Invited paper

"The perspectives of synthetic holography"

Jacques Desbiens

École des Arts Visuels et Médiatiques (E.A.V.M.), Doctorat en Études et Pratiques des Arts
Université du Québec à Montréal (U.Q.A.M.), Montreal, Quebec, Canada.
www.i-jacques.com

ABSTRACT

The structure of a synthetic hologram is made of thousands of 3D computer graphic images corresponding to as much points of view on a three-dimensional scene. This technology brings back a perspectivist approach to holography. However, the multiple viewpoints of these holograms depart from the fixed single point of view of classical perspective. To appreciate the entire space, the observer has to vary his points of view; he has to move, to walk. Holographic panoramagrams are indeed panoramas.

In the history of imaging, very few occidental artists have undertaken the representation of space and volume from variable points of view, whereas this approach is widespread in oriental landscape painting. In this paper, we take a look at the history of multiple points of view perspective to seize the particularities of synthetic holography and better understand its place in the historical development of 3D imaging and holography. Searching in the texts of renaissance treatises on perspective and oriental treatises on painting, we can find several indications that the artists of the past centuries where aware of the necessity of representing multiple points of view and attempted to do so.

From Jean Pélerin Viator and Kuo Hsi, the concepts of multiple viewpoints in spatial representation have found their way into synthetic holography, to create the necessary conditions for imaging space in its entirety.

Keywords: Synthetic holography, computer generated hologram, perspective, multiple points of view.

1. INTRODUCTION

When we look at the history of 3D imaging, we usually start from the "invention" of perspective attributed to Filippo Brunelleschi (1377-1446) and end with 3D computer graphics. Holography is often seen as a particular case, developed into the evolutionary path of photonics. In recent years, walking into the steps of multiplex holography, 3D computer graphics and holography have merged to produce synthetic holograms from hundreds of perspectives images. This approach to three-dimensional imaging gives to multiple viewpoints perspectives the optical display that it needed for freeviewing the represented 3D space. It also link holography to a long history of trial and errors in representing space and volumes. When we look at the texts that punctuate the chronological development of perspectives, we can find several indications that artists and scientists of the past were already considering spatial representation from multiple points of view perspectives.

Before we go through a historical path that established the application of a perspectivist approach to holography, we have to consider the structure of synthetic holograms. Often called "multiplex holograms" or "holographic stereogram", these computer generated holograms use 3D computer graphic software to produce a series of perspective views on a 3D scene. Hundreds of point of views are rendered and processed to reconstruct three-dimensional space and volumes that the observers can perceive with apparent continuous parallax. In the holographic technology I use[1], horizontal parallax holograms are prepared by setting up a virtual camera, in a 3D computer graphic software, that registers a sequence of points of view on the X axis, in front of the 3D scene. The software renders a series of perspective view of the scene, using a set of predetermined parameters (resolution, distance of camera, field of view, camera track, number of images to render). These rendered images are then processed and imaged on the holographic emulsion. By using this configuration, this approach to spatial representation departs from traditional single point of view perspective, or even stereoscopy or autostereoscopy, in providing to the viewer enough variations of angle of view to move freely, choosing angles of observation, alternative points of view and dynamically observe the space and volumes. It departs also from analog holography by simulating 3D space through a limited sequence of images instead of reconstructing the whole wavefront of an object.

Nevertheless, in comparison to other non-holographic 3D imaging systems, realism is greatly enhance by introducing more visual information related to the angular appearance of space and objects. Also, the sequential structure of synthetic holograms outshine the ordinary monoscopic perspective view on a scene, it is a polyscopic perspective. The space represented isn't only 3D, it is dynamic, it is a space one has to observe in movement, by walking, a nomadic perspective.

2. THE CYCLOPS VS THE NOMAD

When Brunelleschi fabricates his *tavoletta* in 1413[2], he paints the San Giovanni Batistery in Florence (Italy) using frontal perspective geometry. He pierces a small hole in his painting at the position of the central vanishing point through which he will observe the alignments of his perspective geometry reflected in a mirror in comparison with the model. The position of this hole corresponds to the position of his point of view on the scene. His apparatus is quite simple and his objective is to validate linear perspective as a geometrical system. Seventy years later, his biographer, Antonio Manetti (1423-1497), describe this experiment for the first time, and clearly emphasis the fact that:

> *"As the painter supposed a single point from which one sees his painting, in height as well as in width and at an angle as from far away, in order to deceive when observed, since any changes of location leads to a different vision."*[3]

When we reconstruct Brunelleschi's perspective experiment[4], it becomes clear that this apparatus is very rigid. Positioning of the perspective drawing and the mirror has to be very precise. Any variation of this position affects the alignments. Moreover, the position of the viewer's eye needs to be extremely precise and fix. Without stillness and precise positioning at the predetermined point, the experiment fails. The *tavoletta* is a device eliminating all variations, choices and freedom for the observer. Classical linear perspective is a focalized projection of space in which the visible has to go through a single point. Using the *tavoletta*, the viewer is a bonded cyclop.

Even though Brunelleschi's experiment establishes a correspondence between the viewpoint and the vanishing point, this relationship is created inside the spatial geometry of the perspectivist construction. This unique point of view is a choice, a selection, a tool for composition, but a denial of the observer's space. This becomes the basic element of Leon Battista Alberti's (1404-1472) perspective construction described in his treatise[5]. His method is essentially a division of the bidimensional pictorial space to determine the position of a point that will direct and distribute the gradual diminution of forms with apparent distance.

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[1] This technology, developed by XYZ Imaging (Montreal, Canada) and Geola (Vilnius, Lithuania), is a computer controlled direct-write holographic imager using a RGB pulsed laser. Large format, full colour holograms are exposed on rolls of films with holographic cells of 0.8mm or 1.6mm. This technology is now used by Geola and Rabbitholes (Gatineau, Canada) among others.

[2] For a detailed description of the *tavoletta*, see: Kemp, Martin, *The science of art – optical themes in western art from Brunelleschi to Seurat*, Hew Haven, Yale University Press, (1990). And: White, John, *The Birth and rebirth of pictorial space*, Boston, Boston books and art shop, (1967).

[3] Tanslated from : Manetti, Antonio (1480), *Filippo Brunelleschi; la naissance de l'architecture moderne*, Paris, L'Équerre, 72, (1978).

[4] In 1988, I fabricated a workshop version of the *tavoletta* to analyse the configuration and perceptual effects of this kind of viewing apparatus.

[5] Alberti, Leon Battista (1435). *De Pictura (On Painting)*, Translated by Cecil Grayson, London, Penguin Classics. (1972).

"First of all, on the surface on which I am going to paint, I draw a rectangle of whatever size I want, which I regard as an open window through which the subject to be painted is seen; and I decide how large I wish the human figures in the painting to be. I divide the height of this man into three parts, (...). With this measure I divide the bottom line of my rectangle into as many parts as it will hold; (...). Then I establish a point in the rectangle wherever I wish; and as it occupies the place where the centric ray strikes, I shall call this the centric point."[6]

Alberti's pictorial space is made of points, divisions, lines and surfaces. His compositional[7] procedure is a selection of proportions applied internally to the surface, an (X,Y) coordinate system. A few years later, Leonardo da Vinci (1452-1519) improves Alberti's method by introducing the "distance points" (fig.1) allowing the artist to consider the distance, the Z axis, and position vanishing points outside the limited surface.

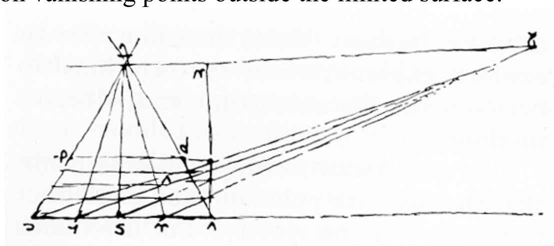

Figure 1: Leonardo da Vinci, *Perspective construction with distance point*, c1492,

Nonetheless, the perspectivists were fully conscious of the limitations of their partial representation of space. Leonardo da Vinci, talking about the mirror image as the painter's ideal, explained:

"Painters often despair of being able to imitate Nature, from observing, that their pictures have not the same relief, nor the same life, as natural objects have in a looking glass, though they both appear upon a plain surface. They say, they have colours which surpass in brightness the quality of the lights, and in darkness the quality of the shades of the objects seen in the looking glass ; but attribute this circumstance to their own ignorance, and not to the true cause, because they do not know it. It is impossible that objects in painting should appear with the same relief as those in the looking-glass, unless we look at them with only one eye."[8]

"(...) unless we look at them with only one eye." In the historical development of classical perspective, this assertion became a rule. The reduction of space through cyclopean vision was presented as a prerequisite to a coherent spatial representation system and the addition of one or more points of view was seen as irrational, an error.

"All those who drew perspectives arrived at the conclusion that all things appearing to vision will end in a single point. Yet, some think that, men having two eyes, it had to end in two point, but nobody, as far as I know, have carried out or succeeded in carrying out differently than with a single point, that is to say one single view. (...) I say that although we have two eyes, we have no more than one common sense, and those who witness the anatomy of the head were able to certify that the eyes nerves unite in the same manner than the viewed object. Although it enters through two eyes, it ends in a single point of the common sense. (...) Be that as it may, and from my experience in this art, I was never able to find that we could rationally proceed with more than one point. Here is my opinion, may we proceed with one single point, and not with two."[9]

Ignazio Danti's (1536-1586) reference to anatomy as an argument for single point of view perspective is part of a debate among renaissance European scholars regarding vision. Several centuries before, Erazmus Ciolek

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[6] *Idem,* book 1 #19. p. 54.
[7] « *This method of dividing up the pavement pertains especially to the part of painting which, when we come to it, we shall call composition." Idem*, book 1 #21, p. 58.
[8] Vinci, Leonardo da, *A Treatise on Painting*, translated by John Francis Rigaud, chap. 124, London, J.B. Nichols & son, 57-58, (1835).
[9] Translated from : Danti, Ignazio (1583), *Les deux règles de la perspective pratique de Monsieur Giacomo Barozzi de Vignole »,* Paris, CNRS édition, 223, (2003).

Witelo (1230-c1314) and John Peckham (1230-1292) had proposed that the fusion of binocular images occurs at the *chiasma*. *"Oculorum dualitatem necesse est reduci ad unitatem"*[10] states Peckham in is 13th century optics treatise. This theory is at the basis of William Charles Wells (1757-1817) cyclopean vision[11] and Bela Julesz (1928-2003) cyclopean perception[12]. The fact is that even though stereoscopic and autostereoscopic images are made of two or more points of view, the relative limitation of the field of view restrain the possibilities of perception of three-dimensionality in continuous observational movements.

Yet, although Ignazio Danti rejected perspective method other that those using single viewpoints, he asserted in his perspective treatise that: *"Things that we see under many angles are seen more distinctly."*[13]. Before Danti, Jean Pèlerin Viator (1445-1524) wrote in his treatise *"De Artificiali Perspectiva"*[14], the first perspective treatise to be printed (1505) and widely distributed:

> *"Besides, the diversity of views on things placed in front always have to be considered, for buildings also. For that we see them from the front or from an angle, that is to say from ahead or from a corner. And we can see them equilaterally or inequilaterally, and from a common level or elevated, and from a close or distant view."*[15]

Important considerations follow from this statement on how perspective construction should be approached: choices of points of view, angles and distances. While Alberti and his successors were proposing a closed and inert system, for Viator the eye is moving around the object to be represented, the artist himself is inside the space. Obviously, Viator maintain the single point of view as the main element in perspective construction however, he is introducing a concept of dynamic perception to perspective.

Apparently, Giovanni Battista Della Porta (1538-1615) experimented with binocular drawing, yet his interpretation of stereopsis is flawed. There are also the controversial drawings that Jacopo Chimenti da Empoli (1554-1640) created (fig. 2). Although only partial stereoscopy can be perceived in these drawings, they are often considered to be the first side-by-side stereoscopic drawings. However, since they don't present a coherent stereoscopic system, their authenticity as a proof for an early invention of stereoscopy is doubtful.

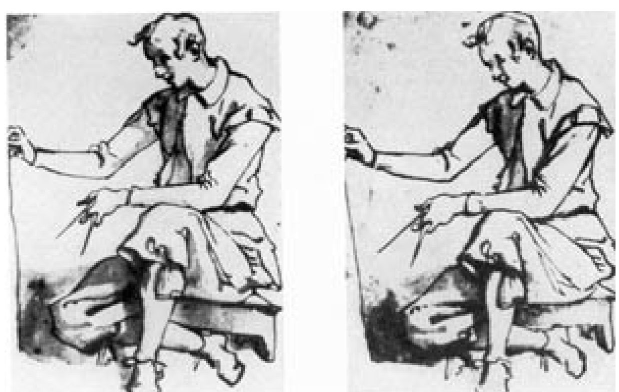

Figure 2: *Jacopo Chimenti da Empoli, stereoscopic drawing, 13th century.*

Danti's reference to a perspective process using two points of view seems to allude to binocular perspective. His statement may be related to different experiments using multiple vanishing points and lines that converge on an axis. If stereoscopic drawing was experimented during the renaissance, freeviewing must have been the only method to perceive these 3D images.

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[10] *"The duality of eyes should be brought back to unity."* Peckham, John, *Perspectiva Communis*, 13th century. I, #32. First published in 1480.

[11] Wells W.C. *Two essays: upon a single vision with two eyes, the other on dew*. Constable, London. (1818).

[12] Julesz, Bela, *Foundations of Cyclopean Perception*. Chicago: The University of Chicago Press. (1971).

[13] Danti, Ignazio, *Op. Cit.,, p. 147.*

[14] Pelerin, Jean, known as Viator. (1505). *De Artificiali Perspectiva.* Published as a facsimile in: *On the Rationalization of Sight*, Ivins, William M. Jr. New York, É.U. Da Capo Press. No page numbers, (1973).

[15] *Idem*.

In a way we could assume that the "invention" of binocular perspective was associated to the development of an apparatus to display and view artificial 3D. Apparently, with the invention of the mirror stereoscope in 1833 by Charles Wheatstone (1802-1875), 420 years distances the traditional single point of view perspective to the development of a functional system that includes a second point of view. During the renaissance, the absence of an optical device for viewing 3D images seems to have invalidated further researches in stereoscopic image making. As for autostereoscopy, in 1692, G.A. Bois-Clair painted transforming images using a parallax grid, but 3D wasn't his purpose. It is not before 1903, with Frederic E. Ives (1856-1937) parallax barrier and Gabriel M. Lippmann (1845-1921) integral photography, that this kind of autostereoscopic devices were used for 3D imaging.

Even though linear perspective became the main approach for spatial representation, these single viewpoint images seen from any other position than the predetermined point of view produce distortions. Most renaissance perspective images were either murals or paintings that were made for a predetermined position. For smaller format perspective images, as Brunelleschi needed the *tavoletta* to validate linear perspective, a perspective viewing device was also often used to observe the images. It uses a plane mirror and a large convex lens through which the viewer could focus and observe the perspective from the right point of view. The "zograscope" was invented in early 18th century in France and beneficiated from the growing popularity of printed images. In 1784 it was described by the Japanese printmaker and painter Kōkan Shiba (1747-1818) (fig. 3). His description emphasis the necessity for a single predetermined viewing position and the need for stillness.

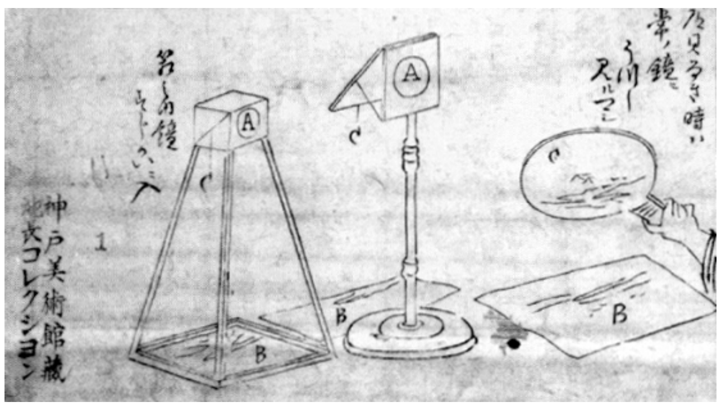

Figure 3: Shiba Kōkan, *Optiques*, 1784, Kobe City Museum.

For oriental painters of that time, the unique, fixed and inert point of view was rather awkward. For them, representing space was a task that one does while walking in the landscape. Space was divided in a series of blended zones in which brush strokes, tones, light and dark, forms and voids were arranged to reconstruct a landscape symbolizing the path of the artist and the observer. In his XIst century painting treatise *"Lofty Messages of Forests and Springs"* (*Lin ch'üan kao chih*)[16], Kuo Hsi (1023-c1085), the Chinese painter and scholar describe this attitude toward spatial representation in these terms:

> *"A mountain viewed at a close range has one appearance; a mountain viewed at a distance of several miles has another. When viewed from a distance of scores of miles, it has still another. The change of appearance caused by the varying degree of distance from the object is figuratively known as "the change of shape with every step one takes." The front view of a mountain has one aspect; the side view another; the back view still another. The ever changing view from whatever side one looks is described as "different shapes of a mountain as seen from every side". Thus a single mountain combines in itself several thousand appearances. Should we not realize this fact?"*[17]

"The change of shape with every step one takes." Kuo Hsi clearly identifies the modifications of shapes and forms in relation with variations of points of view. Without proposing a geometrical system for representing 3D

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[16] Kuo Hsi (1117), Lofty Messages of Forests and Springs (Lin ch'üan kao chih), translated by Shio Sakanishi and published as An Essay on Landscape Painting; John Murray, London, (1935).
[17] *Idem,* p. 37-38.

space, his approach is based on observational movements. Nevertheless, Chinese painters had found a way to represent objects and architectures while maintaining a multiple points of view structure. Instead of using a conical perspective with converging lines toward a vanishing point as in occidental perspective, they developed a parallel perspective method that allowed them to represent wide sceneries that subtly transforms itself to maintain a coherent appearance of depth.

Examples of oriental parallel perspective are found in many horizontal scroll paintings such as the description of the Qing Ming Festival by Zhang Zeduan (1085-1145). This long handscroll (fig. 4) place the viewer at a higher level and present a view on the landscape, architectures, people and many events and activities during a festival in the city. While illusionism isn't the main goal in parallel perspective, nonetheless it presents many advantages in visual descriptions of geometrical structures. This method of axonometric drawing was introduced in Europe, from China, in the 17th century, and is widely use in architectural rendering.

Figure 4: Zhang Zeduan, *"Upper River during Qing Ming Festival"* (detail), XIIth century.
Horizontal handscroll; ink on silk; 24.8 x 528.7 cm. Palace Museum, Beijing, China.

These long handscrolls are usually highly detailed. They are descriptive scenes, in which volume and linear structures seem to "switch" angles while the observer goes along the scroll (fig. 5). This allowed the artist to construct a scene that the viewer could observe dynamically, passing from one area to another. What is lost in terms of illusionism, compared to classical perspective, is gained in narrative capabilities. Distances are pictured by diminution of elements, tones and overlapping. On the other hand, the wide angle of view, and the observer movements required for perceiving the whole scene, produces an impression of space.

Figure 5: Xu Yang, "*The Qianlong Emperor's Southern Inspection Tour*" (detail), 1770.
Horizontal handscroll; ink on silk; 168.8 x 1994 cm.
Metropolitan Museum of Art, New York, U.S.A.

"Because of the open space of the plain at one side and the lines of the peaks vanishing, continuous as ocean waves in the horizon, the beholder will not weary of the distance; for human eyes can encompass a wide view."[18]

[18] *Idem.* p. 47.

In the synthetic hologram “The broken window” (fig. 6), I tried to illustrate the analogy between horizontal panoramic scroll of oriental landscape painting and holographic panoramagrams by representing a scroll unrolling when the observer moves from left to right. With his viewpoints variations, the observer can see calligraphy appear and subtle movements of the leaves apparently floating in the wind. Here, perspective is related to the broken window through which we see the landscape. Perspective and holography are both based on viewing space through a window however, holography breaks this window by adding space in front and behind it and giving back to the observer the possibility to move away from the cyclopean viewpoint.

Fig. 6: “The Broken Window”, Jacques Desbiens, 2006.
Synthetic hologram, 140cm X 38cm.

3. HOLOGRAPHIC PANORAMAGRAMS AS PANORAMAS:

Representation processes similar to Kuo Hsi’s *“change of shape with every step one takes”* are a rarity in occidental art. We could compare these panoramic views to cylindrical panoramas[19]. These paintings inside a rotunda were created around a single, central point of view, as if the artist would position himself in the center of the world and rotate horizontally, depicting what he could see around him. The panoramas can’t be dissociated from their cylindrical displays without producing important distortions. In fact, in classical perspective, geometrical distortions appear when the field of view exceed 25 degrees[20]. These distortions were already experimented in early perspective images such as many paintings by Jean Fouquet (c1415-c1478), where curvilinear distortions are visible (fig. 7).

Fig. 7: *“Arrival of the Emperor at St-Denis”, Jean Fouquet, c.1470*

[19] Many painted panoramas were created in Europe during the XVIIIth and XIXth centuries. These images were painted inside a large cylindrical room usually depicting war scenes, cityscapes and historical events.

[20] Dubery, Fred, Willats, John, *Perspective and other drawing systems*, New York, Van Nostrand Reinhold, 84, (1983).

When a wide field of view is projected on a flat plane using classical perspective, distortions are clearly visible (fig. 8). Field of view limitation in classical linear perspective is well known and was already described by Leonardo da Vinci during the early development of perspective. Wide-angle distortions are anamorphic. When projected on the picture plane (PP), objects seem wider as they recede from the viewer (V) on the X axis. To correct the distortion, the plane has to be curved (AB). Such wide-angle distortions are point of view related. Consequently, not only single point of view perspective prevents observational movements, its narrow field of view also prevents it to provide angular views without anamorphic corrections.

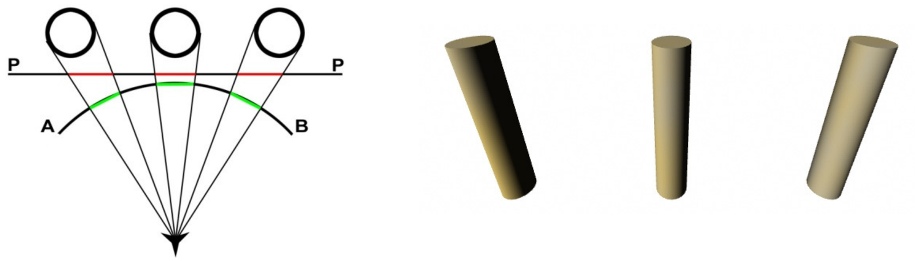


Figure 8: wide-angle distortions in perspective drawing.

Artificial perspective is prone to distortions. As we can see from all these references, perspective implies a rigid display unless the observer accepts distortions. Unless distortions are corrected, multiple points of view and wide field of view are beyond illusionist capabilities of classical perspective. While experimenting synthetic holography and analysing holographic image quality, it became necessary to experiment and validate computer generated holograms in comparison with perspective construction. During the summer of 2003, I designed a perspective image (fig. 9) and imaged it as a synthetic hologram on one of XYZ Imaging's direct-write holographic imager. Synthetic holograms produced with this technology are horizontal parallax only. The viewer, moving side by side in front of the hologram, will perceive a three-dimensional scene larger than the actual horizontal dimension of the holographic plane. As if it was a window opened on a larger space.

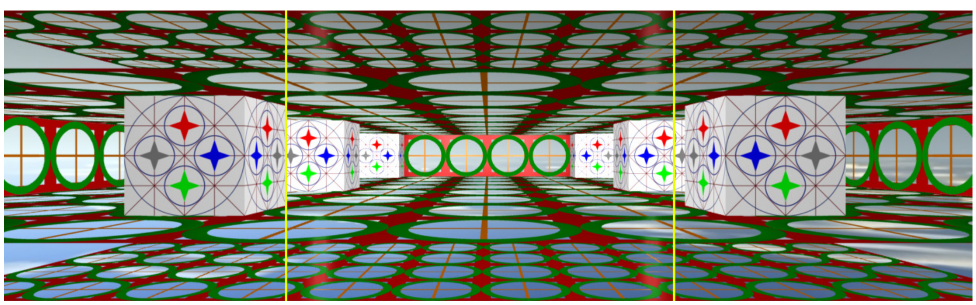
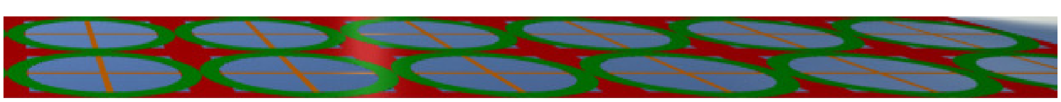


Figure 9: Wide-angle perspective for a synthetic hologram, Jacques Desbiens, 2003
Vertical yellow lines represent the frame limits.

The scene presented a large room with patterns and cubes. It was a frontal perspective with a depth of 3.6m. The cubes were positioned at 1m, 2m and 3.5m. The hologram was 40cm X 30cm and the holographic cells were 0.8mm. The perspective images obtained were a sequence of 749 images rendered from a virtual camera positioned at 60cm, aimed parallel to the central Z axis and moving along the X axis.

When we look at the extremities of the rendered images (fig. 10), wide-angle distortions are obvious. Circles on the floor, on the left and right side, are farther but seem larger than the closer circle in the center. They appear to be stretched in concordance with Leonardo da Vinci's observation and the 25° field of view limit.



Center---far right
Figure 10: Distorted circles on the wide-angle perspective floor in the rendered images

However, when we look at the hologram, this anamorphic distortion disappears. At any position inside the holographic window field of view, the observer sees any angular perspective from the corresponding angle of view, thus compensating for the anamorphic distortion. Synthetic holograms produced through this 3D imaging process are perspective displays offering wide-angle distortions correction while maintaining freeviewing.

In a cylindrical panorama (fig. 11), distortions are corrected by curving the image and maintaining a central point of view. It is a centralized configuration where the artist, and by extension the observer, are in the center of the world, at the pivot point, scanning the represented space around them. Only the viewer in the center of this space sees the representation from the right point of view, undistorted. All other points of view cause distortions.

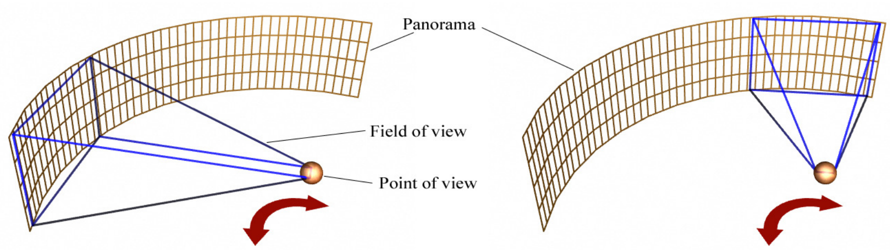


Figure 11: Spatial configuration of a cylindrical panorama. Horizontal scanning of the image.
The point of view rotates on a central pivot point.

In a synthetic hologram, the field of view is widened. But most important, the viewer is displaced from the central pivot point; the hologram becomes the central point around which the whole spatial configuration rotates (fig.12). This allows the observer, and the artist, to be able to move in space for viewing the whole spatial representation. Not only is it a multiple points of view system, it is a dynamic system were variations of the observer's position are echoed in the appearances and perception of the content. From a conception of spatial representation from a fixed point, this approach to 3D representation asks the observer to be active, to walk.

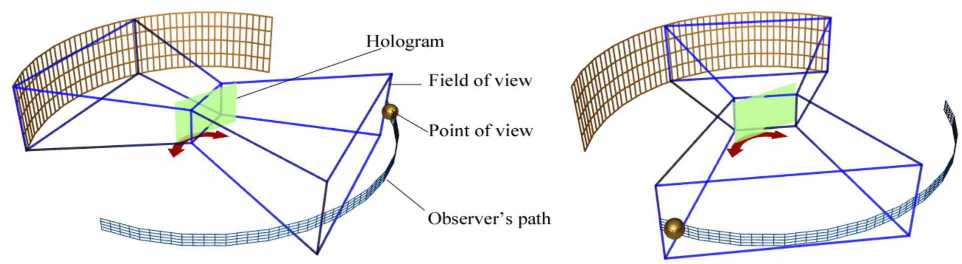


Figure 12: Spatial configuration of a synthetic hologram. Horizontal scanning of the holographic space.
The points of view rotate around a central pivot point placed at the hologram plane.

In his book, "*Three-dimensional imaging techniques"*[21], Takanori Okoshi (1932 -) comments on the term "holographic stereogram": "*It would better be called a holographic panoramagram since it allows observation from almost continuously different directions."*[22]. Synthetic holography utilizes perspective images while overtaking the limitations of single point of view perspective, of cyclopean perception, and produces the illusion of continuous parallax for wide field dynamic observation. Holographic panoramagrams are indeed panoramas.

Synthetic holography offers a solution to the age old distortion problem of occidental linear perspective, the addition of a wide field of view and dynamic observation of the oriental horizontal scrolls, gaining that way unprecedented potential of narrativity and spatial illusionism. The representation of three-dimensional space in its entirety has to depart from the unique. It has to present images that the optical structure gives rise to multiple observations in movement and time. Movement of the eyes obviously, but also movement of the body, free wandering of observation, nomadism of points of view.

[21] Okoshi, Takanori, *Three-dimensional imaging techniques*, New York, Academic Press, (1976).
[22] *Idem*, p. 247.