Invited paper

"Experiments in image composition for synthetic holography"

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ABSTRACT

By blending holographic imaging and 3D computer graphics, synthetic holography offers new possibilities in visual effects and image composition, some of which are impossible to conceive with any other medium. The multiple points of view and the ability to display content linked to the positions and movements of the observer makes synthetic holography a medium for which there is a whole new pictorial language to develop. This paper describes a series of experiments that shows the particularities of synthetic holography and deduces a few principles in image composition for computer generated holograms.

In synthetic holograms, many image composition elements operate in a singular manner. The reversibility, decentralisation, simultaneity and synchronisation of content, the variability of alignments, the relationship between volumes and void, depth clarity and the spatial zones, temporal incoherence and the effects of time-smear, are all linked to the structure of the hologram and the movements of the observers. The optical characteristics of synthetic holograms have an impact on content choices. By understanding the elements of composition, the structure of multiple viewpoints perspective and the dynamics of observation in movements, the holographic artist can compose images that may lead spatial representation into new territories.

Keywords: Synthetic holography, composition, computer generated hologram, multiple points of view, spatial synchronisation, time incoherence, time-smear.

1. INTRODUCTION

Synthetic holograms simulate continuous parallax by combining hundreds of computer generated images. In a 40cm X 30cm hologram for example, as much as 1280 rendered images corresponding to as much points of view on a 3D scene can be used to produce an illusory three-dimensional space. In synthetic holography, as in any other imaging medium, the structure of the image has an impact on content choices, presentations and perception. This paper presents observations that were gathered through a series of experiments concerned by the repercussions of this imaging process on the composition of space and time in synthetic holograms. Understanding the relationship between the spatial and temporal structure of these computer generated holographic images and the final appearance of the image features and content is essential to obtain a high degree of image quality and an efficient composition process. Optical structure and image composition are linked.

2. COMPOSITION ELEMENTS IN SYNTHETIC HOLOGRAMS:

Synthetic holograms are made of thousands of small juxtaposed and partially overlap holographic cells[1]. The imaging technology I use can produce large format holograms from holographic cells of 0.8mm or 1.6mm[2]. Each of these holographic cells is in fact a small hologram. In fact, the holographic cells grid, the geometry of the 3D computer graphic images, the display conditions and the movement of the observer are interdependent and will determine and modify the appearances of images features.

Each holographic cell diffracts light toward the eyes of the observer to reconstruct the whole 3D image. As the observer moves and modifies his angles of view, he perceive a sequence of images, stereoscopically, in which variations of image features such as forms, colours, luminosity, three-dimensional spatial organization and others characteristics can appear to be animated. When preparing images for this type of hologram, the artist has to take in account the variations of angle of view. Soon, it becomes clear to the artist that he doesn't only represent space and volumes, but also a movement in space.

Synthetic holograms display images created by using multiple points of view perspective[3]. It is the first freeviewing 3D display that can present to the observer enough points of view on a fictitious 3D space to produce the illusion of continuous parallax. This innovation implies that we consider new image components in the analysis of these computer generated holographic images. Not only we can identify the usual elements such as shapes, lines, textures, colours, etc., but the three-dimensional structure of the holographic space and the dynamic variations of appearances corresponding to the observer's movements, increase the significance of several characteristics.

By adding a third dimension, depth, holograms emphasis volumes and the interplay between real space and holographic space. Not only volumes can appear behind the surface, but 3D elements can be visible in front of the surface. The plane is no longer a limit. Furthermore, the observer can choose an angle of view and scrutinize content in variable appearances. The ability to display actions, transformations and successive contents becomes part of image composition in an unusual manner. The artist creating a synthetic hologram will build a three-dimensional space, position volumes and voids, lights and shadows, alignments and actions. Furthermore, his visual information can be spread over space for the viewer to observe from different points of view, in a non-linear manner. Contrary to cinema or video, in synthetic holograms, movements are under the control of the observer. At his rhythm, he can observe the hologram from left to right or reverse the direction, stop or move faster. The viewer has a choice.

Consequence of its spatial interactivity, several optical, geometrical and perceptual characteristics will affect the way we compose images for synthetic holography. There is no rule of composition but parameters. Defects for one can gain aesthetical value for another. Experimentation of synthetic holography, and multiple viewpoints perspective, unveils several compositional elements worth considering. These elements are the building blocks of new narrative forms adapted to dynamic observation.

3. SPATIAL COMPOSITION IN SYNTHETIC HOLOGRAPHY:

For the past ten years I have been experimenting synthetic holography to study image features, visual effects, composition in three-dimensional dynamic space and narrative possibilities. From this experimental approach, several optical, compositional and perceptual characteristics stand out as being peculiar. Some of these holographic image features are common to analog holography or other approaches to digital holography. However, experimentations and observations of perceptual effects show a prominent set of characteristics that are introduced, transformed of increased by the optical structure of synthetic holography. Here are some examples:

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[1] Sometimes called: holographic pixels, holopixels, hogels...

[2] This holographic imager was developed by XYZ Imaging (Montreal, Canada) and Geola (Vilnius, Lithuania). It is now used by Geola and RabbitHoles (Gatineau, Canada) among others.

[3] We explained the basic set-up of perspectivist construction for synthetic holography in our other paper. See : Desbiens, Jacques, *The perspective of synthetic holography*, ISDH 2009, in this same proceedings.

3.1. Spatial zones:

The holographic space is shaped like two truncated pyramid joined together at the hologram plane (fig. 1). This space can be divided in three main spatial zones: 1- The hologram plane itself, this is the surface of the plate (inside the brown frame). 2- Behind the hologram plane (in blue), that is a fictitious or virtual space. 3- In front of the hologram plane (in yellow), which is real space.

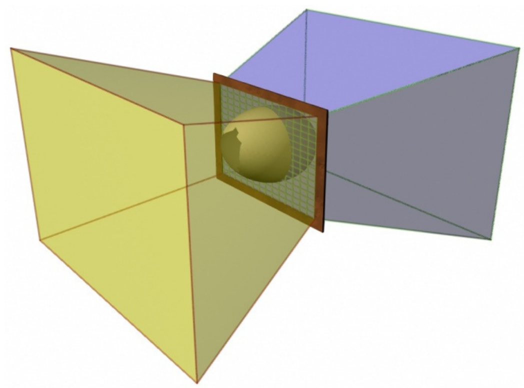

Figure 1: holographic space

This obvious observation has lead many holographers to compose their 3D space according to certain forms, trying to occupy these spatial zones in a manner that will produce an efficient three-dimensional appearance. Among the most used spatial configuration forms are what I like to call 'the egg in the window", where an object seem to float in space, a small part of it in front of the hologram plane and a bigger part behind. We also often see "crossing compositions", in which different elements cross each other at different angles, going from one side of the plane to another. Then, we have the "stairs composition", where lower part of the scene is in front of the hologram plane, a middle portion close to the hologram plane, and the top part of the hologram is occupied by elements farther behind the hologram plane. Obviously there are many variations on these forms and other spatial arrangements that work well in presenting 3D content.

3.2. Volumes and voids:

Composition of a 3D scene for a synthetic hologram is often an arrangement of volumes and voids. Usually in 2D imaging, these positive and negative spaces are simply interplay of flat forms that the artist balances to create equilibrium, tensions, directional vectors, etc. In an image made from multiple points of view, which is sequential and variable, and mostly a three-dimensional image, the arrangement of volumes and voids may be more complex. 3D perception will be easier if reference points allow the observer to perceive clear gaps and interposition of objects. When positioning volumes and considering their spatial relationship with each other, void become an important part of this composition. In fact, what we often consider as being "emptiness", lose this attribute to become itself a volume. It often defines visibility, how the observer will perceive distances, alignments, tensions, rhythms and contrasts.

This characteristic of voids, as being volumes which determine visibility, is analogue to the role played by voids in oriental painting, in which voids are far from being emptiness but rather a chaos, a fog or cloud, where everything takes form, where the painter regulate mass, balance and rhythms. Voids are a tool in spatial composition and a concept that allow the painter to link and alternate between different "distances" as theorize by Kuo Hsi (1023-c1085) in his XIst century painting treatise "*Lofty Messages of Forests and Springs*" (*Lin ch'üan kao chih*)[4]. Kuo Hsi's three distances" (*sanyuan*): "high distance" (*gaoyuan*), "deep distance" (*shenyuan*) and "level distance" (*pingyuan*), are different from our three holographic zones. His approach tries to understand how positioning, tones and forms can suggest depth, and how voids can suggest the passage from one distance to another. Its interplay between voids and volumes help us understand the dynamic of positioning objects in an illusory space. In a hologram, sharpness of objects will vary depending on depth of field, distances, animations and display conditions. Composition will enhance visibility.

[4] Kuo Hsi, Lofty Messages of Forests and Springs (Lin ch'üan kao chih, 1117), published as An Essay on Landscape Painting; translated by Sakanishi, Shio, John Murray, London, (1935).

Our synthetic holograms are holographic panoramagrams and offer to the observer a wide field of view; nevertheless they possess real tangible limits, borders. In these arrangements of volumes and voids, borders can provide a position reference for the viewer that may not be always suitable. If an object is positioned in front of the hologram plane, but when the observer moves toward the sides and parts of the object become occluded because it is outside of the holographic window, this will introduce a spatial contradiction. In reality, something in front shouldn't be occluded by a border behind. In such a case, perception will choose the easiest solution between two contradictory stimulus, and "push back" the element behind the hologram plane.

In my experiments with synthetic holography, among many optical characteristics, I investigated perspective coherence in regards to this multiple viewpoint imaging system. While we gain extensive three-dimensionality, motion parallax and spatial interactivity, synthetic holograms may undergo diverse distortions that can modify, reduce or stretch shapes and volumes. All holograms can display spatial distortions caused by lighting distance, position or viewing distance. Usually, these distortions are hardly noticeable by the viewer unless he is aware of the true dimensions of the represented objects. However, deep space remains problematic. In synthetic holography, the light source and the virtual camera have a pre-determined position. In a horizontal parallax only holographic imaging system, if the observer moves closer to the hologram than the distance of the virtual camera, then far away shapes may stretch vertically. If the observer moves farther the camera distance, far away shapes my stretch horizontally.

Because of its panoramic field of view, synthetic holograms can gain from a decentralized composition. Content may be spread over space and be transformed according to the observer's movements. That way, variety, oppositions, directional elements and other tactics may establish points of interest, emphasis, balance, synchronisation, contextualisation and interplay between elements of the composition. This opens the door to narrative possibilities that, in most part, are still to be investigated.

3.3. Spatial synchronisation:

Since content can be spread over a large space and that the observer has to move, even walk, to perceive the entirety of the representation, content variations should be composed in relation with points of view. Besides, the observer is free of his movements, a sequence of content may not be observed in a linear successive manner. The succession of subjects may be non-linear. Obviously an animation in a synthetic hologram can be display as a linear succession of events. However, unless there is some kind of control over the display conditions for the content variations to appear according to a pre-determined succession of events, we have to hope for a willing participation of the observer moving in accordance with the animation. Unfortunately, my experience observing the behaviour of many viewers leads me to assume that the observational movements of animated holograms are very chaotic. For that reason, spatial synchronisation of content is an implement for building a narrative structure detached from a successive, ordered, sequence of events. In cinema, what happens now is linked to what has happen before and what will happen after. In a narrative synthetic hologram, what happens here is linked to what happens there.

This narrative form is unusual. It breaks from storytelling as we are accustomed to in literature and cinema. It necessitates an approach were the observer has to collect information from various locations and reconstruct the subject. Consequently, spatial organisation goes beyond positioning and balance of components and aim at establishing relationships between components. In a hologram simulating the total solar eclipse over Europe in 1999 (fig. 2), the image show one hour of eclipse. The observer can, if he wants to, watch the shadow on the earth moving from England to Romania. However, since the image also provide the viewer with information about time, position of the sun, a view of the eclipse from a telescope and cities where the eclipse was total at a given time, the observer can understand the subject by collecting information about what happen at different particular moments. All visual information is synchronized in this hologram to match the variations of the event depicted at different moments. The elaboration of this holographic composition made me become aware that, even though I was representing an hour, in fact the end result was a series of distinct moments expanded over several viewing zones.

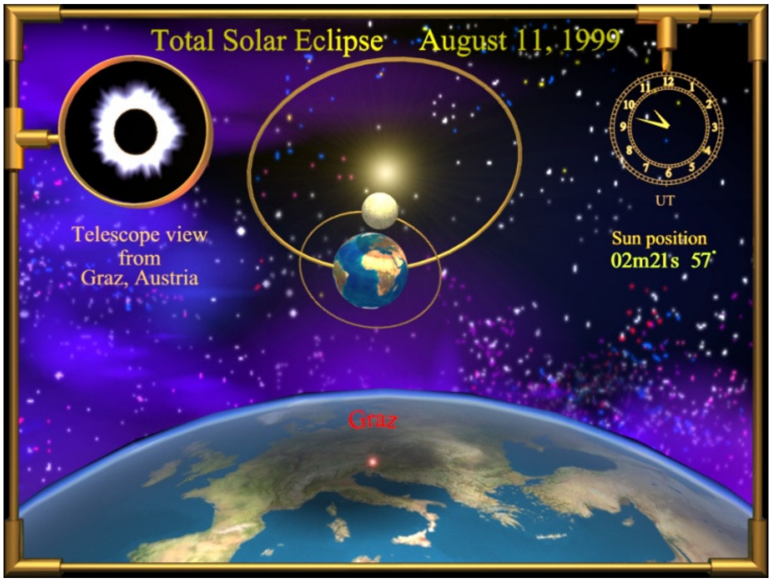

Figure 2: *Simulation of the 1999 total eclipse over Europe*; Jacques Desbiens, 2004.
Synthetic hologram, 80cm X 60cm.

3.4. Divisions:

The ability to divide and distribute content over different sections of the hologram is an important consequence of spatial synchronization in a multiple points of view system. The hologram "*Tractatus Holographis*" (fig.3) is an example of this division. This hologram presents to the viewer a 16^{th} century fictitious treatise on holography. When the observer is in the left part of the viewing zones, he sees the first and second pages of an open book. Moving toward the right, he sees a page flip and when he is in the right part of the viewing zones, he can see the third and fourth pages. Two different compositions are presented in one single holographic image.

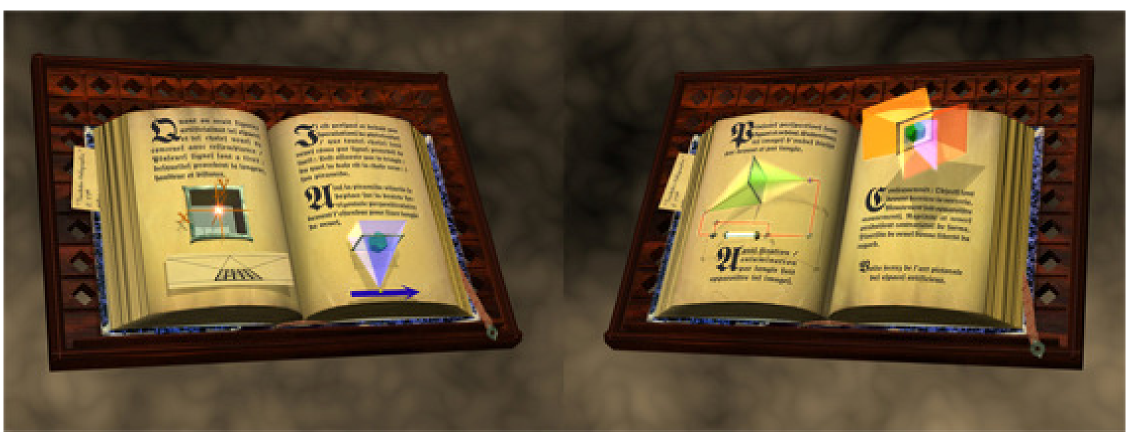
Figure 3 : *Tractatus Holographis*, Jacques Desbiens, 2005.
Two points of view on a synthetic hologram, 60cm X 40cm.

A hologram such as "*Numbers*" (fig. 4), demonstrate that we can create many divisions of the viewing zone to distribute content. In the hologram, numbers from 0 to 9 changes when the observer moves. This small format hologram shows that at least 10 different content configurations can be distributed in the holographic space. The maximum amount of divisions will depend on the size of the hologram and parts of the content or the entirety of the subject can vary.

Figure 4 : N*umbers*, Jacques Desbiens, 2009.
Three points of view on a synthetic hologram, 174mm X 250mm.

This compositional approach can have many applications in visual communications especially when the designer knows beforehand where the hologram will be exhibited. Visual information could then be linked to specific angle of view. Also, a large quantity of information can be spread over a series of viewing zones. This kind of distribution can overcome confusion in displaying visual information. Spatial synchronization could use different narrative forms that can be particularly useful in explaining phenomenons and describing different levels of a complex situation or action.

3.5. Multiple levels of visual information:

In addition division of viewing zones, spatial synchronisation is enhanced by using multiple levels of visual information such as: 2D texts, 2D images and graphics, 2D animations, 3D texts, 3D objects, 3D graphics, 3D animations, transformations and simulations, and a direct and natural interactivity given by the variations of angle of view. In applications such as scientific visualization, art, education, museology and other visual communication applications, multiple levels of visual information could be more crucial than 3D itself.

The fact that observers have a choice of points of view breaks up the narrative structure into segments that can be spatially synchronized in a three-dimensional space. The observers then have a choice in "reading" the information as it is presented or in a different succession. With multiple levels of visual information, the content may be presented in a dynamic form into several viewing zones where descriptions are based on spatial relations between different components, and where the observers has to scrutinize the content to reconstruct its meaning. Then, not only content is spread over the whole panoramic view of a synthetic hologram, it is also expanded in a diversity of representations. The synthetic hologram is then elaborated as an information display.

3.6. Directional elements:

One of the most peculiar visual effects in synthetic holograms is the possibility to make an object follow the movement of the observer. People often say, while contemplating a painted portrait, that it is so realist that the eyes of the character seem to follow us. This illusion can now be realized with synthetic holography. Any computer generated object included in the composition can be targeted to the virtual camera and change its orientation according to the camera's movement. Then, when the observer is moving, the objects angle will always be directed toward the observer or follow its movements.

In a three-dimensional space, the complexity in the arrangement of directional elements is augmented by the multiple viewpoints structure. The impact of elements orientations will be affected by the observer's positions and movements. Thus composition balance, the interplay of volumes and voids, colours, contrast and the arrangement of virtual lighting and shadows will determine the efficiency of directional elements. Eyes, finger pointing, arrows or any other elements can create a personal link with the observer, be associated to the display environment, have a symbolic signification or produce dramatic effects.

When a designer knows beforehand where the hologram will be displayed, directional elements could link the content to a given environment. For example, 3D maps could be realistically oriented and directional elements could be used in a signage hologram, such as a "*you are here*" map, and point out the real direction toward a destination. Fictitious components could be added to a real architecture or site. Many applications in museology, architectural planning, signage and scientific visualization can be imagined using directional elements associated with proper orientation and placement of a synthetic hologram.

3.7. Simultaneity:

With a composition based on angular variations, observers see different aspects of the hologram from different points of view at the same time. Someone at the left sees something different than someone at the right. By observing how people move in front a synthetic hologram in which the content has variations, we quickly notice that viewers move to appreciate the animated content and then choose a few angles of view. Depending on composition, subjects, memories, knowledge, questioning or any other criterion, they have preferences and apply them to their choices of points of view. People look at different parts of the whole content at the same time and reconstruct their own sequence of events. The linear "beginning, middle and end" structure is not only broken, it is perceived differently by each observer. The holographic artist abandons this control over the succession of events to the freedom of observation. Every observer chooses its own chronology and sequences of viewing. Synthetic holograms can be viewed by a group of people, but content is reconstructed by each individual.

4. TEMPORAL INCOHERENCE:

In cinema, content is spread over time. Everybody sees the same things at the same time. Movements and speed are determined by the filmmaker and his camera. The viewers are captive. When content is spread over space, as in synthetic holography, and the observer can freely perceive one or more subjects in a different chronology by moving at his own rhythm, time can be represented only in a symbolic form. There is no "real" time in a synthetic hologram; there is only the viewer's time of observation. There is no speed in an animated synthetic hologram; there is only the observer speed of movements. In synthetic holography, the artist has to compose his subject, his narration, in a non-cinematographic form, where space is done and time is undone.

4.1. Reversibility:

Freedom of observation brings the possibility for the observer to reverse the chronological structure of an animation. A succession of element appearing when the observer moves from left to right will reverse itself when the observer moves from right to left. Something opening will close. Something appearing will disappear. Something going down will go up.

This effect may not be a problem for most subjects, the observer quickly understanding and accepting that there is a direction to follow. However, reversibility can create some logical contradictions or modification of meaning. A waterfall will flow upward. A bird flying will appear to go backwards. An assemblage will be deconstructed. Content with an introduction and a conclusion could be problematic. Reversibility shows that the optical characteristics of synthetic holography have a direct impact on content choices. The represented time can only be a collection of events, synchronized in space, but narration may not be chronological anymore.

4.2. Time-smear:

In this structure of holographic cells, when there is an animation added to the sequence of images, one eye sees the moving object at a position while the other eye sees the same object at a different position. If the action is a transformation, one eye sees the transformed image feature at a different state of progress than the other eye. In other words, when the observer moves, both eyes see two different moments of a single time set. When we perceive this simultaneity of moments, time is smeared. However, its visible effects are spatial.

As an object shift over many holographic cells, stereoscopically perceived, its components (contour, shape, texture, etc.) are broken, dismantled. When the two stereoscopic images are fused, the differences in position or appearance of these details will be distorted. In most case, we will only perceive a blur, but depending on the shape of the object, the orientation of the action and the size of the transformation in relation to the amount of holographic cells covered, different effect can be obtained. To visualize some of these visual effects according to their orientation and composition, I designed an experimental hologram in which objects are moved in different directions. This synthetic hologram is 176mm X 250mm and made of 0.8mm holographic cells.

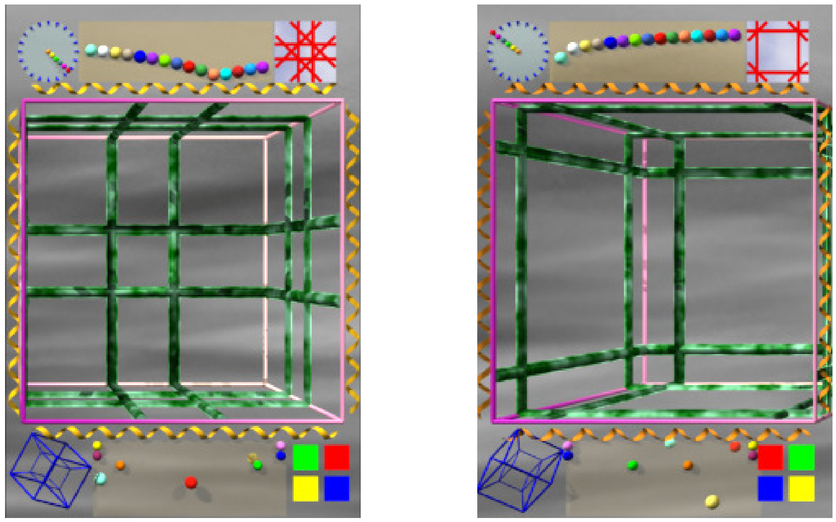

Figure 5: *Distortions,* Jacques Desbiens, 2009
Two points of view of the rendered images for a synthetic hologram, 176mm X 250mm.

Time-smear caused by moving objects on the vertical axis (Y) is a common case. The gap in the alignment of two stereoscopic images will elongate and blur the image. When the object moves on the horizontal axis (X) at the plane of the hologram, the distance between the two stereoscopic images are modified by this movement. An object moving from left to right, in the same direction of the virtual camera and the observer, will appear to be farther than the position it should be. An object moving in the opposite direction will seem to be closer. Objects moving straight on the Z axis will appear to make a curved path. Yet these distortions will vary depending on size, positions and amount of cells on which this action occurs.[5]

All these modifications of apparent positions are caused by variations of the level and interval between two associated images features in a stereoscopic couple. When the object is more complex or wider, the distortion cause by time-smear can modify shapes and forms. This is visible in the horizontal lines of the cube in the "*distortions*" hologram (figure 6). Straight horizontal lines moving vertically will appear tilted towardbone side or the other, depending on lighting and viewing distances. Moving closer or farther than the optimal viewing distance will reverse the tilt angle. Vertical lines moving horizontally won't tilt but they will appear at different depth.

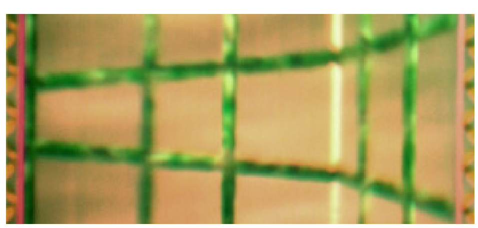

Figure 6: Detail of *Distortions* hologram*,*
Jacques Desbiens, 2009

[5] For a mathematical investigation of time-smear, please see: Teitel, Michael A., *Animation in holographic stereograms: the time depth paradox*, Practical Holography III, SPIE Vol. 1951, 205-215, (1989).

Rotations are movements that shift their orientations gradually. In consequence, time-smear distortions will vary according to the orientation. A complex object in a chaotic rotation, such as the hypercube in the lower left corner of the above experimental hologram (figure 5), will produce an animated distortion that vary with the orientation shifts of the rotating object.

Time-smear is a complex visual effect determined by many variables. The optical characteristics of the holographic imaging system, image processing, the orientation of the animations, lighting distances and even the position of the observer will affect the appearance of the distortions. Again, the appearance of content is transformed by the observers' movements.

4.3. Doubling:

Time-smear can also produce other visual effects specific to the geometry of this 3D imaging approach. Since our two eyes will see two different moment of an animation, a quick event, such as a flash will be apparently doubled. One eye will see the flash and then, as the observer moves, the other eye will see it again. This is visible in the telescope view of the sun in my *"Eclipse"* hologram (figure 2). This doubling, seeing twice the same event, can be reversed in a transformation when the two eyes see two different features as one. This is the case of the colour changes in the lower right corner of the *"distortions"* hologram. Not only the transformation of colour seems to occur as a wipe, but the colours seem to be optically mixed. What is supposed to be a sudden, instantaneous switch between colours, appear on this synthetic hologram as a gradual but uneven transformation.

Time incoherence is a component of synthetic holography that needs further investigations. Not only we must learn how to compensate time-smear and distortions to assure higher realism, but we should also experiment the esthetical possibilities of time incoherence in spatial compositions as part of singular characteristics of synthetic holography.

5. DIEGESIS : BEYOND MIMESIS IN SYNTHETIC HOLOGRAPHY:

In most holograms, objects are shown. Either with realist or abstract components, three-dimensionality gives an illusion of presence. By modifying its angle of view the observer can see the side of objects, hidden parts, a space made of volumes and voids. Because of its illusionist capabilities, holography has become an instrument of *mimesis*, of imitation. The sequential structure of holographic panoramagrams introduces the possibilities of modifying content, movements and actions can be depicted. Not only synthetic holography can use *mimesis*, but it also can tell a story using successive content variations, it can be a instrument of *diegesis*. *Mimesis* shows, *diegesis* tells.

Synthetic holography offers possibilities in mimesis beyond any other imaging technology. On the other hand, its sequential content structure, spatial composition and synchronisation, its deconstruction of time and even its distortions seem to depart from what could be considered a mimetic medium. However, these same characteristics may be the ground on which we can build narrative forms in which the viewer freely scrutinises, studies and selects. He could be an active observer. As holography artists, as content producers, we are encountering a medium with an additional dimension of spatial interactivity, a new form of diegesis where the observer's movement in real space will reconstruct meanings.

"He first copied down the insect as seen in the clear lens;
Then it was just an insect,
But who would not now think it a bird flying through the woods?
Who would doubt it to be some heroic beast running over low hills?
He copied its shape in colour,
And it fills the entire screen.
Look at it closely, the downy hairs have become gigantic.
Now I realise the labour of creation."[6]

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[6] Minagawa Kien (1734-1807), *Shanon Kien Bunshũ shõroku*, pp. 387-8. in Screech, Timon. *The lens within the heart – The Western scientific gaze and popular imagery in later Edo japan*, University of Hawaii Press, Honolulu, 56, (2002).