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PERCEPTUAL ARTEFACTS, SUSPENSION OF DISBELIEF, AND REALISM IN STEREOSCOPIC 3D FILM

IN THE EARLY DAYS of 3D film there was considerable resistance to the medium among many in the industry. Spottiswoode and Spottiswoode[1] attribute this to their belief that many of the established critics and directors felt that stereoscopic film was an intrusion of technology and science on the arts. Since artists did not initiate it, the 3D medium was considered a negative influence for it made artists change their approach to fit the technology. This attitude continues today, as some film critics and filmmakers argue that the use of S3D is merely a trick or distraction that constrains the filmmaker and is not integral to the art of storytelling. Of course this view is not held by all, and there are many in the film industry who would agree with Murray Lerner who argues that 3D is not just an enhancement to 2D but a rich and distinct art form.[2] The attraction to and aesthetics of S3D film are inherently complex topics. Here we discuss some of the factors that keep audiences coming to 3D productions and the ways in which these can be incorporated into the syntax and grammar of cinema.

Historical and Perceptual Context for S3D Film

Binocular viewing adds information to the viewer's moment-to-moment sensory impression of the world around them. This (combined with dynamic changes when the viewer or objects in the scene move) helps to disambiguate the 2D images formed on the retina. A 2D photograph or retinal image is inherently ambiguous as it is a 2D projection of a 3D world. However, assumptions about the structure of the world enable the use of pictorial cues that artists have used to portray the "missing" depth for centuries: linear perspective, relative size, occlusion, atmospheric effects, and so on. Our ability to interpret photographs and paintings attests to the utility of these pictorial cues and is the perceptual basis for television, cinema, and still photography. Nevertheless, the monocular image is ambiguous and prone to erroneous interpretation and illusion.

This ambiguity can be greatly reduced by including a second view of the scene taken from a different vantage point that constrains the possible interpretations. That two eyes are important for

depth perception was known in ancient times. However, the basis of this link was not understood until the celebrated Victorian scientist, Charles Wheatstone, invented the stereoscope in the 1830s. His invention clearly demonstrated that it is the differences or *binocular disparities* between the two eye's images that form the basis of the enhanced binocular depth perception. Noting the vividness and solidity of the 3D forms produced, Wheatstone called depth from binocular disparity *stereopsis* or "solid sight." Wheatstone's invention and its subsequent modification by Holmes, Brewster, and others triggered one of the first media crazes of the modern era. Combined with the new technology of photography, a market for stereo photographs grew rapidly. Stereoscopes were common in Victorian parlours and served as sources of entertainment and conversation.

The stereoscope's dominance as an entertainment device was eventually superseded by new technologies such as motion pictures. Stereoscopic presentation was a goal of many pioneers of cinema as it was for the early still photographers. Even Edison patented a stereoscopic motion picture device, known as the kinetoscope. Technically, stereoscopic cinema was demanding since the alignment, matching, and synchronization of two film sequences had to be maintained through filming, editing, printing, and projection. Thus, widespread distribution and commercial success of stereoscopic 3D film did not occur until the S3D boom of the 1950s. Although there were many reasons for the rapid decline in the number and box office returns of S3D films after the peak in 1953-1954, some of the most important are related to our current topic of visual perception. While technically excellent S3D could be produced with 1950s techniques, delivering this content to the viewers' eyes required skill and meticulous care at all stages. This was difficult to reliably achieve with the analog technologies of the time so that misalignment and mismatch led to irregular user experiences and the classical problems of S3D: fatigue, eyestrain, discomfort, poor image quality, double vision, and loss of the stereoscopic depth effect. Ironically, even with the improved precision and repeatability of digital cinema, irregular quality, notably substandard image brightness and poor 2D to 3D conversions, once again impact the viewer experience and threaten the viability of S3D film as a commercially successful art form.

What Does Stereopsis Bring to the Perceptual Experience of Film?

We believe that it is important for filmmakers and film theorists to understand the impact of stereopsis on the sensory and perceptual appreciation of film (and of course on the aesthetic and narrative aspects, but we will only consider a few select examples in this essay). The most obvious contribution made by stereopsis is the qualia that it enables or enhances: the third dimension. This not to deny that 2D images do not provide depth impressions (see the discussion of pictorial and motion cues above) but rather the implication is that stereoscopic viewing makes these impressions more concrete or quantifiable. In line with the dimensionalization view of S3D, stereographers—specialists on S3D film crews who focus on stereoscopic production values—often concentrate on the range of disparity in a given scene. This is pragmatic as these parameters are highly relevant to avoiding the unwanted side effects of S3D discussed in later sections. While there is no question that stereopsis improves the ability to precisely judge depth we argue that the simple addition of depth is not the most relevant aspect of stereopsis for S3D film. Instead, the perceptual experience is strongly dependent on less quantifiable factors. Going back to the etymological origins of stere-

FIG. 1 A frontal view of a mirror rig shows the lens of the camera which films through the partial (beam splitter) mirror, as well as the reflection of the lens of the second camera that would record the image reflected off it. The distance between the two lenses is the inter-axial distance (IA). If there was no horizontal separation and lenses were vertically aligned as well, only one lens would be seen.

FIG. 2 Ali Kazimi, Director, working with Director of Photography Rozette Ghadery who is operating a stereoscopic 3D mirror (beam splitter) rig during the filming of the short drama *Hazardous*.

opsis as solid sight gives insight into what impressed Wheatstone. Stereopsis lends a sense of solidity and volume to objects and of space and separation between them. It helps to define surfaces and their edges and to highlight surface properties such as sheen and texture. Here we will outline how this enrichment of spatial perception supports various artistic goals such as realism, spectacle, spatial consistency across shots, and intimacy. Stereopsis has also been shown to be important for perceiving the layout of the world about us and guiding our motion through it. Thus, we will also argue for a role in supporting artistic goals such as immersion, embodiment, and spatial context.

Stereoscopic presentation also brings perceptual challenges and artefacts to the experience of a film. To the casual reader this might be surprising as stereoscopic vision is our natural way of viewing the world but the simulation of a stereoscopic view of the world is only rarely geometrically perfect. As discussed below, geometrically "correct" viewing conditions can only be met for one individual positioned at a particular location in a theatre—all other observers will experience a range of geometric distortions. To a point, audiences are remarkably tolerant of such distortions. A potentially more serious challenge to the S3D experience is distortion due to the choice of rig parameters or due to variation in the size of the screen. Stereoscopic rigs consist of two separated cameras—one offset to the right and one to the left—to provide the right and left eye views, respectively. Key parameters include lens selection and the amount of camera separation (FIG. 1). The screen size variation is particularly problematic in our era of IMAX screens and handheld displays. Filmmakers must make choices regarding stereoscopic effects that can cause perceptual distortions and artefacts.[3] The use of a large camera separation, for instance, can induce miniaturization effects where objects and people appear toy-like. Other artefacts may make the world seem artificially large (gigantism) or people appear as cardboard cut-outs. With careful consideration most of these distortions can be minimized, accommodated, or as described below used to enhance the intended ambiance (FIG. 2).

Other Worlds: Immersion and Looking Through the Window

S3D can support a variety of experiences and one of the most intriguing aspects of the media is its ability to present a compelling 3D environment. Our experience of this environment varies depending on the technology and artistic intent—we can be drawn in and immersed in it, view it as outsider, view a world beyond and out of reach through a window, draw parts of that world toward us or hold it in our hand on a mobile device.

The window is a common and compelling metaphor for stereoscopic film. It is useful artistically and as a pragmatic response to perceptual and geometric constraints. In conventional cinema, the edges of the screen define the area where stereoscopic (or 2D) imagery can be presented. Obviously, objects located outside the field of view of the image above or below the screen cannot be represented in the image. These can be troubling or ignored depending on the degree to which they attract attention. Objects traversing or extending across the space from in-screen to beyond-screen (we will reserve the terms off-screen and on-screen for depth relative to the screen) may be more disturbing, particularly if they extend beyond the sides of the screen.

Why might this be so? To the left and right of the screen the situation is more complex as objects can be visible to one eye but not the other. Such monocularly visible objects are powerful stimuli for depth perception.[4] In the natural world monocular features commonly occur at the edges of objects where one eye can see slightly more of the background (or of the object itself) than the other. In these situations the monocular information is used along with the disparity information to interpret the depth in the scene.

Stereoscopic presentation introduces a perceptual asymmetry in what can be represented in front of or beyond the screen. Consider an object that is placed beyond the screen so it is visible to one eye but not the other (FIG. 3). This arrangement is entirely consistent with the view in the latter eye being blocked by the opaque edge of the screen (and wall or curtain beyond). Thus, the object appears to the viewer as it would through a window, and the edges of the screen define a window into the world beyond. This is a natural and comfortable situation experienced in everyday life anytime we look out a window. An object presented in the monocular zone in front of the screen however has no such natural interpretation. Under rare circumstances the object could be camouflaged against the surround of the screen in one eye but typically is inconsistent with the scene. Such discrepancy can draw attention and be disturbing, can result in the loss of the depth impression or cause features to be "pinned" to edges of the screen. While this might conceivably be used for artistic purposes it is generally to be avoided.

Given these factors, stereographers often embrace the window defined by the screen and use it to effect their purposes. This is often referred to as viewing through the "proscenium arch" in an allusion to the window around the scene and performers on a proscenium stage. In some recent films such as *Up* the action deliberately takes place nearly exclusively through the window of the screen. Bob Whitehill, stereoscopic supervisor at Pixar on the film explains "… we want stereo 3D to be a window into a new world, not draw attention to itself. People go to the movies to get lost in the movie."[5] Many other movies rely on the window metaphor with occasional out-of-screen effects for dramatic purposes. In this paradigm, out-of-screen objects that cross the screen edge boundaries are known as stereo window violations. They are usually avoided by controlling the camera parameters mapping real world depth to screen depth in order to push possible window violations back beyond the screen plane.

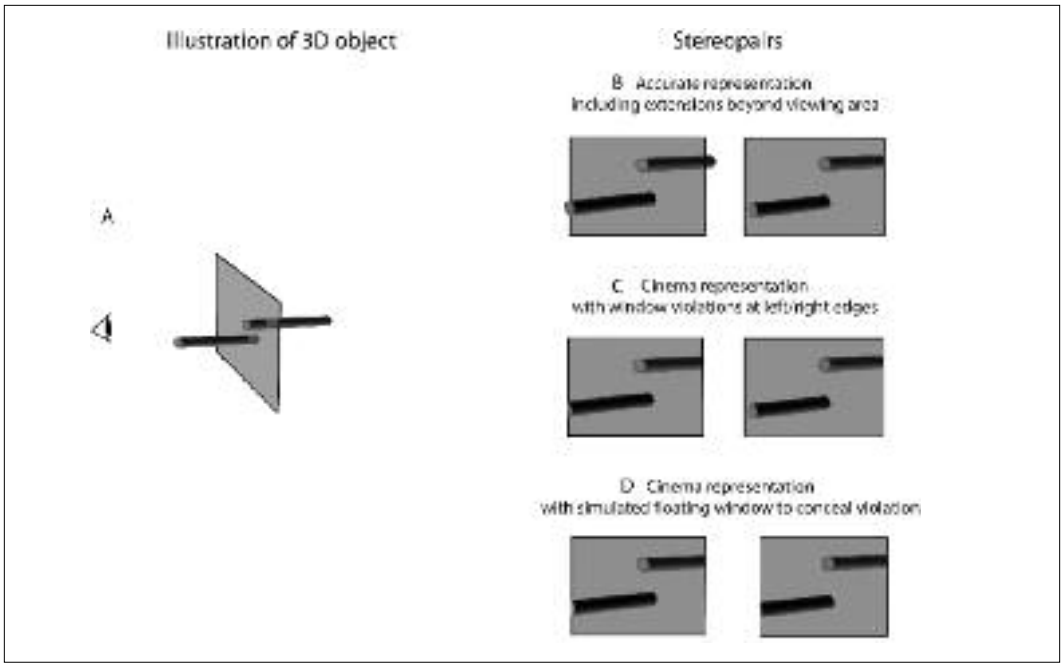

FIG. 3. Monocular occlusion and the asymmetry between out-of-screen and into-screen screen stimuli. On the left is a 2D representation of the stimulus, a pair of rods that extend beyond the borders of the screen either behind and in-to-screen (top rod) or in front and out-of-screen (bottom rod). The stereopairs to the right show how the objects should look naturally (B), where the occlusions occur when projected on the theatre screen (C), and how floating windows can be used to reduce the negative effects of window violations (D). In all cases, when crossing the eyes to fuse the stereograms (http://www.starosta.com/3dshowcase/ihelp.html), the upper rod extends into the screen and the lower bar extends in front. Monocular occlusions occur in both cases of window violation (C), but as outlined in the text, are more disturbing in the case of the protruding bar.

Another classic technique used to cope with window violations is known the "floating window." In this technique part of the image on the edge of the screen is masked. The masking is given disparity to set it off in front of the screen forming a virtual window floating in front of the screen. If this window floats in front of the potential stereo window violation the perceptual inconsistency is removed, as the window will naturally occlude the object. The technique can be introduced on one side of the image only, leading to a slanted floating window (although the screen is usually too wide for this to be noticeable). The floating window is an effective way to manage window violations but will introduce changes in the projected window size. Further, filmmakers using this technique need to be aware that their careful planning can be undone when it is exhibited—theatres have reportedly magnified the image or masked the sides of the screen with curtain to eliminate the "incorrect" changes in image size over the course of the film.

Bringing objects through the window frame allows the filmmaker to draw the action into the theatre space. This is then analogous to "breaking the fourth wall" in a proscenium theatre when the actor intrudes into the audience space (or directly addresses them). This space has been used in the past for spectacle and gags but can also be used more subtly to draw parts of the scene toward the viewer. A deep and rich space centered on the screen has been used to promote a sense of immersion, albeit not in the enveloping and interactive sense of virtual reality. Bringing action into

very near space is sometimes used in theme park films and in games. Perceptually this has the advantage of operating where stereopsis is most acute and in the range where the role of the vergence and stereopsis in hand movements and direct interaction with objects in the environment can be leveraged. In long-format film however such effects can only be used sparingly due to the unwanted side effects of visual discomfort.[6]

Stereopsis provides important information about the layout of the world and our motion through it. Thus it is important for situating ourselves in the world and making spatial sense of our surroundings. One of the most compelling aspects of S3D film is its ability to create a vivid sense of immersion such that the viewer feels as if they are part of the scene or story. An excellent example of the use of S3D to put the audience in a location occurs in the IMAX film Space Station.[7] The director of photography James Neihouse points out that the 3D gives the audience the sense that they are present inside the station with the astronauts in a way that 2D could not.[8]

Immersion in the enveloping, surrounding sense of virtual reality is limited in the conventional cinema. The stereoscopic window provides a window into a rich 3D world but also separates the viewer from it. In conventional theatres, immersion has been fostered by wide field displays that fill large parts of the visual field. Part of the decline of S3D films in the 1950s was due to the rise of competing technologies such as CinemaScope and Cinerama, which promised immersion through wide field of view rather than stereoscopic depth.

There is of course no reason that immersion cannot be fostered by both enveloping displays and S3D. IMAX pioneered the use of large format 3D and produced films that remain S3D classics and are renowned for their immersive quality. In addition to their orthostereoscopic approach outlined below, the sense of being in the scene is significantly augmented by the size of the IMAX theatre screen (22 x 16.1m). From the majority of locations in the theatre the edges of a screen this size are well outside the high-resolution region of the visual system when a viewer looks at the centre of the screen. This loss of a cinema window combined with the use of negative parallax (in front of screen) reduces barriers to immersion and enhances the feeling of being there. Future unconventional cinema, theme park rides and special purpose exhibits can heighten the sense of immersion by enveloping or wrapping the display around the viewing in CAVEs or wide-field displays, and by adding other sensory information such as motion and touch.

It should be noted that immersion does not necessarily imply realism or engagement. Some S3D experiences can be akin to watching a live stage show—realistic and engaging but with separation of the audience as outside observers rather than immersion. Hitchcock's 1954 S3D classic, *Dial M for Murder*[9], is a prime example of an engaging and compelling story but viewed as outside observer. The S3D effect is much the same as watching a stage play which suits the films' origins (being adapted from a West End stage play). The ability to support the intimacy and theatricality of live entertainment may explain why the medium is popular for dance and concert films. In the acclaimed *U2 3D*[10] production, both aspects of S3D are used to great effect, so much so that reviewers talk about coming away from viewing the film feeling as though they have seen the group live. One reporter writes that "By the end of *U2 3D*, I truly felt like I had attended a U2 concert, with added the privilege of having communed with the music in a way that an ordinary concertgoer never could."[11]

While powerful and effective, the sense of immersion in S3D film can be tenuous regardless of the format or screen size. As described above, content scaling can produce unwanted distortions

that not only distract the audience, but in doing so break the sense of immersion in the scene. For example, a common consequence of presentation on a smaller than intended display is flattening of objects and people so that they appear planar, but at separate locations in depth. Such effects can draw attention to the mediated nature of the film, and disturb immersion. Technological issues can also be responsible for reduced immersion in S3D. Crosstalk is one important issue and refers to the situation where part of the left eye image is visible to the right eye (and vice versa). The presence of crosstalk as low as 4% has been shown to degrade stereoscopic depth percepts[12] and cause discomfort. Lack of control over projection venues is another common concern for the S3D production industry, particularly with respect to screen brightness.[13] Under optimal conditions, the amount of light that reaches the audience is a fraction of that available in 2D cinemas (approximately 33%) primarily due to the use of polarized[14] filters and eyewear to separately present the two eye's images. Unfortunately, theatres may not ensure optimal luminance levels; lamps will last longer if not used at maximum output levels and consume less power. In addition, lamps are used as long as possible, even though brightness falls off as projector lamps reach the end of their anticipated lifetime. Low image brightness can significantly affect the both the sense of immersion and enjoyment of a S3D film. With extreme luminance reduction colours will appear muddy (less saturated) and image contrast will be degraded, resulting in a concurrent loss of stereoscopic depth. Finally, even if immersion is compelling it can have unwanted side effects. Virtual reality research has suggested that increased immersion may be tied to motion sickness symptoms and a recent study suggests this may also be true for immersive cinema as well.[15]

Reality, Fantasy, and Abstraction

One of the defining and exciting characteristics of S3D is its potential to increase the fidelity of the cinematic world presented to the viewer. The enhanced realism through natural binocular perception and improved depth representation is often touted as a major factor in support of adopting S3D. It helps explain the popularity of the format for virtual reality, simulations, documentary, and theme park films. On the other hand, in many respects modern narrative cinema is not very realistic and relies on convention, film language, and expectation (see below) to define the experience and story telling rather than a faithful, high-fidelity rendition of the events and scenes. How the potential for improved realism and fidelity can be effectively integrated with the conventions and language of film has been a major concern for stereoscopic filmmakers. S3D techniques might allow for simplification of these conventions as more spatial understanding might be implicit in this media rather than explicit through film grammar. Although not yet studied, the capability of S3D to support spatial understanding and orientation might be expected to provide a more coherent sense of the layout in the scene and hence of continuity across cuts and changes in vantage point. It is likely that S3D will call for its own unique conventions built upon but different from existing 2D language.

One of the long standing approaches to achieving realism in 3D film is to try to mimic the geometry of the human visual system during filming and to ensure that the viewing distance and angle correspond to the placement of the cameras relative to the scene. This is the approach taken in virtual reality and other high-fidelity stereoscopic graphics displays such as aircraft simulations and is referred to as *orthostereopsis*. The resulting projected image will be a faithful reproduction of the original scene, including depth relationships and object size/shape. Perfect orthostereopsis is not

feasible for cinema, because it can only be created for a single location in the theatre, for individuals with exactly the same interocular separation as the separation of the dual cameras, and it puts severe constraints on filming conditions (e.g., distance of the cameras from scene).

Many IMAX films, especially those involving S3D pioneer Hugh Murray, have used a philosophy of approximate orthostereopsis. The wide field of view allows the use of lenses with a perspective similar to the audience's view, parallel cameras and effective disparity appropriate for the eye spacing of the average viewer. The intent is a human scale perspective on the world presented to the audience.[16] When the scale is natural it helps to support the sense of immersion inherent in the IMAX format. Such a goal is reminiscent of the aims of immersive virtual reality in promoting presence. Presence is defined as a state of being there—the sense that one is located in and engaging with the virtual world and that the events in that virtual world are actually happening despite *knowing* this is not the case. Given that presence is fostered by natural and consistent simulation, it is related to the suspension of disbelief believed to be critical to narrative cinema.

However, in movies, the suspension of disbelief also depends on the viewers' willingness to engage with the story. The success of this endeavour then relies on their readiness to discount the knowledge that they are witnessing a mediated experience and become engaged and engrossed in the story. Such suspension of disbelief is important for the perceptual experience of watching a film in that it drives and supports the storytelling. As a consequence, attempts at realism can interfere with suspension of disbelief and narrative in a number of ways related to perception.

First, as we have discussed above, S3D media are prone to artefacts and a truly orthostereoscopic experience is not feasible. The 2D cinema is not a high-fidelity representation of reality either but we have grown accustomed to the conventions of cinema. Therefore, despite the artificiality of cuts, scene changes, time distortions, and so on we seamlessly accept these as part of the 2D storytelling process. These mechanisms are essential for effective storytelling but their artifice might become more apparent in the heightened reality of a high-fidelity stereoscopic film.

Second, artefacts and limitations might become more troubling as the representation approaches reality. This would be a manifestation of the well-known phenomenon of the "uncanny valley" introduced by Mori[17] to describe the strange disturbing sensation experienced as an artificial experience (in his case humanoid robots) approaches but falls short of reality.

Third, the S3D experience can call attention to itself rather than the narrative. For example, the novelty of the experience can detract from the narrative. For instance, a viewer may visually explore a rich and complex stereoscopic scene or attempt to reach and touch an object in near space. Spectacular effects can sometimes interfere with the suspension of disbelief and draw attention to the movie as a mediated event. Rob Engle notes this can often occur with out-of-screen effects (negative parallax):

> When you're talking about narrative cinema, anytime you use overt negative parallax, your have the potential for taking the audience out of the narrative. You're reminding them that they're watching a movie. And most filmmakers don't want to do that.[18]

He argues that even in horror and comedy, where such effects are deliberately and effectively used, the filmmakers needs to draw the audience back into the narrative afterwards.

Ray Zone repeatedly argues, in his book on the origins of stereoscopic cinema, that realism and spectacle were, on one hand, the driving force that fuelled interest in stereoscopic media but, on the other hand, also limited it to novelty status due to perceived impact on narrative and suspension of disbelief. In one passage he sums up both the problem and the potential solution:

> The utopian dream of stereoscopic images in cinema, then, was a double-edged sword. The heightened realism it presented was alluring, but it had to be justified in the context of narrative.[19]

Reality is not relevant when the scene is fantastic or not on human scale. As discussed above, S3D distortions such as miniaturization and gigantism are normally artefacts to be avoided. However, these can be used for effect to produce the impression of doll worlds or larger than life scale. Stereo 3D media have been effectively used to show a large range of scales from the impressive vistas used in IMAX documentaries to the microscopic world of insects. In the popular large format film *Bugs!*[20], the tiny performers are filmed with minute camera separations of approximately one third of an inch, and then displayed on an enormous screen. The 2D larger-than life effects combine with the stereoscopic effects to create a compelling intimacy on a large scale. Sean Phillips the director of photography of the film, notes that while the creatures would still appear larger than life in 2D, that venue would provide a less intimate experience.[21]

One of the enormous advantages of 3D filmmaking is the ability to create impossible scenarios where, for instance, the amount of depth varies from scene to scene. In a number of films the camera separation is changed within a single shot, as the cameras move from a distant vista to an interior scene. For instance, Murray describes changing the separation between cameras from 100 feet to 2.5 inches in a single shot in *Cyberworld*.[22] Transitions of this type may be effectively invisible to the viewer, but maintain the sense of 3D space in the scene that would be lost if a fixed separation were used.

As mentioned previously, changing camera separation over a large range can create distortions of size and shape. While these distortions are typically avoided by filmmakers, they can also be exploited to create the sense of the bizarre and unnatural. Murray Lerner used this technique in the Disney theme park show, *Magic Journeys*.[23] He shot separate components of a scene using widely different camera separations, and then composited them to generate toy clowns, and a boy dancing on the rim of a magician's hat.

On similar lines, in some cases it is possible to intersperse 2D footage within 3D film. If done effectively, the audience is unaware of the absence of stereopsis. This can be achieved by only using this technique for distant landscape shots, where naturally the depth from stereopsis will be minimal, or by combining multiple cues to depth within the shot, to lessen the impact. In *Avatar*[24], James Cameron employs a conservative range of depths overall, and intersperses shots with no stereoscopic depth throughout the film.[25] Occasionally, in some films, 2D content is presented with a disparity offset relative to the screen so that it appears behind the screen. Such "poor man's" stereo is surprisingly effective especially for brief shots. We believe that the offset from the screen breaks the expectation that the shot is 2D and promotes the use of the monocular depth cues in the image.

The combination of 2D and 3D effects can also be used to create spectacular effects. In his short 1996 tribute to Hitchcock's *The Birds 3D*[26], Lerner leads the audience to think they are going to see

old film footage, and suddenly (in 3D) the screen rips, and birds fly out at the audience. For an instant the viewer feels that they are being attacked and so, in a remarkable twist, Lerner is able to convey the sense of terror so prized by Hitchcock himself.

As well as intermixing 2D and 3D shots, conceivably 2D and 3D content could be mixed within a shot for dramatic effect. Similar techniques have been with other parameters, for example like colour and black and white content was mixed to aid the narrative in *Pleasantville*[27] or even how cartoon animation and live action were integrated in *Who Framed Roger Rabbit?*[28]. Depending on the choice of content and stereoscopic shooting parameters the dimensional discrepancy could be obvious and could draw attention or be unobtrusive. As far as we know, such mixed shots have not been used in film.

Spectacle, Emotion, and Intimacy

Stereoscopic 3D can have a profound effect on the viewer's visual experience and, as a result, on their understanding and response to the film. S3D can be used to impress and fascinate or to evoke engagement and emotional responses.

The best-known but perhaps crudest use is the ability to present spectacle to the viewer. Spectacular effects based on large disparity such as impressively deep scenes and large out-of-screen effects ("spear poking") have been a mainstay of the S3D cinema since the earliest days. These effects are especially common in the comedy and horror genres where they are used to impress, surprise, or titillate. In other genres such effects are less common since, as discussed above, they may draw attention to the medium itself. This is not to say that spectacular effects are not judiciously used; for example, in the famous out-of-screen effect in the murder scene in *Dial M for Murder*[29] and in the aftermath of the death of the villain, Voldemort, in *Harry Potter and the Deathly Hallows: Part 2*.[30]

In contrast, the use of S3D to influence emotion is usually more subtle. One of the most exciting and open issues in S3D filmmaking is the relation between stereoscopic depth and emotive impact. Filmmakers are starting to experiment and explore these aspects. Prior to shooting, control of the key stereo rig parameters is usually carefully planned by the stereographer for comfort, visual impact and dramatic effect. Often, particularly in animation, a depth script is produced that lays out the depth range on a shot by shot basis to ensure appropriate scale and a match to the desired emotional response. For example, in *Up*[31] Bob Whitehall points out that they

> …created a graph of how we would use stereo. In the beginning when the character is happy there is a deep space, then it flattens out when he loses his wife and then it slowly increases throughout the film. Just like the lack of color in dark scenes make the vibrant images stand out more, so do the flat scenes enhance the scenes where you are more aggressive with the 3D.[32]

Similarly, in the film, *Coraline*[33], the depth is increased in her "other world" along with colour saturation to enhance the distinction between the two places. In *Beowulf*, the depth was subtly changed to reflect the power relations among the characters and was slightly exaggerated to highlight the unreality of dream sequences.[34]

The spatial and emotional aspects of S3D can combine to promote a sense of intimacy with the characters. This intimacy is related but distinct from the sense of immersion. As opposed to (or pos-

sibly as well as) being enveloped in an immersive world, the viewer is drawn close to the subject and can engage with them in a more personal way. Some of the most compelling examples are in the portraits in Wim Wenders' *Pina*[35], close-up S3D shots of the dancers in the film looking into the camera with voice overs of their thoughts. The effect is very powerful and best expressed by the director himself:

> There was "volume." Roundness, no longer a flat surface, like in any close-up I had ever seen before, but a true "presence." There was the aura that you only see when you are confronting somebody and really recognize him, or her. When you can reach out and touch, not only with your hands. You can also touch somebody with your eyes, when he (or she) is there. When there is a you and a me. I and the other. That is a situation we only know from life, not from cinema.[36]

An often-overlooked aspect of the intimacy that is afforded by the S3D medium is the viewer's social/interpersonal reaction to the images on the screen. It is well known that in many societies there are firmly established norms for acceptable distances between individuals, particularly strangers. As Hall famously documented in 1963[37], interpersonal space can be divided into categories which include an intimate space (0-1ft) and a personal space (1-4ft). Within the intimate space smell, touch and body heat can be experienced, but within the personal space these are typically absent. Many studies have shown that there are strong physiological reactions when a stranger invades one's personal space. We have shown that this negative response (both physiological and psychological) also occurs in response to stereoscopically presented images of individuals at a viewing distance of one metre.[38] Further, these responses were statistically equivalent to our participant's reactions to these people presented "live" under similar conditions. These and other studies suggest that our natural discomfort in response to invasion of personal space has not been re-calibrated for mediated stimuli. As argued by Lombard in 1995[39], humans have not had sufficient exposure to mediated imagery to adapt their social response appropriately. This little-recognized aspect of S3D film could have important consequences; filmmakers could capitalize on the discomfort to enhance feelings of fear or anxiety, alternatively by increasing the apparent distance or space between the audience and the actors, filmmakers could reduce these negative reactions. On the other hand, a positive intention, say in using a close up or beauty shot, may be thwarted by inadvertent violation of the audience's interpersonal space.

While it has a history as long as filmmaking itself, 3D cinema has often been viewed by critics as a fad, a technical trick meant to startle but with no subtly. This view is changing as each stage in the filmmaking process from capture to projection becomes more accessible to artists interested in S3D. The consequences of the rapidly advancing technologies cannot be underestimated as more filmmakers with limited or expansive budgets are able to explore the possibilities of this medium. As they do so, they will develop a new film grammar, one that embraces the perceptual intricacies and vagaries of stereoscopic 3D. From this grammar will emerge 3D films that delight, amaze, and touch audiences in ways that were envisioned by the pioneers of this field. At the same time, audiences will become more 3D literate and their expectations and understanding of the medium will also evolve. Perceptual vision science forms the foundation of this understanding but only provides a substrate on which to build the emotional and narrative context of an enhanced cinema. Good stereo can achieve these goals with care and attention to detail; poor stereo has the potential for

discomfort and unsatisfactory experiences distracting the viewer and taking them away from the story. The complex relation between the perceptual experiences enhanced by S3D and its relation to supporting the narrative and emotional aspects of film is only beginning to be understood and will be an active area of inquiry for years to come.

NOTES

1 Raymond Spottiswoode and Nigel Spottiswoode, *The Theory of Stereoscopic Transmission & Its Application to the Motion Picture* (Berkeley: University of California Press, 1953).

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