45 + the machining on one side	Relatively simple, avoid scratching. Attracts dust due to electrostatic charges.	Abrasion is higher than with glass, more easily scratched	One surface is sanded down with mechanical sander or by hand	Low Cost Simple fixing and handling Light weight Frame less fixture	State of transparency fixed Does not allow clear visual access to the area behind the screen Thermal movement Electrostatic charge Limited view angle	Acrylic plastic

info not available yet	info not available yet	Might tear if not handled with care	Plastic material is treated to allow for different optical qualities	Optical quality Relatively leight weight Possibility of curvatures Sound permeable versions available (front projection) Immersion might be strongest with wrap around screen. Availability	State of transparency fixed Does not allow clear visual access to the area behind the screen	Flexible Film Screens
info not available yet	More time consuming as larger pieces	Might need a lot of looking after. Elements might tangle	strings of clear threads are fixed to beads or plastic pieces	user can step through closest to rain curtain	State of transparency fixed Does not allow clear visual access to the area behind the screen low image quality	Curtain