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The Visual Language of Holograms

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1. Introduction

Any medium which represents three-dimensional space via a two-dimensional plane employs a representational system. Perspective, a system in which lines, which recede from the foreground to the horizon, create the illusion of depth by converging to the vanishing point has become the dominant means of representing space in western civilisation. Just like other representational systems, display holograms represent space in an abstract way through a series of conventions, which are defined by recording procedures and replay methods. The holographic representational system is so radically different from perspective, enabling the subject to appear in front of, straddling, or behind the hologram plane, that at times it seems invisible to viewers who believe they see the subject by a kind of magic. Even astute theorists, Umberto Eco (Eco,1987) who saw holograms as *hyperreal*, and Jean Baudrillard (Baudrillard,1997) who thought of them as *simulacra*, were implying that the hologram did not have a representational system, that it was a replica of reality. Though holograms can have a high level of spatial verisimilitude, this is variable, as is the resolution, spectral range, blur and the shape and location of the viewing zone.

A primary aim of this chapter is to introduce the properties of the representational systems of several hologram types, including HOE holographic optical elements, laser transmission, white light reflection, 'rainbow' white light transmission, white-light transmission holographic stereograms and printed synthetic holograms. Secondly the chapter will trace how the expressive potential of pictorial qualities such as light and darkness, transparency, reflections, colour and impossible forms operate within these representational systems. Case studies by artists such as, Margaret Benyon, Rudie Berkhout, Brigitte Burgmer, Salvador Dali, Paula Dawson, Jacques Desbiens, Mary Harman, Dieter Jung, Eduardo Kac, Martina Mrongovius, Seth Riskin, Andy Pepper, Martin Richardson, James Turrell, Doris Vila and Sally Weber will be examined.

Occasional comparison will be made between the effect of using the same pictorial qualities – light, darkness, transparency, reflections, colour and impossible forms in holograms and in other traditional media. Thirdly, the chapter looks at some factors, which are likely to impact on viewer reception and interpretation of the visual language of holograms: the bodily experience of interaction with the holographic image, the physiological and psychological aspects of depth perception and other influences such as historic genres and the associations of related media.

2. Representational systems

By representing space one makes programmatic statements about the kind of relationship between subject and space that is at stake when one makes an image (Alphen, 2005).
The holographic image is capable of completely renouncing illusion… moreover holography confronts the principle of illusion perception with a totally new aesthetic effect and a new model of perception, whose special characteristic is the correlation of physiological perception and psychological perception (Zec, 1989).
Holography is not just a medium to explore 3D space. We now have a medium in which it is possible to explore our own perceptions, the subtleties of human awareness (Law, 2008).
The Broken Window (Fig. 1) by Canadian artist Jacques Desbiens evokes the spaces of Chinese scroll painting, perspective and the holographic representational system. (Desbiens, 2009) The viewer is confronted with a visual paradox by the holographic plate containing the scroll, which contains the window, which is traversed by tree-branch and moving leaves. The scroll is positioned at the plane of the holographic plate and rolls open and closes rather like a pair of theatre curtains. Though not continuously unraveling space by one side unwinding while the other winds up, the all-important function of the scroll in revealing and hiding sections of the image is clearly indicated. The windowpanes, also located at the picture plane of the hologram, are framed as an aperture to a scene.
The window on the right, framing the scene behind, evokes a perspectival notion of the image as a window onto a world. Whereas the window pane on the left is broken and through it comes a more beautiful and intense light, a protruding branch which extends from behind the picture plane into the viewer’s space and a floating leaf. These elements, the broken picture plane, the strong presence of light and the spatial and temporal distribution of the image, are key points to the holographic representational system.

Fig. 1. Jacques Desbiens, *The Broken Window*, 2006, Printed Synthetic hologram, computer graphic (not the actual hologram) of the 1100^{th} point of view (total of 1280 points of view) 140 x 38cm.

However, the functioning holographic representational system of this synthetic reflection hologram, which enables the viewer to see the subject matter of the scroll, the window the branch and falling leaf, is not directly visible. To conceive of this representational system, like any other, it is necessary to strip away the subject matter to reveal its underpinning structure.

Beaudrillard's and Eco's discourses, which set the tone for the appreciation of display holography, do not describe the specifics of holographic representational space. Rather they describe the effect as a *simulacra* or a part of a kitsch trend towards the *hyperreal*:

…as you shift your gaze you can see those parts of the object that you were prevented from glimpsing by the laws of perspective... Holography could only prosper in America, a country obsessed with realism, where, if a reconstitution is to be credible, it must be absolutely iconic, a perfect likeness, a "real' copy of the reality being represented (Eco, 1987).

The hologram simply does not have the intelligence of trompe l'oeil, which is one of seduction, of always proceeding, according to the rules of appearances, through allusion to and ellipsis of presence (Baudrillard, 1997).

Underpinning the arguments of simulacra and hyperreal is the assumption that a hologram replicates or simulates reality, leaving no room for cultural interventions such as expression and abstraction, or a representational system, and by extension no potential for conceptual content.

By contrast, from the above example, *The Broken Window*, it is clear that the hologram is not necessarily a replication or simulation of a physically real thing, that its referents can be highly conceptual and in fact engaged with the very nature of its representational capabilities. The potential offered by the synthetic hologram's representational system clearly extends the scope of the functionality of the hologram well beyond *simulacra* and *hyperreal*. The representational systems of laser transmission holograms, holographic optical elements, one and two step reflection holograms, rainbow holograms and white-light transmission stereograms each operate in a different way and therefore make available other types of compositions. But before examining the specifics of holographic representational systems it is useful to first establish the basics of representational systems in general. These are firstly their formal abstract properties, secondly the way in which these interface with the beholder and finally the meanings which are ascribed to them.

Fundamentally, representational systems are abstract codified means by which spatial and temporal information can be represented and interpreted. They underpin the majority of the images we see. Representational systems can be employed in hand-made works such as drawings and paintings, or through optical/digital photography, film, computer generated environments, video and diffractive holograms. Depending on the representational system used, the same subject matter can have quite a different appearance. For example, visually, the image of a house using the representational system of perspective would differ from the same house rendered in oblique projection, because in perspective the rules of abstraction dictate that the lines running away from the viewer will converge to a vanishing point and in oblique projection these lines remain parallel. Both achieve the objective of abstracting the three-dimensional space in such a way that the viewer can deduce that the two-dimensional image signifies a house.

In each case the representational system shapes the way in which information about the subject will be formed into an image. In some cases the properties of one representational system can be used across many media. Perspective for example can be applied to drawings, painting, computer graphic environments and holograms. Traits of some representational systems can also be quoted or appropriated in others.

We have seen that there is a range of examples of holograms, which engage in a didactic or overt way with other representational systems, such as *The Broken Window*. Early optical holograms such as Bridget Baumer's work *Leonardo's Baby* a "Denisyuk" reflection hologram employs a physical model based on a line drawing by Leonardo da Vinci from the Codex Atlanticus. This work is engaged with the representation of anamorphic distortion, one of the artifacts of perspective within the holographic diffractive environment.

…the hologram is distorted and the plastic anamorphosis grows enormously in the pseudoscopic, so that it becomes more anthropomorphic than the model (Burgmer, 1987).

Also concerned with re-stating perspective space, but within one step laser transmission holograms, is the work by Salvador Dali, *Card Players,* which refers to the spatial composition of a painting by Diego Velasquez by employing physically built sets and live actors. Using laser transmission holography, Margaret Benyon in 1969 made a work entitled *Picasso* in which the elements of *Les demoiselles d'Avignon*, considered the essential lexicon of cubism, were represented by cardboard cutouts of the subjects of the painting placed at angles to a physical cube. As Coyle and Hayward remark:

Cubism provided one particular starting point in this area and [Benyon] responded to Cubist attempts to render three-dimensional materiality without recourse to traditional painting techniques of perspective or colouristic logic (Coyle, 1995).

Andrew Pepper used the oblique projection system to make a projected drawing, *Drawing 1 (from a series of 5)* which is recorded as an optical reflection hologram. David Pizzanelli transposed the animation process of Muybridge's original gravure photographic prints by alignment of side by side photographic views in a mirror-backed holographic stereogram on glass, *Bruno Walking to the Left,* 20 x 13cm, 1989. (Pizzanelli, 1989) When the beholder walks left to right Bruno walks to the left. When the viewer walks right to left Bruno walks backwards.

Muybridge was working several years before the invention of the cine camera, so in order to expose his plates in quick succession a number of individual cameras were triggered by the subject's passing laterally in front of each camera in turn, recording not just the motion but different perspective views of the subject…synthesized into a single three-dimensional animated scene, showing all the depth and solidity of the original event (Pepper, 1995).

The visibility of the sprockets and frame numbers in Patrick Boyd's work *Bartus takes the Downtown train* (Fig. 2) alludes to the illusion of time being generated though the series of still frames of the super 8 film. As the viewer moves across the train moves either in or out along the z axis.

The purposes of representation systems vary enormously. Some generate illusions. Others transpose salient factors of the subject to an image, which clearly can be recognized as referencing the subject, but in an abstract way. The representational systems of Cubism or a plan view do not entail what we commonly call illusions, yet they refer effectively to the subject in a symbolic way. All representational systems in some way address and reciprocate perceptual and conceptual capabilities of the beholder, for it is through these that the image is readable.

In humans the information for perception of spatial environments comes from approximately nine sources – occlusion, relative size, relative density, height in the visual field, aerial perspective, motion parallax, binocular disparities, convergence and accommodation. The relative importance of these has been shown to vary according to the size of the space the beholder occupies (Cutting, 1995). In examining holographic representational systems of different types, which operate within the zones of personal space or action space, it will be seen that some cater more to certain source types of three-dimensional information than others.

Fig. 2. Patrick Boyd , *Bartus Takes a Downtown Train*, 1990, two colour reflection hologram in a box, 10″ x 8″x 3″.

The diverse motivations behind the early development of the various range of holographic representational systems has been thoroughly documented by Sean Johnston (Johnson, 2006). Though varied, the underlying commonality of “display” holographic representational systems is that they generate new types of pictorial space in which representation can take place. The technical basis of these holographic representational systems is extensively set out by Benton, Bove et al in *Holographic Imaging* (Benton, 2007). These techniques enable unique arrangements of the viewing zone in respect to the support (holographic plate) and the image of the subject.

Ernst Van Alphen in the chapter The Representation of Space and the Space of Representation has argued that :

The space of representation is certainly not a fixed entity. The history of art can even be seen as a sequence of changing conceptions of the space of representation. There have been periods in which representational space was defined as illusionistic space; in polemical reaction to this many twentieth century artists have devoted their careers to fighting illusionism and have instead explored the flatness of the painted image (Alphen, 2005).

The three kinds of representational spaces are identified by Van Alphen as operational in two dimensional and shallow relief works, namely: the illusionistic space behind the picture surface; secondly the two-dimensional space of the picture surface and thirdly the lived space of the beholder between the image and the viewer. To describe holographic representational systems additional elements are needed – the replay light, the image space in front and through the support and also the viewing zone. The holographic viewing zone, (the volume of space in which the viewer must be located in order to see the image) is rarely the same as the volume of physical space in front of the holographic picture plane that the beholder can occupy. The beholder, as is customary, looks towards the support (holographic picture plane) in order to see the subject. The holographic image may appear to extend behind and or out into the viewer's space but it can only be seen when the beholder is inside the prescribed viewing zone.

Van Alphen has argued that though perspective's requirement of stability of the viewing position, which causes the viewer to become stationary and fixed to the ground, limits the viewer's response, compositions which bring attention to the surface exclude the viewer from pictorial space. The limited nature of the *ideal* viewing zone, or point, for perspective imagery does not prevent the beholder from seeing the image from a complete range of angles because the image and its support occupy the same two-dimensional space. However due to the physical properties of the hologram there is a limit to the range of angles through which light can be diffracted to produce an observable image and so if the beholder of a hologram walks outside this viewing zone, though still looking at the holographic picture plane, they will not see the subject at all. The beholder becomes conscious of the shape of the viewing zone and its boundaries when its edges occlude the subject, inside the angle subtended by the viewer's eyes and the perimeter of the plate.

The following examples demonstrate the way in which aspects of holographic representational systems such as the viewing zone, the hologram plane and the position of the subject are used in conjunction with other pictorial agents to convey ideas. These are works which must be experienced, as they mobilise the beholder in a complex interplay of embodied engagement over time, with spatially distributed visual information.

3. Holographic Optical Element (HOE)

The holographic optical element (HOE) diffracts light as though it had passed through some type of optical device such as a lens, focusing, fragmenting, expanding or collimating the light. The diversity of forms available with HOEs is so extensive that it is not possible to generalize however the two following examples give a sense of the scope of this representational system.

Seth Riskin *Figure With Crowns* (Fig. 3 and 4) employs the fundamental relationship of the replay light of the hologram to the support (the holographic plate) in determining the nature of the reconstructed image, to generate a dynamic performance.

Holograms are different from other image types in the way in which the image is formed at the moment of viewer observation. The image is frequently referred to as a "reconstruction" shorthand for the term wave front reconstruction, the event in which a wavefront of light is changed usually from being quite simple to complex through the process of diffraction. It is significant that all holograms are seen by the diffraction of light from a replay source from an interference pattern. The distance, orientation and wavelength of the replay source effects the way in which the image appears. The same diffraction pattern could produce quite different qualities in an image if the lighting used in replaying were to be altered. These changes in the image can range from a complete change in colour, to slight shifts in spectral range towards reds or blues, changes in scale of the subject from large to small or vice versa, the introduction of distortions and appearance of the image as virtual or pseudoscopic (inside out). Such changes to images which are painted, photographed or drawn cannot take place as these images and the surfaces to which they are recorded (the support) are synonymous.

Fig. 3. Seth Riskin, *Figure with Crowns*, 2002, HOE, installation, Sky Art Conference, 24” x 20”, Ikaria, Greece.

“Display” holographic representational systems are seen though the conjunction of a light and some sort of screen or plate, which holds the interference pattern. These two elements, one intangible and the other imperceptable, the light and the interference pattern, are employed sending the diffracted light away from the screen or plate to other locations to form the image. In addition, there is residual light passing through or being reflected from the surface of the plate, depending upon on whether the hologram is played back with light passing from behind (transmission) or in front of the plate (reflection). Because the replay light is redirected by the interference pattern distributed within the volume of the photosensitive material attached to the substrate,which in the case of painting or drawing would be called the support, it is necessary for the viewer to look in the direction of this plate or film to see the image. The subject of the holographic image may appear to extend out into the viewers space but the subject can only appear in locations, which fall within the angle subtended by the viewer’s eyes and the perimeter of the plate. For this reason the hologram viewing space constantly changes shape according to the position of the viewer. In most instances the replay beam is stationary and the beholder moves, whereas in this case the reference beam source, the laser diode, is attached to the moving performer who is viewed simultaneously with the changing holographic image he is influencing.

Fig. 4. Seth Riskin, *Figure with Crowns* , 2002, HOE, 24" X 20", Installation, Sky Art Conference, Ikaria, Greece

In Riskin's *Figure With Crowns* performance the transparent hologram support is held on a tripod, which is placed at a vantage point overlooking the shoreline. The performer is up to 30' away from the hologram support on the shoreline. The performance and viewing of the HOE takes place at sunset to enable a mixing of the orange and golden hues of the natural environment with the blue monochromatic subject of the HOE. As described by Riskin:

The performer casts an enlarged beam of blue light onto the hologram as viewers look through it onto the figure, the shore and the sea. In the eyes of the viewer, two rings of blue light hover, flanking the body, "attached" to it as the figure moves in the landscape (Riskin, 2011).

The spatial locations of these discs are in a plane with the light source which is attached to the performers body and appear as extensions of the performers body. The subject of the HOE is therefore not a spatial object but rather it embodies the changing spatial relationship between the beholder and the performer through the translucent subject.

Alignment, by Sally Weber, is a HOE that projects blue, green and red vertical lines of light 6 to 8 feet in front from a 7-foot high curved acrylic structure. In the following discussion the z axis is a line perpendicular to the plane of the holographic plate. The beholder can mix colours and alter their intensity by moving towards and away from the acrylic support within the long z-axis viewing zone. The image of the coloured bars is available at every height on the y, (height) axis. An important characteristic of this viewing zone is the change in the subject, which is perceived as the viewer's distance from the holographic picture plane changes along the z-axis. But most importantly the beholder can stand *in* these bands of light with the sensation of the light being at the eye. When this physical shift occurs a phenomenological transition takes place in the perception of viewing from exterior to interior. The light is not shone on the beholder, rather it is perceived as being inside the body of the beholder. The product of the large freedom of movement of the body in relation to the coloured bands is not so much the experience of entering a rainbow as of having a rainbow enter the body.

When the piece is viewed from a distance, the focal lines drift and merge as the viewer moves from side to side in front of the sculpture until he or she is aligned with the three lines. At this point the colours blend towards an achromatic balance. This is a calm place, a balance point, where harmony is symbolized by a shift towards whiteness. Moving closer, the viewer sees the blending and shifting off the hues become more vibrant. When the viewer is aligned with the lines at the focus of the holographic image, he or she is surrounded by whirling, brilliant fans of colours that flow across the curve of the sculpture…Standing in this axis of light, the viewer experiences a physiological response as the light seems to rush upward through the spinal chord (St. Cyr, 1989).

Perhaps the only other artwork to achieve the sensation of a light image existing inside the body is the projected poetic words by Centre for Advanced Visual Studies MIT, Fellow, Elizabeth Goldring, which employ a scanning laser opthalmoloscope to draw imagery directly on the retina. The beholder is tethered to the apparatus and therefore the light can only exist as an image inside the eye, unlike *Alignment* in which the beholder roams between experiencing the holographic image as an exterior and as an interior phenomenon.

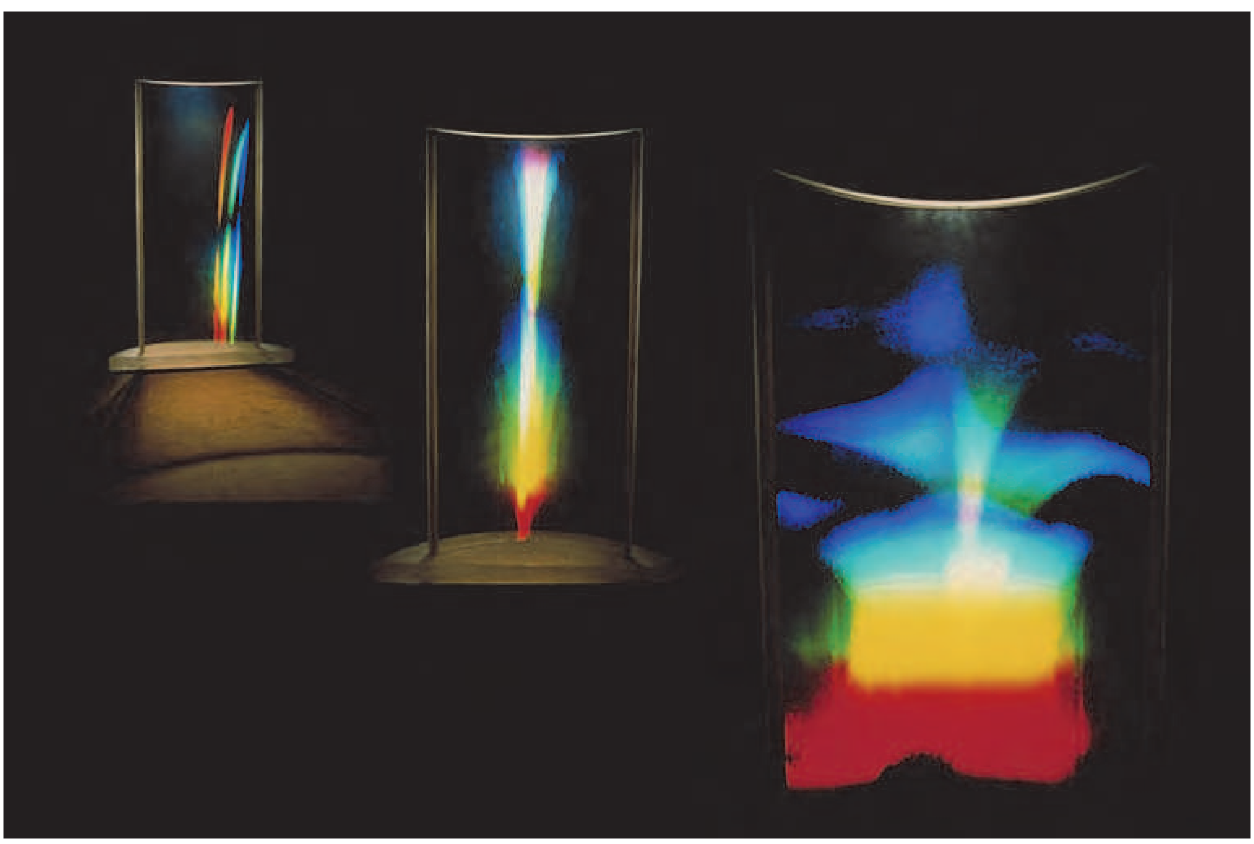

Fig. 5. Sally Weber, *Alignment*, 1987, HOE, 7'x 3'

Peter Zec in his paper for the International Congress on Art and Holography 1991 commented:
As light is not only a generative principal but also a subject and the basic substance of the holographic reconstruction as well, the self –referencing of light represents an essential form for the articulation of the holographic message (Zec, 1990).

4. Laser transmission hologram

The space represented in the laser transmission image extends from the entire surface of the holographic plate back to the extremities of the subject, exactly in the same way that a windowpane acts as a boundary to a view. This is also true for one step optical reflection holograms.The free viewing zone is the same as viewing an object from any vantage point in through a window, the viewing zone is 180 degrees horizontally and vertically from the plate. The image can be seen just as easily from near or far. The space is unfocused and undistorted – it is an exact spatial replica of the subject and elicits perceptual cues of the physiological type which are precisely in accord with the perception of real objects.
The one- to- one scale of the representation of space occurs at a resolution higher than is perceptible by the human visual system. Other representational systems use scaling, whereby the original image is larger, distorted or smaller than the original subject. All the sources for information of depth come to the beholder as they would for a real world object separated by a piece of glass, in particular the physiological cues of accommodation and fusion which are critical at close range. It stands to reason that a key effect of the one step optical transmission holograms representational system is a strong phenomenological link to its real-world referent.
The dominant textural property of laser transmission holograms is the grainy quality of laser light known as laser speckle. This minute dotting in three-dimensional volume lends a somewhat worn, aged, yet constantly mobile micro surface to all image elements. A correspondence between physiological operations of the eye in the perception of laser speckle and the need for alterations in aperture of the camera in documenting laser transmission holograms can be deduced from Graham Saxby’s explanation:
Laser viewable holograms are particularly difficult to photograph successfully owing to the presence of obtrusive speckle and to the very high contrast they often possess… the speckle size is large and more obtrusive for small lens apertures and in order to minimize the effect it is important to use the largest possible lens aperture (Saxby, 1988).
To the beholder it may seem that the real-time movement of the laser speckle directly reflects the constant shifting of their eyes. This gives the effect of a deep silence, which Karl Frederick Reuterswald refers to in his finger language – the silent movement of fish in an aquarium.
Holographic space has its own time and depth; yet it also has a profound silence, as in an aquarium. To me the silence of the aquarium is more impressive than the colour or the movement of the fish (Reuterswald, 1989).
Laser transmission holograms are generally monochromatic and replayed in the same wavelength in which they were recorded though they can be full colour by using a combination of lasers to record and replay.

4.1 Boundary of the holographic picture plane

Because laser light is less bright than the typical level of gallery lighting this draws the viewer to the holographic plate. In the case of large format, large-scale holograms in which the reconstructed image is confined to the space behind the plate, viewers physically lean onto the plate in order to look at the image more closely. The result of the image being very spatially realistic and also behind the picture plane is to necessarily heighten the feeling of exclusion from the scene depicted. The holographic picture plane is not always interpreted as a physical boundary, except in one –step optical, and laser transmission and reflection holograms.

On a physical level the boundary of the plate can cause the viewer to want to occupy the space of the image or a conceptual interpretation could be that the image is a metaphor for an aspect of memory- imagery being present yet physical accessibility being blocked. The interaction of the spectator with the subject with some holograms, which have the image in front of the plate may relate to the way Alex Potts has characterized the work of the sculptor Richard Serra, in contrast to the way that this type of viewing zone behind the plate invites a response analogous to the work of other contemporary sculptors:

Serra was well aware that physically involving the viewer …in an interplay between exteriority and interiority involved not just formal or perceptual effects, but carried a certain psychological charge…but this psychological dimension was a muted one as he conceived it. It is striking how his work which allows the viewer to enter produces a much less psychologically charged sense of interiority than works such as Hesse's or even Judd's where the viewer feels drawn towards an interior space from which he or she is barred, and feels it to be strangely alluring and inviting yet separate (Potts, 2000).

Additionally the distance over which the eyes are able to travel in the x, y and particularly the z-axis has a bearing on beholder reception. Laser transmission holograms can depict scenes up to approximately ten meters in the z axis such as *To Absent Friends* by Paula Dawson (Popper, 1993). The experience of looking towards a distant space can be similar to daydreaming. The size of the support (holographic plate) also determines the distance at which the beholder will decide to stand. As has been discussed, resolution also plays a role in selecting a suitable viewing distance. Therefore z axis movement of the beholder before the hologram picture plane, similar to the viewing of two-dimensional imagery, is primarily dependent on the size of the support.

4.1.1 Darkness

Darkness, which has always has been a pictorial device of great importance in traditional media has also frequently been employed by artists to create ambiguities in optical holograms. Michael Baxandall in *Shadows and Enlightenment* pointed to an example of a drawing of a Roman soldier by Tiepolo in which the overall lighting pattern has nested within it smaller zones in which the lighting behaves in a completely different way (Baxandall 1995). This enables the viewer to make two possible interpretations as to where the leg of the soldier is located. This ambiguity as to the position of the leg engages the viewer in perceptual switching. In Margaret Benyon's, one- step laser transmission work *Hot Air*, 1970 laser transmission hologram 20 X 25cm, the beholder sees within one composition still – life objects, which display a full range of tonal values, and also a hand–shaped black void area. Similarly to the Tiepolo example, there is one overarching lighting arrangement of the objects in the scene, however, within this arrangement is the totally black hand, which is inconsistent with the overall pattern. The primacy of the artist's presence being registered through a negative rendering of their hand is immediately brought to mind, but in reverse, for the precise volumetric rendition of the hand instead creates a poignant sense of absence through the three-dimensionality of the trace.

Fig. 6. Margaret Benyon, *Hot Air*, 1970, laser transmission hologram, 20 X 25cm

Although the hand-shaped black hole in this hologram has little visual detail, it subjectively captures the essence of the hand, which was once there and stimulates questions about the owner of the invisible flesh…something beyond the 'object', something which is intangible and untouchable - the roots of an idea or conceptual improbability (Pepper, 2008).

The six panels of *Working Model One*, laser transmission holograms by Paula Dawson, each show a plaster frame straddled by a curved section of plaster cornice. The lighting of the overall scene of the plaster cornice frames seems consistent, however, as the viewer moves, a darkness, which cannot be ascribed to shadowing, also moves over the three-dimensional space of the curved piece of plaster. This unusual soft edged zone of darkness traveling in unpredictable ways through the image volume lends a sense of mystery. Dawson achieved this effect by applying the holo-diagram, a graphic invention by Nils Abramson for plotting physical zones of the repetition of laser coherence and incoherence (lightness and darkness) (Abramson, 1981). Abramson's application of the holo-diagram enabled him to avoid the dark zones and thereby record a large piece of machinery all in light with a short coherence laser whereas Dawson intentionally located the zones of darkness in a different way.

In order for the interference pattern to be recorded as a hologram, all elements involved in the recording process including the optics and the subject must remain absolutely static throughout the duration of the exposure time. Unless a pulsed laser is used, a living hand cannot be static to the required extent. Benyon's effect was achieved by intensionally using the long exposute of a continuous wave laser to allow the stable inanimate objects to be successfully recorded as bright light forms and the living hand to not be recorded and therefore become dark. Darkness of a holographic subject is generally regarded as a mistake. Saxby's fault- finding chart proposes that the only way to get around the problem is to "use a more rigid subject" (Saxby, 1991). As Benyon points out in discovering means for manipulating this representational system:

The physicist tries to get an approximation close to reality, to eliminate properties of the medium that distort, whereas it could be exactly those properties that make it unique to the artist (Benyon, 1994).

5. Reflection hologram – one and two step

Andrew Pepper in his article *Holographic Space: A Generalised Definition*, conceptualizes the spaces available for the subject of a hologram as being box like, behind the picture plane "Box 1", in front of the holographic picture plane "Box 2"and then a third space which spans these two. As Pepper notes:

When objects in the hologram are in a position between "Box 1" and "Box 2" they straddle the flat holographic plate. Because we know that a solid object cannot pass through a solid holographic plate, we visually ignore the plate and are no longer confined by it.

The previous examples of HOE's were either "Box 1" Seth Riskin or " Box 2" Sally Weber. Similarly, one step laser transmission imagery of Margaret Benyon and Paula Dawson occupied "Box 1" (Pepper , 1989).

Andrew Pepper's one-step optical reflection hologram protruding drawings are a perfect example of the opening of the third type of subject space, one that traverses the support (holographic picture plane).

Pepper explains the process:

The drawing series was produced using a simple single beam Denisyuk system. The 'drawings' (isometric projections of a cube), were placed into the single reference beam, causing its shadow to fall onto the holographic plate, pass through it, and 'fall' onto the featureless white background situated behind the holographic plate. Once processed, the hologram was rotated around its horizontal axis so the shadow of the cube (originally visible behind the holographic plate) becomes visible as a pseudoscopic image, protruding out of the hologram and manifest in the space between the observer and the plate. The drawing exists in two places simultaneously: one on the surface of the holographic plate; another slightly in front of the plate. The two' images' naturally interfere with each other visually and spatially (Pepper, 2011).

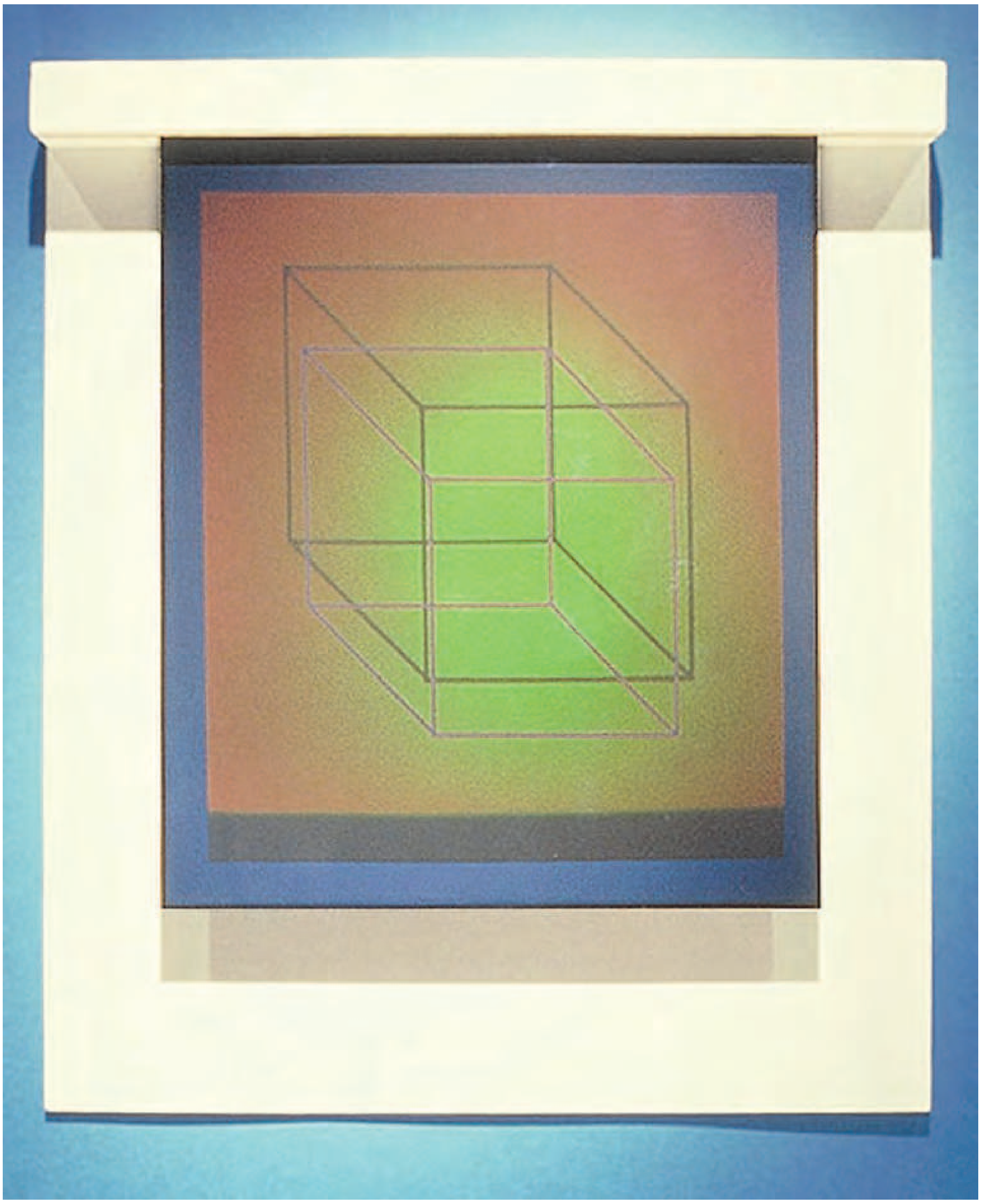

Fig. 7. Andrew Pepper, Drawing 1 (from a series of 5), 1987, "Denisyuk" one step reflection, 20.3 x 25.4cm.

Drawing A, 20.3 x 25.4 cm, sets up a dialogue of paradox with the beholder by using a two-dimensional drawing which employs the representational system of oblique projection to represent three-dimensional space in two dimensions as its subject. Though the image is lit from the front, a shadow hovers above the plate. It is the shadow of the drawing seen in the hologram. The shadow, which can be seen from almost any possible viewpoint, occludes the drawing giving the existence of the shadow a priority over the image. It is in fact the three-dimensional location of the shadow, which is so confounding. The beholders sense of illusionism is challenged, partially as illusions of space are usually linked to the representation of three-dimensional objects. Here the subject is completely flat, a drawing, so in a sense there is no spatial illusion.

The historical antecedent of this work is Jan Dibbets', *Perspective Correction* (*My Studio1, 1-Square on a Wall*) 1969 black and white photograph on photographic canvas 110 X 110cm. Dibbets draws a distorted shape on a wall of his studio which when photographed becomes a square. The drawn square appears to have separated from the wall within the foreshortened photographic space and rests on the picture plane of the image.

5.1 H1, H2

One method for producing the effect of the subject passing though the box 1 and box 2 spaces is to make a hologram (known as H2) of the pseudoscopic image reconstructed from another hologram (known as H1 or Master hologram), the two steps of the process being first the making of the H1 and then the recording of the H2 from it. When the H2 is produced, the subject position is determined by the placement of the H1. When the beholder observes the subject in the H2 they do so by looking through the image of the H1 view port. The size of the H1 support becomes the aperture size of the viewing zone of the H2. The subject can appear on both sides of the holographic picture plane.

Mary Harman's *Figure with Metal Base* 1992 is a two step reflection hologram of a hand-made miniature reclining figure which is projected through the holographic picture plane to match up spatially with a highly reflective metal cube. The cuboid viewing zone restricts the viewers point of view, encouraging them to focus on the highly reflective cube placed behind the holographic picture plane. As the hologram is monochromatic the subject seems as a figure made from light but with a convincing spatial presence though it passes through the boundary of the hologram plate. The awkwardness of the figure pose and its lack of physicality are at odds with the materiality and formality of the cube, and this creates a tension. The close space of the viewing zone almost grotto like, draws the beholder into the miniature world. As the beholder moves, the translucent figure is not occluded by the physical metal cube instead it appears to pass through it.

...the aesthetic effect of holographic space is based on the loss of materialization rather then on the addition of a third dimension (Zec, 1990).

In the *Cosmetic Series: Margot* Margaret Benyon employs the small rectilinear viewing zone through which the three- dimensional portrait can be seen in two ways. The limited viewing zone acts as an extended spatial frame, which contains the movement of the viewer, encouraging a face- to- face orientation to the subject who returns this frontal gaze. The effect of moving sideways out of the spatial viewing zone is that the image moves in the z axis from the three-dimensional space behind and in front of the holographic picture plane to its two dimensional flat surface. This is accomplished by having a gouache painting of the subject directly behind the hologram plane. The beholder can see the painting of the subject from any orientation but it is only when the beholder is directly facing the subject that the subject projects forward towards the beholder. A constant dialogue between the reflected and diffracted colour of the two and three-dimensional surfaces are encouraged by the use of painting, both on the surface of the subject's skin and what appears to be on the holographic picture plane.

The holographic images are frontal and central, partly to give a classical, hieratic quality…a spatial image had to be merged with a flat image on the image plane, and a full frontal view is flatter than any other orientation of the head (Benyon, 1989).

Benyon's work employs a synthesis between the monochromatic hologram and its underlay of a brightly coloured gauge painting. Full colour, either highly realistic or abstract through the use of multiple exposures with different colored lasers or by swelling the emulsion to different thicknesses between exposures is also a feature of reflection holograms.

The latter technique,'pseudo colour' was employed to great effect in *Healing of Broken Hearts* (1985) by Melissa Crenshaw. Rather than hanging on the wall the work is mounted in a display case so it can be viewed from above. This evokes in the beholder the method of looking at precious items in a display case. The play of light over the intensely coloured surfaces is reminiscent of light playing on insect wings, or other Lepidoptera, a favorite subject of this type of hologram to demonstrate verisimilitude. The colours of Melissa Crenshaw's work are highly saturated, green, blue, violet, red and black and the composition remains static as the viewer moves. The formal arrangement of the colour along diagonals which intersect with a broken circle also encourages the beholder to circle the plate and interpret the composition from multiple view points.

Crenshaw introduces us to a plastic, lineal and geometric holographic universe inspired on the first third of the twentieth century's constructivist and neo-plasticist avant gardes, a field restituted here by light. Colour acquires a structural and emotive function in an obvious way (Carreton, 1996).

6. Rainbow – white light transmission hologram

In this representational system the viewing zone is much smaller than for optical one- step holograms or HOEs. The viewing zone is of appreciable angular spread in one direction only in one direction, usually horizontal; in all other directions is is very narrow, only a few degrees.

Also there is a specific distance along the z-axis between the plate and the viewer at which the image seems best. As the viewer walks towards the holographic plane they tend to stop at this point, well away from the support. The basic characteristic of the image is that the subject appears in 3 D only in the horizontal plane, known as HOP horizontal parallax only. The image presents spatial information about the subject which accords with motion parallax, stereopsis, but not with the physiological cues of accommodation and fusion. The image is astigmatic, and, except in the case of the achromatic rainbow hologram, the colours change when the viewer moves along the y-axis.

Once the viewer walks out of the viewing zone the image appears to wipe off the plate. The viewer usually turns back and walks towards the other extremity of the viewing zone. Similarly, if the viewer moves above or below the narrow horizontal viewing aperture the image vanishes. The shape of this invisible aperture and viewing zone has been explained as a letterbox, a narrow wide slit aperture onto a volumetric scene.

It is not a straightforward matter for the beholder to locate themselves within this type of viewing zone. Sometimes a prescriptive approach has been taken. As Mark Diamond comments of early exhibitions at the Museum of Holography in New York.

…we did a lot of placing of little stickers on the ground… like those games where they show you how to tango, and where to put your feet; it was instructions on how to view the holograms, because people were unfamiliar with how to view the space (De Freitas, 2003).

These holograms are usually played back with a "white light" point source. Because of the dispersion of wavelengths over distance, when a white light source is used for replay, the image will be most focused at the hologram plane and become less focused in both + and – z.. This effect is more noticeable with large depth images. The decrease in resolution the closer the image protrudes into the + z space in front of the holographic plate is contrary to the experience of aerial perspective where the resolution of the image becomes less as it becomes more distant. Therefore although the cue of aerial perspective is not consistent with real-world experience, in practice it has little significance, because this cue is only significant over long distances and typically rainbow holograms are of a size that fits within personal or action space.

Rudi Berkhout's three colour rainbow holograms such as *Future Memories, Event Horizon* and *Toba* which include HOEs are types of landscapes in which elements undergo spatial transformations as the beholder moves from side to side. There is a use of a combination of types of H1, some of which portray abstract forms with a constant position such as fields of bubbles and others, which warp space in unpredictable ways.

In *Event Horizon* I was able to generate an image element totally by optical means. This was a breakthrough for me, for the first time I was able to draw with light. Starting with a point of laser light, I stretched multiplied and curved coil-like structures that I placed over a sphere (from a second master) in the final transfer. The third master used in this piece was of a forced –perspective field made of receding lines (Berkhout, 1989).

The spatial stability of randomly dispersed elements provides an alternate framework to the grid for navigating the space. Though on supports of modest size, like landscape paintings, the beholder's experience is that of traversing an immense and complex space.

For the most part these artificial light realities oppose the onlooker's perspective and visual habits. One reason for this is Berkhout's particular partiality for apparently impossible spatial arrangements of geometric bodies and forms… here Berkhout speaks of the creation of hyperperspective spaces (Lipp, 1985).

The complexity of these compositions has the effect of prolonged beholder engagement.

…for me part of the uniqueness of the holography is that the image is simultaneously there and not there, depending on the viewer's position…being able to see the work from the sides and from behind allows the viewer to examine and consider all angles of the image (Berkhout, 1989).

6.1 Colour

The most striking feature of the rainbow hologram is that the same subject is seen in different colours according to the height in the viewing zone. The relationships of the different colours of separate subject elements are preserved, yet the colours themselves change. Colour behavior, because of its decoupling from stable relationships with surfaces of forms, probably cannot be processed by the brain in the usual way. As Zeki has shown the brain processes colour information in a very specific way:

The brain is principally interested in acquiring knowledge about the constant and invariant characteristics of a surface, namely reflectance. This it does by comparing the wavelength composition of the light reflected from it with the wavelength composition of the light reflected from its surrounds. By doing so, the brain is able to discard all the variation in the wavelength energy composition of the light reflected from a surface and assign a constant colour to it (Zeki, 2009).

If the colour of the form does not match the colour in memory then information is processed in another area of the brain. Zeki's results from functional MRI imagery of brain activity while viewing Fauvist paintings may serve as a model for understanding viewer response to rainbow holograms:

… I would like to draw another conclusion from the …survey of the Fauvist brain, which activates a distinct part of the monitoring system in the frontal lobes. I do not imply that this part is devoted to seeing Fauvist art, rather, it is an area that monitors the incoming information for any conflict with previous experiences (Zeki, 1999).

From these data it can be assumed that the way in which colour changes according to viewer position in rainbow holograms already activates the part of the brain which is concerned with abstract problem solving and resolving ambiguities.

In Dieter Jung's *Present Space* 1984 (Fig. 8.) the beholder sees an array of coloured horizontal bars of varying height and width- more widely spaced at the top and bottom (Fehr, 1991). The colour appears to exist in space without any material surface and is translucent. As the beholder moves from side to side the planes of colour overlap each other to generate new colour mixtures. There is no observable modulation of form of the colours in the z-axis. Jung makes sense of the wiping off of the image at the side edges of the viewing zone by locating two large black rectangles, one at the top and the other at the bottom of the composition, which are also empty.

The horizontality of the composition encourages a side-to-side motion in the viewer. The physical shifting of the beholder and the corresponding dynamic immaterial colour mixing of the composition is intended as an analogy to the "oscillation structure of the activity of our consciousness" (Fehr , 1991).

Doris Vila's *Chart: Space-Time-Sex-Money-Continium* monotype 1985 employs a one step rainbow hologram technique. The beholder of this very long 17 ½ x40 " image becomes immersed in layers of simultaneous narrative. The layers appear floating in the space between the viewer and the support, each of a different colour. The visual field holds in transparent layers overlapping stencils and found objects in multiple exposures; the translucency of these negative forms suspends them from concrete interpretation. The narrative metaphor is extended by the replacement of the usual white light replay source with a film loop of money falling into the image.

As Vila comments:

Most importantly the narrative line of the imagery was synthesized in the process of shooting, with many of the objects existing only for the moment of the shot; therefore the only record of their existence is the shadow they made at the moment of exposure. Some of the objects used were stencils of simply cut shapes that allude to natural phenomena, transparent forms of glass or plastic, fabrics and found objects…viewing the hologram is like adopting a memory, where each person's keys to the experience have a unique sequence (Vila, 1989).

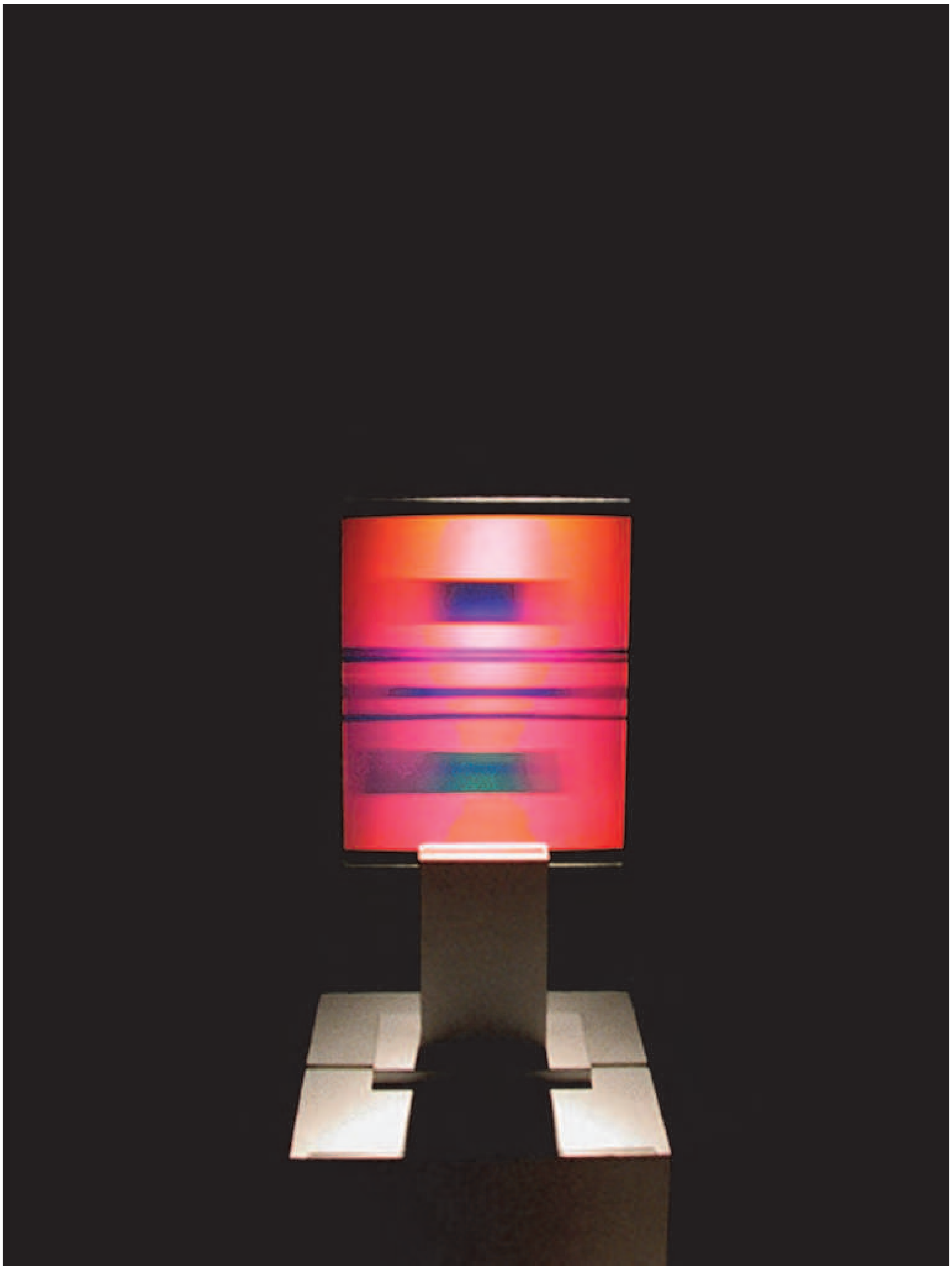

Fig. 8. Dieter Jung, *Present Space*, 1986, Benton hologram, 42 X32cm.

7. White light transmission holographic stereograms

The representational system of the holographic stereogram is characterized by the spatial arrangement of an array of two-dimensional views, which correspond, to the position of the beholder relative to the subject across a horizontal field of view. Typical source image types for holographic stereograms are film footage, photographs and computer graphics all of which use perspective. A batch of any type of two dimensional perspective images is exposed firstly to the H1, which is then transferred as an H2 in order to locate the array of 2D images away from the holographic picture plane. Typically this process introduces many optical aberrations and the output stereograms have distortions. The sequences of 2D images can be of sequential side-to-side viewpoints of a static three-dimensional space or sequential side-to-side viewpoints of a dynamic space over time.

The first type of representation, of a consistent, static space can be seen in James Turrell Pace Wildenstein 2009 exhibition of "transmission light works". In these works the position of a single shape--a triangle, rectangle, ring or a conjunction of two forms, remains static in the centre of the composition. The stereogram is replayed with monochromatic light lending the form a specific hue almost reminiscent of Bauhaus (Kandinsky) and Russian constructivist (Malevich and Kliun) correspondences between hues and forms. The conditions for stereopsis and motion parallax are satisfied. The lack of occlusion of the subject gives it a less material feeling while holding a stable spatial position (Gallery, 2009).

The second type of imagery, that of a dynamic field of information necessarily deprives the viewer both of motion parallax and stereopsis as side-by-side views now carry information about objects in displaced positions. In order to be able to track the image elements the amount of motion has to be very restricted. Too much movement of the subject in the initial 2D images will result in "time smear" where the parts of the subject do not match up in side-by-side views and consequently cause retinal rivalry. Because the animation of the holographic stereogram is activated by the walking of the viewer side to side, the motion of the subject will be read in forward and reverse.

The fluid motion of floating text in Eduardo Kac's, *Adhuk* , 1991 encourages the viewer to walk right and left to locate the point at which the letters coalesce into a word. At this point the viewer pauses. Instead of the beholder observing the three-dimensional representation of a space, the imagery instead designates that the beholder will be in a specific space in relation to the subject and the hologram plane.

Language plays a fundamental role in the constitution of our experiential world. To question the structure of language is to investigate how realities are constructed. My holograms define a linguistic experience that takes place outside syntax and conceptualise instability as a key signifying agent (Pepper, 1995).

Similar to the rainbow hologram the optimum viewing position within the viewing zone for the beholder of the rainbow stereogram lies along a line, which is at the same height as the centre of the holographic plate. The imagery can appear behind, in front of, or straddling the hologram plane. The viewing zone generally extends to the right or left of the plate or film. The locations of the horizontal boundaries of the viewing zone are variable depending on how the hologram is made.

The confines of this type of viewing zone have been used to great effect in works by Martina Mongrovious. "*Pater Noster*", 300 X 400 mm stereogram reflection print, was first exhibited at the centre for the Holographic Arts in New York and then in the Stairwell Gallery Melbourne.

Fig. 9. Martina Mrongovius, *Jumping Jellies*, 2007, rainbow stereogram, 30 X 40 and 60 x cm

In both these installations I wanted the viewer to mimic ascending /descending in the image. The subject's (my) holding of the camera links the viewer's proprioception to the subject, establishing an emotional and imaginative connection of shared experience…(Mrongovius, 2009).

In *Figure 8* the beholder is propelled at an increase speed in an office wheelie chair along a horizontal line parallel to the plate at the optimum viewing distance and in *Jelly*, the beholder jumps on a trampoline to fly past the small aperture located on the vertical y-axis. Here there is a deliberate reference to the inability to see the stereogram except from a specific height.

Falling, running, jumping and skipping are descriptions of movements but also come with strong emotive connotations. In the *Jumping Jellies* installations it is the physical mimesis between your own sense of blubber and the jellyfish movement that establishes the image. The intention of this work is both playful and to illustrate how proprioception can create a reading through experience (Mrongovius, 2009).

8. Printed synthetic hologram

Printed synthetic reflection holograms are composed from thousands of perspective views of a static or moving 3D scene. The viewing zone for these images is deep, the images being readable from both near and far with no particular point along the z-axis from which they seems best. The subject can appear in full colour and holograms are played back with a white light source. The side- to- side movement available to the viewer within the viewing

zone is wider than the holographic plate, approximately 25 degrees, which encourages the viewer to move in a random way.
The recording process of this hologram type involves the sequential exposure at the film plane of tiny holographic elements, or holographic pixels known as 'hogels', which are recorded in such a way, that corresponding yet different views of the same scene are distributed to each of the beholders eyes. The parallax and disparity effects enable the beholder to perceive the scene as three-dimensional. The smaller the size of the 'hogel', the higher the resolution of the image.
In *Holographic Imaging*, Michael Klug and Mark Holzbach, the authors of Chapter 20 Holographic Stereograms and Printing refer to the approach:
Holographic printing represents an amalgamation of 3-D hardcopy concepts proposed, developed and refined over the last one hundred years…In addition, image processing algorithms, derived from models of optical recording system and applied to perspective imagery made it possible to anticipate distortions and pre-distort component imagery to preclude their effects (Benton, 2007).
A three channel, synthetic, optically formed, fringe digital hologram *Shadowy Figures* by Paula Dawson simulates three scenarios of light and darkness identified by Michael Baxandall as important case studies in the analysis of shadow(Baxandall, 1995). If the beholder is standing to the left hand third of the image, at every position, high and low and side to side, the light relative to the figure seems to originate from the position of the viewers eyes. This effect was achieved in the CG environment by moving the light source to the position of the capture camera for each of the holographic pixels making up the image. If the viewer stands in the centre of the field of view, a static light from the back left shines towards the front right and illuminates the side of the figure,while on the right a source of darkness is projected from in front of the hologram plane very low out of the field of view. Thus by moving side to side the role of the beholder is radically transformed. On the right the viewer witnesses by movement of their body the interaction of the darkness source obliterating the light. In the centre they are a passive witness to a scene in which the lighting and subject are locked together whereas to the left, the effect of the light source being decoupled from the scene and instead attached to the viewer position has the effect of implying that the beholder is a light source. Conceptually, luminosity of the beholder is indicated by the changing composition (Gage, 2003).
Martin Richardson's *Over the Rainbow* incorporates within an overall spatial scene, a montage of animations, which are replayed out at the speed that the viewer moves in front of the hologram film plane. The embedded animations activate and disrupt the pictorial space. The spatial field is in the first instance composed of disparate montage elements. These retain their spatial fidelity while introducing an uneven flow of space-time over the image surface. A woman is holding crumpled surfaces in front of her eyes, while behind her is a landscape – a still of the yellow brick road from the *Wizard of Oz*.
Returning to *Broken Window*, the key elements : the broken window, the light and the tree-branch signifying the holographic picture plane, the replay light, and the subject traversing the space of the picture plane have been discussed. The motion of the scroll is of critical importance as it is possible to track through this visual element the moving boundary of the image zone.
In each of the three above-mentioned examples there is very little z-axis depth and only shallow information on the side edges, which could potentially be cropped by the edges

of the viewing zone. Richardson introduces a large black border in the background making the wipe of the image zone less noticeable, Dawson uses 2D imagery for a large surrounding of the figure, which is in a niche, and Debiens employs the rolling scroll. The tapering of the z-axis space near to the edge of the holographic plate where it will be cropped has some similarly to the tolerance of the framing of film scenes. As Peter Greenaway comments:

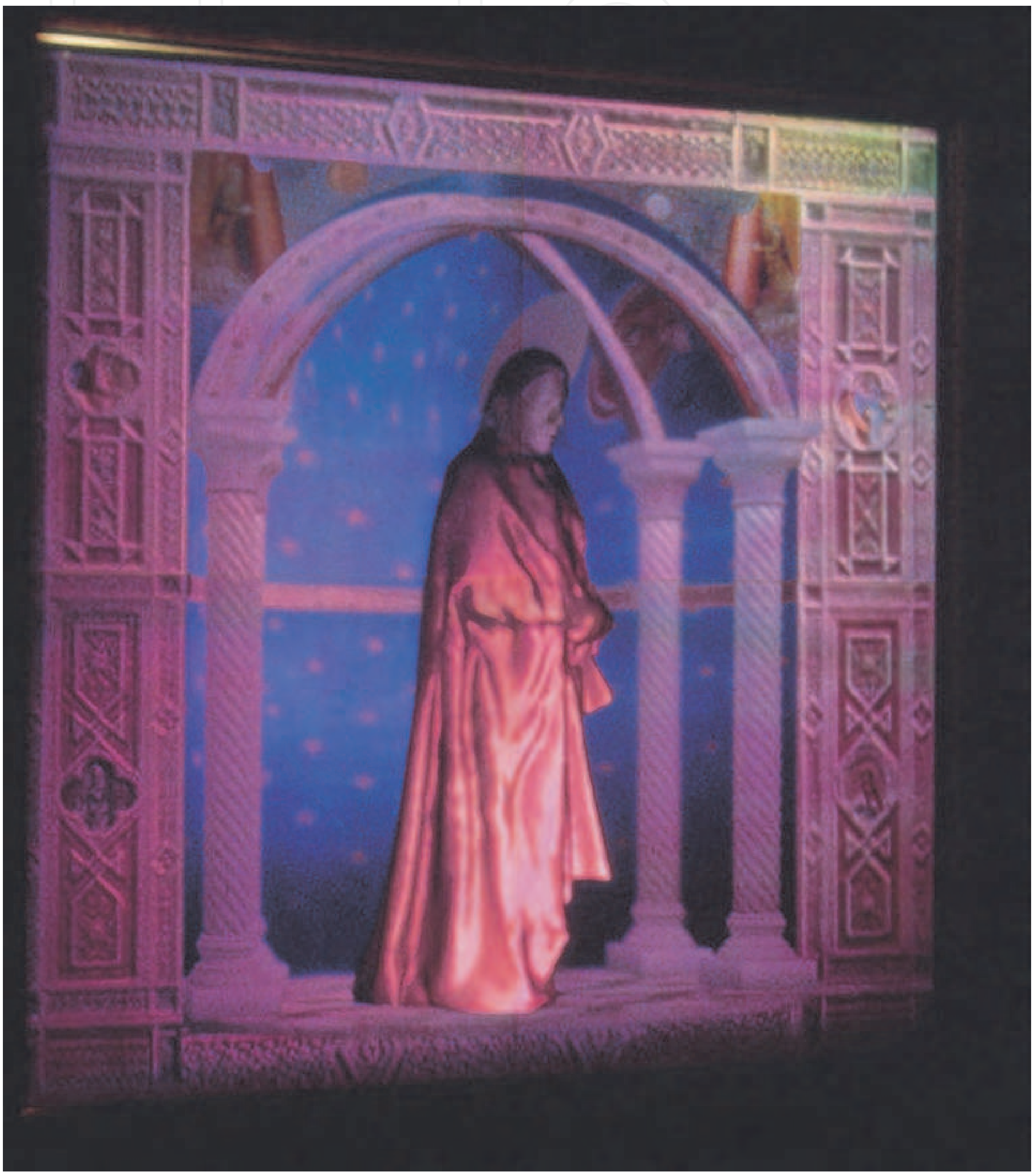

Fig. 10. Paula Dawson, *Shadowy Figures*, 2003, printed synthetic optically formed fringe digital hologram, 120 X 120cm.

Fig. 11. Martin Richardson, *Over the Rainbow*, 2009, iLumogram image taped to an invisible plane. The solidity of space is built strongly on occlusion. The taped landscape of the back plane being occluded by the torso, which is occluded by the hands holding up the crumpled surfaces. As the viewer moves side- to- side the surfaces reveal movie animations from the *Wizard of Oz* of the Tin Man kissing Dorothy and the great Oz appearing from the flames. The work, which is a subtle comment on the current place of the rainbow hologram and acknowledgement of *Black Rainbow* by Benyon and Benton, is aligned with what Timothy Murray has called the Digital Baroque as "enfolding the user in the energetic present, as articulated in relation to the analogue past while bearing on the digital future" (Murray, 2008).

The painter can pick his own frame, the filmmaker is not so lucky. Having made a selection form the smaller number of film ratios possible, careful composition of a picture into the corners of the frame and right to the very edges is still not dependable when projected. Exact symmetries are not to be relied upon. Tolerances must be permitted. Hence the concept of the floating edge (Greenaway, 1990).

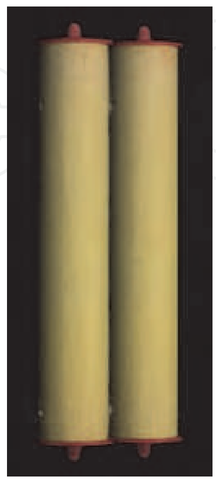

Fig. 12. Jacques Desbiens, *The Broken Window*, 2006, Printed Synthetic hologram, CG render from the left, the first point of view, 140 X 38cm.

The space is deepest at the centre of the holographic picture plane which has the widest angle of view. This central placement of a protruding image element to avoid cropping as the viewer moves side-to-side is common to many holograms. What is quite unique about this representational system is the ability of altering in very subtle ways, hogel by hogel, the structure of the subject as the beholder moves.

Synthetic holography offers a solution to the age old distortion problem of accidental linear perspective, the addition of a wide field of view and dynamic observation …movement of the eyes obviously, but also movement of the body, free wandering of observation, nomadism of points of view (Desbiens, 2009).

9. Conclusion

Holographic representational systems types such as the HOE, laser transmission hologram, reflection, rainbow, stereogram and printed synthetic stereogram have expanded the space of representation. They each accomplish this by using the support (holographic plane) the viewing zone, the replay light, the location of the image (behind, in front of or intersected by the support) and the properties of the subject to engage with the beholder in different spatial and temporal ways.

Holographic representational systems are chameleon-like; they can operate directly with real-world subject matter or draw from other pictorial systems rendered in a wide diversity of media ranging from film, photographs or arrays of computer graphic rendered frames composited within the holographic diffractive optic environment. The types of aperturing of the viewing zone between the beholder and the holographic plate introduce a non-visible formal element of great importance to the holographic representational system. In some cases the shapes of the viewing zones are echoed in the compositional structure of the work in abstract and literal ways.

Like perspective, the range of positions available for viewing the subject is directly tied to the representation of the subject. These are inseparable elements, which form the image space/ viewing space continuum. However unlike perspective, where the ideal space for viewing is confined to a specific point along the x-axis, holographic representational systems range from full X, Y, Z mobility of the beholder to narrow long corridors, thin wide strips and trapezoids.

The fundamental property which all holographic representational systems share is that they precipitate and reciprocate the movement of the beholder with further visual information distributed in space and time. From the above mentioned examples it is clear that the additional information gained by the beholder from moving though the viewing zone, rather than confirming the *simulacra* and *hyperreality* of the subject, can equally be used to introduce ambiguities of tone, colour, space and time which challenge initial assumptions.

As Zeki argues:

…the capacity to give multiple interpretations is not a separate faculty invented or used by the artist. It is instead tied to a general capacity of the brain to give several interpretations, to instill meaning by applying several concepts, a capacity that is important for art in its role of acquiring knowledge. It is on this physiological basis that the prized quality of ambiguity in art is built (Zeki, 2009).

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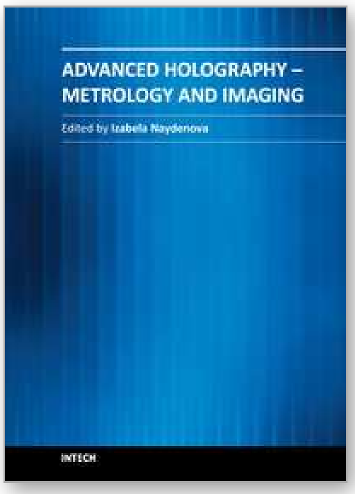

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Advanced Holography - Metrology and Imaging covers digital holographic microscopy and interferometry, including interferometry in the infra red. Other topics include synthetic imaging, the use of reflective spatial light modulators for writing dynamic holograms and image display using holographic screens. Holography is discussed as a vehicle for artistic expression and the use of software for the acquisition of skills in optics and holography is also presented. Each chapter provides a comprehensive introduction to a specific topic, with a survey of developments to date.

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