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Individual Realities: Customizing Aesthetics in Shared Immersive Virtual Environments

David. W. Sprague and Amy A. Gooch

University of Victoria, Victoria, BC, Canada

Abstract

Immersive virtual reality systems such as CAVEs and head-mounted displays offer a unique shared environment for collaborations unavailable in the real world. Virtual environments not only provide users with novel interaction and navigation approaches but each person is also generally provided a unique perspective into the virtual world. Provided each participant sees the virtual environment from a unique display, we argue that a group consensus about the world's aesthetics is often unimportant, unlike in the real world. Each user is able to see a unique custom rendering of the virtual world and we predict no negative impact on other participants. Designing for individual aesthetic preferences also provides numerous potential benefits to system usability including better user satisfaction, an increased sense of presence, and improved task performance. These advantages are discussed in detail. We conclude with a brief discussion about potential experiments intended to clarify both the differences between shared and individual virtual environment aesthetics and the impact aesthetic appeal has on virtual reality usability.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Human Factors]: I.3.4 [Virtual device interfaces]: H.5.1 [Artificial, augmented, and virtual realities]: K.4.3 [Computer-supported cooperative work]:

1. Introduction

We believe that shared virtual environment inconsistencies provide opportunities not available in the real world. When communicating or interacting with one another in the real world, people perceive a common environment with the same attributes and characteristics. These cues can act as a common point of reference for discussions. Any differences in aesthetic judgments about common areas are attributed to differences between individuals. This, however, does not hold true for *virtual environments (VE)*. People viewing a virtual world using different displays may not perceive the same visuals due to factors such as colour contrast, update rates and display fields of view. Multiple users with head-coupled *virtual reality (VR)* looking at the same screen will not view the same world due to the provided single perspective [SPB06]. However, customizing content for single user VR systems is reasonable if it improves system usability. For example, a red-green colour-deficient viewer could be presented with a corrected version of the world to remove colour confounds. The frame rate of a VR system with little processing power can be improved by reducing the number of light sources in the scene while ensuring the luminosity is similar to other systems rendering the same world.

We define virtual reality as computer-generated sensory information intended to be perceived as part or all of a user's environment [SPB06]. We also require virtual reality systems to occlude some part of the real world environment from the user with computer-generated elements. Virtual environments are the three dimensional synthetic worlds perceived by a person using a VR system. Head-coupled VR uses the head (or eye) position of a user and the position of the display screens to determine the correct perspective into the virtual environment. Head movements ideally result in the same perspective shift in VR as a person would experience in the real world [SPB06]. We define immersive virtual reality as a VR system that occludes most of the real world and provides a head-coupled perspective with optional stereoscopic images. VR CAVEs, head-mounted displays, and immersive walls are all considered immersive VR systems [BF98]. Fish tank VR and VR workbenches will also be considered in this paper, although much of the real world is still visible using such systems. These virtual reality systems are briefly described in section 3. Non-immersive VR systems will not be discussed in this paper because they are not constrained to a one display to one user ratio.

Our working definition of virtual reality aesthetics is the interpretation of sensory information in relation to judgments of realism, presence and appeal. Realism does not mean the VE must look like the real world, but instead, the environment is perceived to be possible when disbelief is consciously suspended. We are restricting our discussion of aesthetics in this paper to virtual reality aesthetics. *Aesthetic factors* in VR are listed in Table 1. These are properties of the virtual reality system that can be adjusted to alter the aesthetic judgment of a VR user. Finally, group aesthetics will refer to the amalgamated set of aesthetic judgments taken from a group of people.

Numerous research articles have discussed the use of *shared virtual environments* and the development of virtual communities [MVS*02, SSUS00, BHSS00]. However, few people have recognized the aesthetic disconnect between the virtual world and real world. VR systems simulate real world perspectives using the synthetic camera model and these perspectives must be explicitly generated [FDFH90]. This permits a decoupling between different perspectives into a virtual world. Two people viewing the same virtual environment do not experience the VE in the same way since perfect output correspondence between VR displays is practically impossible [SPB06]. We suggest that these differences can be increased to provide a wealth of adaptability options for each user. Furthermore, we will argue that immersive VR displays can almost always guarantee a 1:1 user to display ratio, unlike most computer displays. This permits private custom content for individuals. Our central thesis is that shared virtual environments do not need to be perceived the same way by all users. Instead, each VR experience can be designed for the unique aesthetic preferences of each user and this can provide usability advantages without impeding usability or collaborations. Due to time constraints, we are unable to empirically test our claims, but we provide evidence from previous literature when possible and suggest ideas for future experiments.

2. Previous Work

2.1. Presence, Aesthetics and Traditional VR Metrics

Traditionally, a VR system's effectiveness was defined in terms of four main metrics: preference, perception, motor performance, and presence. According to our proposed definition of VR aesthetics, all four of these metrics should be used to gage aesthetic appeal in VR. Preference or appeal is simply the user's choice between different conditions and is often collected using questionnaires or during interviews [MAEH04]. Perceptual tests in VR normally attempt to use traditional cognitive psychology tasks to discern perceptual differences between conditions [BPMFPB05, GW02]. Motor performances in VR can indicate how motor tasks in VR such as targeted tapping and object rotation can differ across conditions or from the same tasks in the real world [LNWJ03,AW04,SS02,WG02]. Display field of view, head-mounted display weight, and system lag have all be shown to affect perception and motor performance in VR [EJA97, HGCRT02, WB94, CRWGT05]. Based informally on the author's own experiments, factors that negatively impact motor performances seem to frustrate users and reduce the system's appeal [SPB06].

Presence is the feeling of "being there" in the virtual environment [SS02]. Presence is frequently tested using self-reporting, behavioral observations, and measuring physiological responses [MRWFPB03]. VR latency, interactivity, and passive haptics have been shown to affect presence measures but image quality or realism has not been shown to affect this metric [MRWFPB03,KW05,SS02]. We assume that presence and aesthetics may be correlated, given our definition of VR aesthetics. We believe the primary aesthetic appeal of VR is the immersive experience and thus higher presence measures may indicate a greater aesthetic appeal. Factors that affect presence may affect aesthetic judgments.

Mortensen et al. [MVS*02] define co-presence, with respect to their remote CAVE-based VR system, as the feeling of "being there" with one or more other people. Co-presence provides an important metric for distributed virtual collaborations and shared virtual environments. They also reported that group coordinated interactions with virtual objects seemed to affect co-presence. When two subjects moved a virtual "stretcher", the lack of tactile feedback greatly reduced the feeling of co-presence, as did communication and network lag issues.

2.2. Aesthetics in Virtual Reality

Aesthetics may appear to be a minor issue in virtual reality systems. After all, the initial intent of VR is to present a virtual world as believable as reality. Real world design principals could simply be used in the virtual world. Research by Davies and Harrison [DH96] and Mortensen et al. [MVS*02], however, question this central assertion. Virtual worlds may not necessarily look or behave like the real world and aesthetic judgments may differ. Motor performance and perception in a virtual world may not be critically important in all applications, such as when treating phobias. Traditional navigation methods in the real world can be replaced by more efficient, but less intuitive, methods such as the go-go interaction technique or flying [WF97,PBWI96]. The aesthetic appeal of effective rendering styles and interaction technique may be unrelated to realism [TWG*04]. The Osmose system [DH96] even attempts to alter the viewer's aesthetic appreciations by disrupting our knowledge of the real world from the perceived environment. Synthetic worlds can

Category	VR System Properties That Potentially Affect Aesthetic Judgments
VE Image	Dynamic shadows, image quality, texture, lighting, object opacity and colour
Display and Global Settings	Display device used, field of view, display dynamic range, stereopsis, head-coupled perspective accuracy, and system lag
Haptics and Input	Input device used, haptic feedback, and glove based interactions
Sound	Sound usage, tone adjustments, surround sound, and audio rendering fidelity
Miscellaneous	HMD weight, tethered trackers and displays, and movement constraints

Table 1: *Virtual reality system properties that can be altered to potentially affect aesthetic judgments without altering shared virtual environment collaborations.*

provide useful tools to artists, providing more control and acting as a new artistic medium [KFM*01].

Immanuel Kant and other universal aesthetic philosophy followers assert that aesthetics have a universality derived from a shared human sense. Differences in aesthetic judgments result from personal and idiosyncratic desires and preferences of the individual [Dut01]. Conversely, aesthetic relativism is a philosophy that aesthetic judgments are based entirely on the individual, group, or culture and that no perfect consensus is possible. We will assume this latter school of philosophy is at least partially correct. As such, if each person's judgments are unique, a VR experience could be much more pleasing if custom designed for the individual rather than for the diverse tastes of a group. Furthermore, virtual reality requires that there is a computational mediator between the objects observed and the viewer. Each perspective generated uses a different machine or process and computational abilities are not uniform across viewers. Unlike aesthetic judgments in the real world, the universality of the world itself can not be assumed. Universal aesthetic agreement is thus practically impossible in VR irrespective of any aesthetic philosophy.

3. A Display Based Taxonomy of VR

Immersive virtual environments are generated using one of three traditional methods, categorized by what user or object is tracked and by the display's mobility [BF98]. First, head-mounted displays (HMD) move with the subject's head and are tracked to provide a correct VE perspective. CAVEs, fish-tank VR, and VR walls use stationary displays and tracked head positions to provide the correct perspective. Finally, chameleon VR uses a tracked display to present an appropriate "window" into the virtual world. We discuss each of these techniques in turn, identifying why a single user-to-display relationship can be assumed.

3.1. Head-Mounted Displays

Head-mounted displays provide a key feature unique to VR systems: HMDs remove almost all real world visual cues from the user. Each user experiences a unique VR perspective via view screens placed in front of the eyes. The relative eye to display vectors are considered static. By tracking the HMD's position and orientation, a VE perspective unique to the user's head position can be provided.

For each unique rendering of the virtual scene, a different virtual scene can be presented, even if the same perspective is used. This is a key point: by removing real world visual cues and providing personal displays, two people using two HMDs can experience different virtual worlds and be completely unaware of the discrepancy. If the changes are minor enough, subjects may not note a difference even when allowed to communicate freely with each other. Although the video signal to an HMD can be duplicated and presented to others, a passive observer is not head-coupled to the view of the virtual scene. A passive observer also does not have the same aesthetic experience as an active participant. If virtual scenes do not need to be identical across all displays for users to collaborate, why do the same shading method, image fidelity, and update rate have to be used? More importantly, if different systems are rendering each VE perspective, why not adjust the frame rate, image quality, and audio rendering so that it is ideal for the given system and user? Some users may be more susceptible to VR induced nausea due to system lag. Reducing the image quality to reduce lag is thus ideal for that user but not for all users. Similarly, HMD based VR systems need to render a scene twice each time a non-stereoscopic system renders a frame in order to have comparable update rates. System and user requirements can differ substantially for any shared virtual environment and we believe customizing aesthetics for individual users can take advantage of this issue.

3.2. Stable Screen VR

VR systems that do not require the view screens to move include driving simulators, workstations, VR CAVEs, and fish tank VR systems. CAVEs surround a user with displays, providing the user the ability to see virtual images in almost any direction. Immersive wall VR places a single large screen in front of the user and fish tank VR presents virtual images using a conventional monitor. Frequently in these systems, the head position of the user is tracked (or assumed to be in a particular place) and the virtual perspective is generated accordingly. Therefore, co-present collaborations in head-coupled stable screen VR systems can result in problems. Generally the VR perspective will be correct for only one head position at a time [Smi01]. For other participants, the image may appear skewed, the depth information about the image can be wrong and hidden edges and walls may be noticeable. Aesthetic judgments could be significantly influenced by these perspective issues.

Being able to see a co-located collaborator has advantages, particularly in terms of communication. Co-present collaborations using stable screen VR are also the only times when group consensus about aesthetics need to consistently be considered in VR. This may be why car manufacturers like General Motors have used immersive projection technologies like CAVEs since the early nineties [Smi01]. These systems helped facilitate co-present and distributed collaborations about car prototypes. If immersion and presence are the collaborative goals, then perspective issues with co-located stable screen VR collaborations present a problem. If face-to-face communication is more important than immersion, then these systems are currently optimal [BF98]. Stable screen VR for remote collaborations provides a unique display to each user and perspective issues are avoided.

Shoemaker and Inkpen's [SI01] work on single display privacyware permits multiple unique VR perspectives by splitting the viewing time allotted amongst the number of users. Viewing time can be allocated using the shutter glasses used to provide stereoscopic depth cues. If three people are using a CAVE, then each person's shutter glasses are off for $2/3$s of the time, displaying the left eye image $1/6^{th}$ of the time, and displaying the right eye image $1/6^{th}$ of the time. Viewers never see the virtual world at the same time. Shoemaker and Inkpen's technique means that each user gets a unique display like HMDs naturally provide. Unfortunately, this method does not scale well beyond two users. For n simultaneous co-present users, during every second each user would only see the screen for $1/n^{th}$ of a second.

3.3. Tracked Screen VR

We will refer to the final VR technique as tracked screen VR and this includes Chameleon VR [BF98]. By tracking a viewing screen as it is moved, the display acts as a window or portal into the virtual world. This method allows multiple viewers to see the same VR scene and group aesthetics may need to be considered. If head-tracking is used, the same stable screen perspective issues arise. Large screens can be awkward to move and so most tracked screen VR seems to be aimed at a highly mobile personal screen for each user. In this case, user specific aesthetics can again be provided because a one person to one screen paradigm is assumed.

4. Advantages of Individual Based Aesthetics

We propose that customized aesthetics for virtual reality potentially provides numerous advantages for usability, preference, and presence, provided each particpant sees a unique private display. This allows the virtual experience to be different for each participant, even in a shared VE. Future empirical testing is required to support these claims. We hope proposing these advantages will promote debate, discussions, and research in this field.

VR customizations changes must be minor enough so that objects and landmarks are the same, or appear to be the same between users. We feel aesthetic factors of the VE fit this qualification. Customized aesthetic factors provide affordances not possible in the real world. Wallpaper patterns mapped to the walls of a virtual room may be changeable by the user with presumably little consequence to the collaboration. This could make the virtual experience more enjoyable. If the wallpaper pattern becomes a point of discussion, however, such a customization can be problematic. Saying to other users "Meet you in the plaid room" is counter productive if they see that room's walls as solid green. It is critical that customizations do not impair the formation of shared references between users if collaborations are important. Large custom changes to objects in the VE should be done with caution.

Adaptations to aesthetic factors can help users with perceptual or performance problems. Isoluminant reds and greens are represented with the same intensity to a red/green colour blind person. Approximately 5% of the male population has deuteranomaly [War00]. By slightly adjusting the VE colour scheme for colour blind individuals, isoluminat visual cues can be resolved (Figure 1). Although these colour changes could be done for all users, it may negatively affect the aesthetic appeal of the VE for people with full colour vision. Similarly, customized virtual perspectives could help older users by presenting images with a high luminencence or with sharper edges. Adjusting the image quality of older VR systems or the number of light sources may improve the system update rate, thereby improving the user's sense of presence by sacrificing the VR image fidelity [MRWFPB03]. Increasing the frame rate should also reduce the probability of VR induced nausea, which is a user dependent trait [FH96].

Burns et al. [BPMFPB05] have suggested the use of "tricks" between tactile feedback, proprioception, and the provided virtual reality perspective. These tricks involve a decoupling between real world actions and virtual actions, such as slightly drifting the image of a virtual hand to make the user reach for a place not corresponding with the virtual hand's position. These tricks allow users to experience virtual environments larger than the real world environment permits and to prevent a subject's hands from intersecting seemingly solid virtual objects [BPMFPB05, RSS*02]. It is not clear how two users perceiving the same VE can adjust to these techniques. A user walking into open virtual space may accidentally walk into her partner in the real world. Permitting individual based aesthetics in VR should allow design-

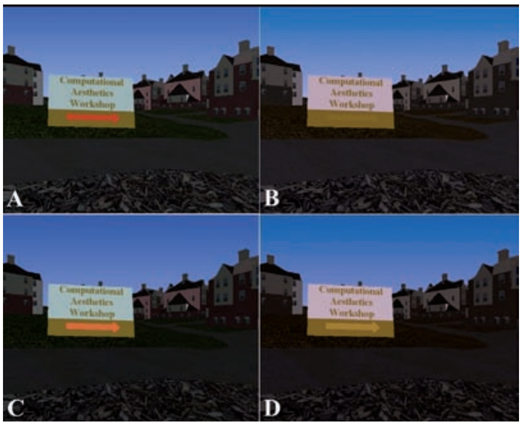

Figure 1: *Customizing a virtual environment for users with deuteranomaly (red-green colour blindness). A) Original scene. B) Original scene filtered by deuteranomalous (red-green colour blindness) filter [Wic06]. C) Mild colour customization of the original for a deuteranomalous person. D) deuteranomalous filter applied to C).*

ers to “tweak” the visuals for some users and not for others, preventing potential accidents in the real world.

The virtual representation of a user in the VE is called an avatar. Slater et al. [SSUS00] suggests that decoupling real world and virtual world actions may provide additional information. An avatar that is sitting down or sleeping may indicate that the person being represented has temporarily left the virtual world. If each user gets a unique perspective then custom information can be supplied to some collaborators but not to others. Perhaps specific avatar colours or labels in the VE indicate who you have identified as friends. Maybe a user’s avatar can be hidden from some users. Two people in a private conversation could have their avatars appear transparent to all other users. Provided each user gets a unique display, a wealth of customizations are possible.

Personalized aesthetics offer a number of customizations and possible advantages to VR users not available in the real world. Furthermore, since equivalent visual information provided to each user is practically impossible, there seems to be little to no performance disadvantages to these alterations. We need to point out two caveats to our argument, however. First, customizing VE content for a specific VR system or user takes time. This time commitment is not always possible [SPB06]. Second, virtual environments should not permit customized aesthetics when a group consensus about virtual objects is absolutely necessary, such as when automobile manufacturers evaluate prototypes as a group [Smi01]. If this trait is required, the head-coupled perspective into the virtual world should also be optimal for all participants and each system should attempt to provide the same display field of view, update rate, and colour contrast to each user. Keeping VR factors synchronized seems critical if a meaningful consensus about a virtual object is to be reached.

5. Future Research Directions

If people in a shared virtual environment experience different aesthetic factors, a series of interesting research questions arise. First, will subjects recognize any aesthetic discrepancies in the VE? If two subjects look at s virtual world rendered using two different shading models, would they notice? How long would it take two subjects to identify a number of differences in aesthetic factors if they are permitted to communicate with each other? Could knowledge of such a discrepancy affect their performance? A clearer understanding of the cost-benefit trade-offs between aesthetic factors is also necessary if customized perspectives are to be intelligently incorporated into a VR system. For example, HMDs with better optics frequently weight more and it is unclear how weight and display quality factors interrelate. A fertile research area may also be the effects of user defined VR customizations on appeal, presence, and perceived realism.

Shared perspectives using CAVEs pose another interesting question. If only one perspective is correct, how does an incorrect perspective affect presence, performance, and VR aesthetic appeal? We are unaware of any research that examines this issue. Examining how well subjects perform a search task or motor task with varying degrees of head tracking correctness could help identify the performance, preference, and presence costs of sharing a stable screen display. Finally, although supported by previous research, the proposed advantages to customized VR aesthetics still need to be empirically tested.

6. Conclusions

For many shared immersive virtual environments, displays are provided for each user, permitting the decoupling of VE design features between viewers. We have argued that customizing aesthetic factors in a virtual environment should provide benefits to usability, presence,and enjoyment with little to no impedance to collaborations. Three major styles of immersive VR systems were discussed as to how and why individual displays should be provided when possible. Finally, we identified several future research directions that should be explored to fully understand the implications of customizing aesthetic factors in VR. We believe that virtual reality provides collaborative opportunities unavailable in the real world, and the role of individual aesthetic preferences are key to these features.

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