UNFOLDING SPACE

Thesis Project Documentation

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Electronic Visualization

University of Illinois at Chicago

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CONTENTS

FIGURES

To my grand parents

Casiano and Mari

FOREWORD

The idea of event and journey influenced my work ever since previous studies of design led to a collaboration with architecture. Design itself is the discipline that focuses on the gaze and how it trails in space[1]. I came to the United States hoping to investigate gaze trailing over three dimensions in the medium of holography. While working towards a Master of Fine Arts at the University of Notre Dame, I studied interactive media, advanced film, anthropology, as well as natural theology (which explores the 'journey'), and sacred images in the Northern Renaissance and Orthodox Icons. Painting watercolor introduced me to Japanese Gardens. My thesis at the time was titled "Reverence and Reference: Meaning in Virtual Reality"[2]; it explored Virtual Reality (VR) in the context of visual navigation inspired by icons and gardens, linked in a sequence of animated panoramic segments. Images and text dealt with the senses, used as reference to describe an experience, but also had a reverential connotation of metaphor to express states of being. The goal of this project was to navigate the space between the senses and states of being, blending into each other in a non-linear but nearly tridimensional space experience.

My research interests at the Electronic Visualization program at the University of Illinois at Chicago (UIC) intended to deepen these concepts. The Electronic Visualization Laboratory (EVL), a joint program betweent the Department of Art and Design, and the Department of Computer Science, fosters free experimentation while providing a strong foundation in Computer Graphics (CG) to overcome the idiosyncrasies of already developed software by working next to computer scientists who are creating software themselves. The critical difference between working on my own, and working with advanced programmers, is that there is an enormous invisible load of intelligence and resource organization which have not been addressed by conventional software packages. In that regard, treating CG as a product, is the same as treating oil painting as such, an attitude which does not belong with academic inquiries. I understand CG as a medium free of constraints —the same way that painting is not limited to realistic portraits, or film is not limited to a documentary approach. Whereas art installations tend to have limited interaction and an outdated domestic appliance aspect to them, which wanders off the content they may have, VR demands control and understanding of the medium, revealing how inadequate and stagnant the era of collage has been for contemporary art, specifically if it seeks to challenge complex mediums which connect to our senses and evolving visual languages in novel ways.

I believe it is important to understand that the role of the University within the world is to open culture to the universal human experience in the discipline one has decided to pursue. From this point of view, already developed software is not a bad thing, but one has to be aware that it has limitations inherited from specific shortcut needs, which should not diminish the scope of one's research. Conversely, the use and interpretation of software alone does not fulfill the goal of University education in Electronic Visualization. At EVL, the close collaboration between art and computer science in the creation of electronic visualization has resulted in high academic standards, because it has allowed researchers —faculty and students alike— to explore without irrelevant constraints.

It is at EVL that I got to collaborate with three computer scientists in three different projects during my stay, including my final thesis. The first project was a video game which was played by dynamically digging tunnels to hunt or run from a hunter[3], essentially a chase game (Fig.1). The second project involved traveling between planets in the solar system[4] and moving to different views of them, while creating a giant helix mobile showing the visited planets (Fig.2). Both projects involved creating a dynamic tridimensional structure out of trails. Other courses I took while at UIC include VR where I built an environment of nested polyhedra[5], the Psychology of Language, that gave me a vocabulary to describe grammatical situations, Sound class, which helped me to understand aural sound and its environmental implications, and most of all, Knot Theory, which allowed me to learn about higher dimensions so I could eventually make the connection between the trails I had been following, and the changes of direction of those trails as extra dimensions in their own right.

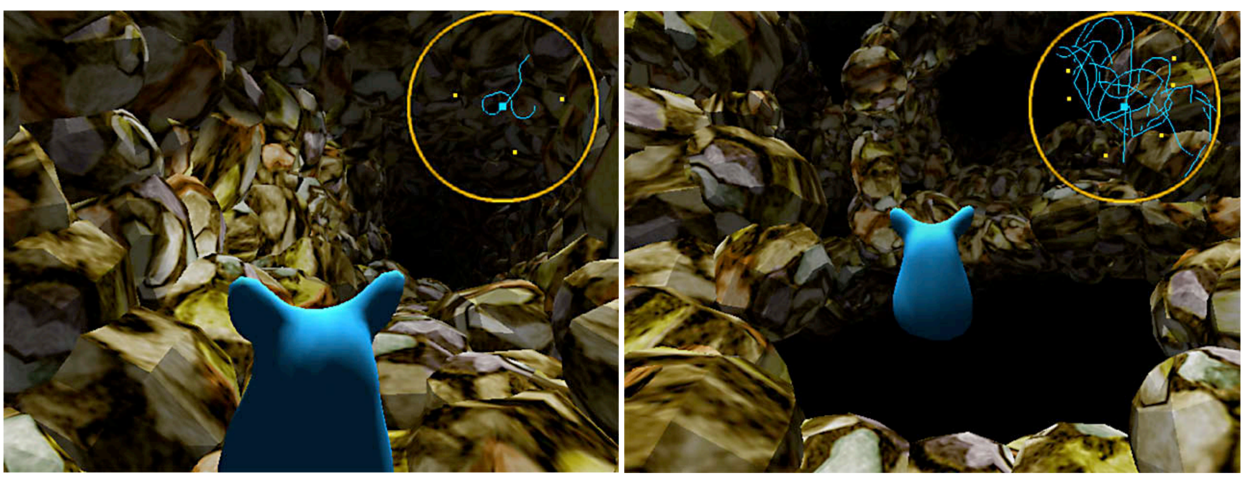

Figure 1: Burrow Chase: a game where space is opened up by navigation.
Screen capture by Byungil Jeong and Julieta Aguilera.

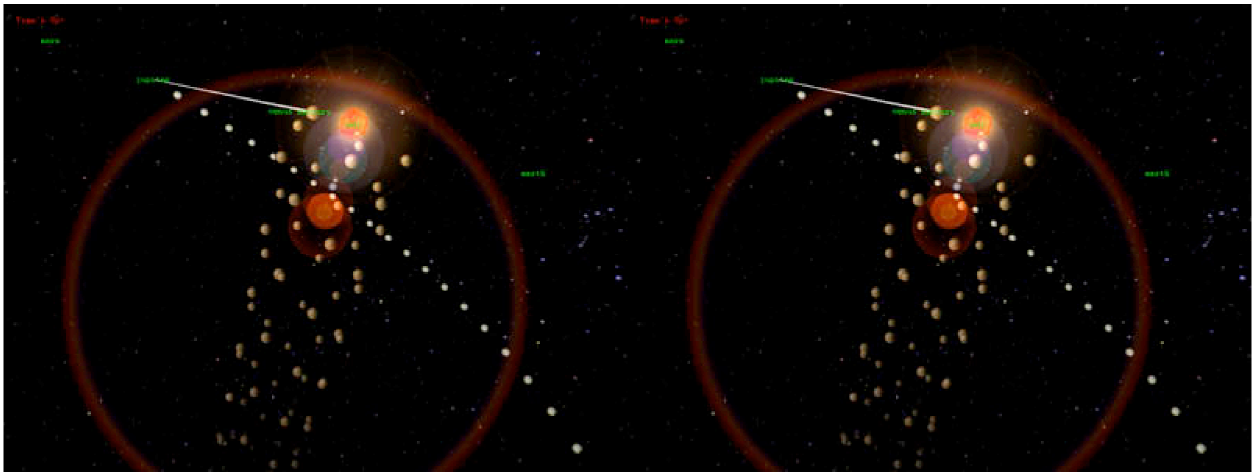

Figure 2: Stereo image of Arcanius: an educational project where the person moves from planet to planet activating helix-like trails which show the relative speed at which the planets move.
Screen Capture by Gideon Goldman.

When drawing a VR environment, mathematics are behind the order, projection, and behavior[6] in which all visible forms are seen from the literally subjective point of view of the person. Limiting the situation to a realistic view is but one option out of many. In a way, my time at EVL has been about deconstructing static tridimensional environments in order to be able to create dynamic higher dimensional ones: something I could not have done through any other media, but which has taken its toll in time spent distancing myself from pretenses which could have neutralized my endeavors. Finally, UNFOLDING SPACE would not have been possible without Andy Johnson, my third and closest collaborator.

1. A DIMENSIONAL WORLD

UNFOLDING SPACE is a VR enveloping landscape of concave and convex forms, which are determined by the orientation and displacement of the user in relation to a grid made of tesseracts (cubes in four dimensions)[7]. The interface accepts input from tridimensional and four dimensional transformations, and smoothly displays such interactions in real-time. Instead of navigating the familiar landscape of volumes, space is attached to the shadow of a higher dimensional grid, which can then be turned around, to stretch or compress their sides to face the person. Such shadow projected to three dimensions use the distortion of tridimensional perspective to organize visual hierarchy. Stereo visualization and real-time computer graphics also allow us to integrate the dynamic abilities of the human body for accessing higher dimensions while assimilating complex configurations. The motion of the person becomes the graphic element whereas the higher dimensional grid references to his/her position relative to it. The person learns how motion inputs affect the grid, recognizing a correlation between the input and the transformations.

Tridimensional projections can be flattened to the screen of a computer, and so can higher dimensions. Higher dimensions may cause concern because we are only used to three dimensions when we move around the world with our bodies. But if we were two dimensional beings, and were to be shown a tridimensional object, all we could see from it would be its two dimensional shadow crossing our plane of existence over time. Since we are not two dimensional beings, but tridimensional ones, UNFOLDING SPACE confronts us with a structure which is one dimension higher than our perceptual world. The design tool to make such space visible is the grid[8]: the same way that a flat space can be shown through a grid of squares and tridimensional space can be revealed through a grid of cubes, four dimensional space, can be revealed through a grid of tesseracts (the four dimensional projection of a cube), in this case, casted into three dimensions. What we end up seeing is a flexible space that expands and collapses, self-intersecting depending on our position in relation to it. Of course the fourth dimension can cast a shadow in either two dimensional or tridimensional space, but I base its parameters on a tridimensional shadow since that is closer to the natural experience of moving our bodies through space.

2. BACKGROUND: EVERYDAY HIGHER DIMENSIONS

When we talk about augmented reality, we may think of being able to see what is not visible to the naked eye, because it is not in human scale, or within human vision capabilities. It also comes to mind the fact that some phenomena does not occur simultaneously in nature, so we augment reality where two or more events are fit into a common space that they would not otherwise share. However, higher dimensions can be considered augmented reality, as they expand space beyond the three dimensions we inhabit with our bodies. Yet, human vision goes beyond three dimensions when perceiving images through natural experience as explained next.

Images persist beyond their three dimensions in our daily experience when they overlap: through reflection, through shadows, through imprints. They join the dimensions of separate objects through intersection. We are used to them. They allow us to understand the world of dynamic spatial relationships we live in. Usually shadows are a two dimensional image of a three dimensional object: when they fall on three dimensional surfaces, they add a dimension to it, melding into a new pattern or form. The intricate foliage pattern of a forest, for example, takes a new dimension when the shadows of the leaves are cast on the leaves themselves. A reflective tridimensional surface can associate with the tridimensional objects it reflects. The resulting intersection of tridimensional forms is perceived simultaneously by a person, and can be clear enough to discern what to look at: whether it is the reflective object, or the reflected object, or even the perfect balance of both images overlapping. An imprint can, in some cases, point to a fourth dimension when an object gets an overlay of the printed image on its surface. The situation may be that of a permanent static reflection on the surface of the printed object.

3. DESIGN: A HIGHER DIMENSIONAL GRID

The previous examples show that we deal with simultaneous imagery in the natural world, that already represent the presence of extra dimensions. As humans, we can make sense of very sophisticated visuals, which reveal complex spatial relationships. In turn, to give structure to complex relationships, designers use the grid (6). A grid can be visible or transparent, as the alignment of the objects contained in it reveal its existence. Two dimensional grids of squares are used commonly in printed matter for two dimensional navigation, and tridimensional grids of cubes are used in architectural installations. A grid's main purpose is to relate elements to each other on a common space through alignment and a common unit of measure. The grid reveals the projection of the space that is visible, and defines the thresholds of relevance. In design, a composition is constructed based on how the smallest significant part is related to the overall form of the whole. This smallest significant part is then used as a measure to build the grid, which then becomes a base pattern for defining the overall form of the navigation. Ultimately this is what we do today when we create programs, which allow us to navigate two dimensional or tridimensional worlds. The grid of tesseracts of UNFOLDING SPACE, that is, the tridimensional shadow of four dimensional cubes, can be navigated with tridimensional or four dimensional motion which evoke a situation of simultaneous shadow and reflection.

The question of how to represent spatial dimensions has been well studied in painting. A whole parade of characters could be placed in front of us following the laws of perspective to dynamically engage us in the sequence of events being represented. Cubism came about breaking that space over time. Projections of space were heavily used in constructionist and futurist designs of the early 20th century. Karl Schwitters worked on abstractly inhabited tridimensional spaces. The distorted realism of Escher represents higher dimensions mapped to surfaces[9]. An example of dynamic grid, or a grid that contains higher dimensions, can be found in the stick charts of the Marshall Islanders who travelled open sea by canoe by means of palm sticks tied with coconut fiber, which map prevailing wave fronts. Shells stand for the relative location of islands while threads indicate when they come into view[10]. The map looks like overlapping grids which fulfill the function of relating the dimension of the sea currents and the dimension of island location. The construction of the artifact suggests that since the sea currents have motion and strength associated with them, the distance of the islands would vary depending on the direction of the path being followed. We could say then that the dynamic grid captures an extra dimension of data, in this case, the sea currents.

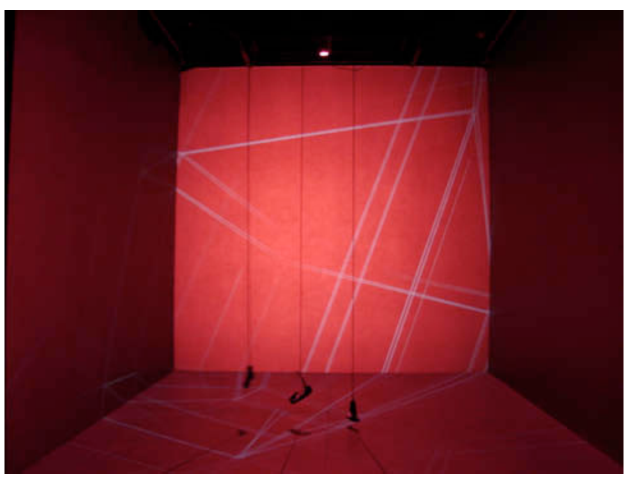

Figure 3: The grid of tesseracts in wireframe mode within VR: stereo projection in real-time computer graphics. *Photography by Kapil Arora and HyeYun Park.*

In UNFOLDING SPACE, the tridimensional shadow of the grid of tesseracts is drawn in VR (Fig.3), tessellating space with textures attached to its surfaces. The perspective projection of the virtual world causes the surface textures to shrink according to distance, as well as more clearly show the surfaces' orientation. As in the natural world, we use the pattern and form of what we see for measurement and continuity. If we are looking at the tridimensional shadow of a four dimensional object, and we manage to either rotate the object in four dimensions, or move the viewer according to the tridimensional shadow of a four dimensional path, the object will appear to move according to rules other than solely perspective. Rotation in two dimensions revolve around a point, and rotation in three dimensions revolve around a line. On the other hand, four dimensional rotation occurs around a plane which when projected to three dimensions, seem to endlessly turn the form inside out as it rotates in four dimensions. Being able to animate a four dimensional rotation on a grid made from tesseracts means we can visualize four dimensional navigation. The distortion that happens to one tesseract, gets extended into pattern when replicated to form a grid. The sides of the grid that have the same orientation draw attention to the direction those sides are facing. The resulting image resembles a building carrying its own ghost as the walls intersect each other.

4. INTERACTION: GESTURE AS DIMENSION

UNFOLDING SPACE explores higher dimensional navigation on a grid structure linked to gesture. The structure changes depending on the body movements of the person linked to it, seeking to internalize the sublime in the evolving forms and sounds we perceive, from mountains to ocean waves, which occur at contrasting speeds, yet move, influenced by several -and sometimes opposing- dynamic forces. The human body, with its limbs moving in relation to the whole, is in a way a multidimensional structure: when walking, biped motion led by the attention directed by the head is quite complex. Limbs of our bodies work as a whole but are capable of moving independently. In other words, our bodies allow us to see with motion, and being in a tridimensional virtual world of static blocks only captures but a fragment of what we are capable of perceiving. It makes sense then to try and connect the motion of the body to a moving pattern of space. Moving the grid with our body also makes sense because the body has very strong visual memory which we use to do all we know, such as sitting on a chair, grabbing hold of things, or playing ball.

In UNFOLDING SPACE, the degrees of freedom in an arm are used to establish the projection of a four dimensional rotation plane, and relate the resulting form to the natural experience and intention of the person (Fig.4). The shadow of the tesseract grid can then be maneuvered to hide and reveal the surfaces of the structure while maintaining the coherence of a labyrinth. This in turn results in a kaleidoscopic form, where the alignment of the faces of the tesseracts alter the shape of the texture pattern. The pattern sequence works as stepping stones or highlights of navigation, which is then internalized like a dance, and further engage us to maneuver space in order to know and experience. Ultimately, the environment becomes an adaptive structure tied to the motion of body joints, as if space was being worn by the person.

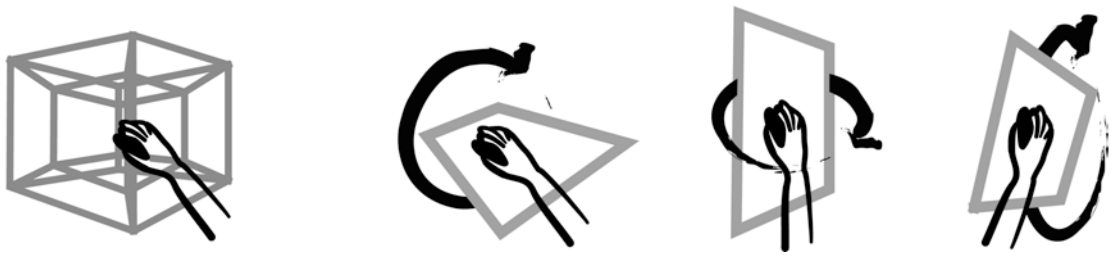

Figure 4: A tracked sensor maneuvering to rotate the tesseract in four dimensions (plane) while the overall environment is drawn from the point of view of tracked stereo glasses.

Figure 5: The tracked wand rotates the four dimensional plane, which results in the stretching the cells of the tesseract grid. These pictures depict the application controlled by a tracked wand in the right hand and a tracked sensor in the left hand inside the CAVE. The right hand manipulates four dimensional rotations, while the left hand manipulates tridimensional rotations.
Photography by Kapil Arora and HyeYun Park.

5. IMPLEMENTATION: PUBLIC EXHIBITION

The software is primarily designed to run in the CAVE(R), a multi-person, room-sized VR system developed at EVL, or similar systems such as the Configurable Wall (C-Wall), a single wall version, or iDesk4, a personal desktop VR device. The CAVE Library(R) is capable of supporting a number of different VR platforms, including simpler graphics workstations[11]. For the final exhibition of UNFOLDING SPACE, all three devices were on display (Fig.6).

The CAVE is a 10x10x10ft. room constructed of three translucent walls (3). High resolution stereoscopic images are rear-projected onto the walls and the floor and viewed with light-weight LCD stereo glasses to mediate the stereoscopic imagery, or in the case of the C-Wall, viewed with polarized glasses. Attached to the glasses is a location sensor. As the viewer moves within the confines of the CAVE or C-Wall, or in front of the iDesk4 screen, the correct perspective and stereo projection of the environment are updated and the user may walk around or through virtual objects. The CAVE's or C-Wall's room-sized structure allows for multiple users to move around freely, both physically and virtually. The user interacts with the environment by maneuvering "the wand" (a simple tracked input device containing a joystick and 3 buttons) in the right hand, which handles four dimensional rotation, and a sensor in the left hand, which handles tridimensional rotations. The buttons in the wand switch sets of parallel faces on and off, allowing the person to create a situation of labyrinthine configurations in order to explore the structure of space further. In these configurations, the alignment of the surfaces of the tesseracts result in expanding and collapsing corridors facing the user (Fig.5 and Fig.8).

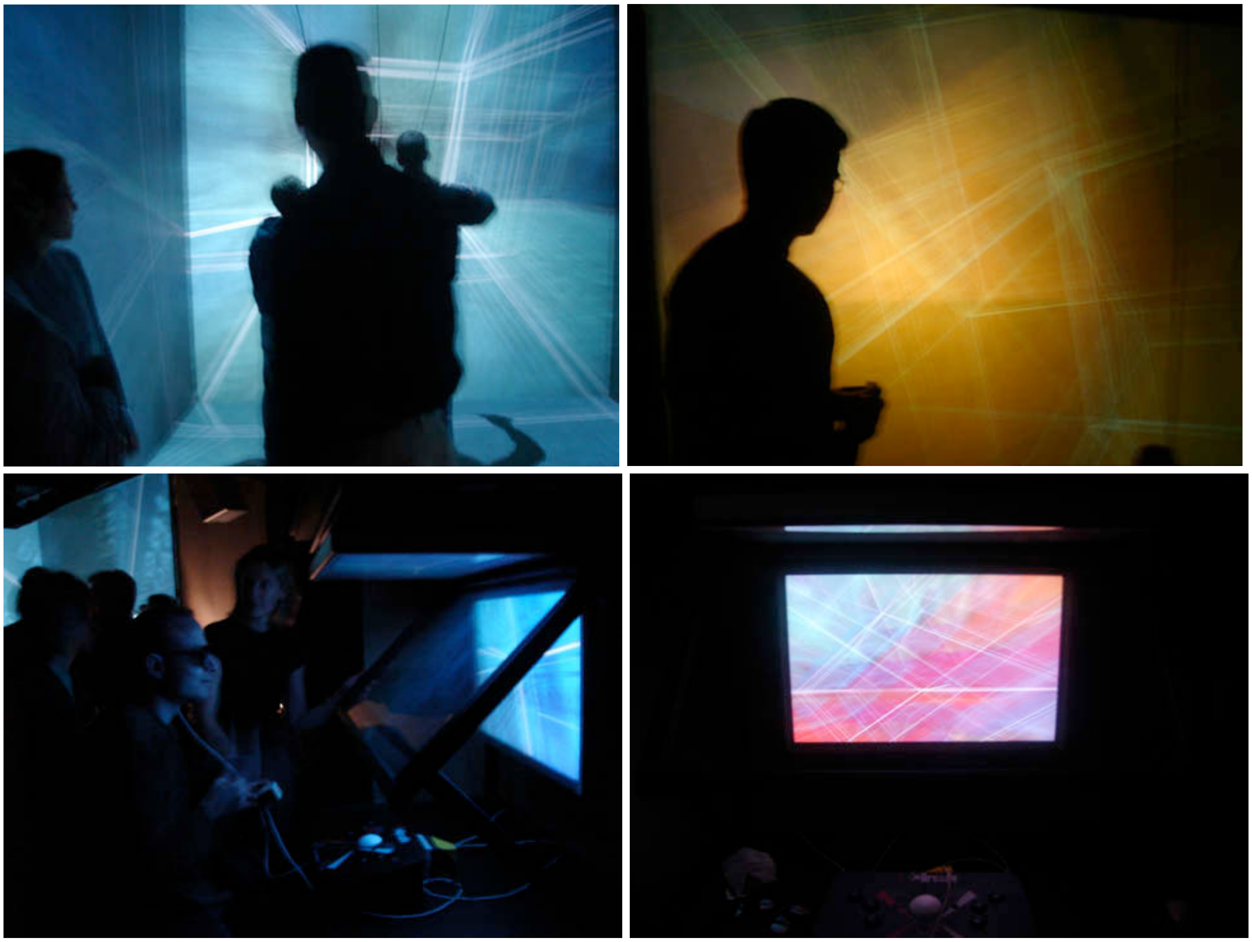

Figure 6: Views of UNFOLDING SPACE runing in the CAVE and C-Wall (top) and iDesk4 (bottom).
Photography by Kapil Arora and HyeYun Park.

The projection of the hypercube takes the method used by Pérez-Aguila[12] to draw the shadow of a tesseract in three dimensions. To form the grid, the center shape is drawn, then the shape is copied and transformed to the locations around the center that share faces or vertices with the central image. This process is repeated outwardly for as many layers as the operating system will allow. To avoid duplicating faces, only half of each tesseract is drawn, with the repeating cells of the grid forming the full shape of it. To create the illusion of an endless grid, the user is moved back to the origin when he/she has reached a given distance from the center of the tesseract. The thickness of the wireframe lines is defined by the distance from the position the person. Lines also change from white to the background color. Fog affects the surfaces of the structure.

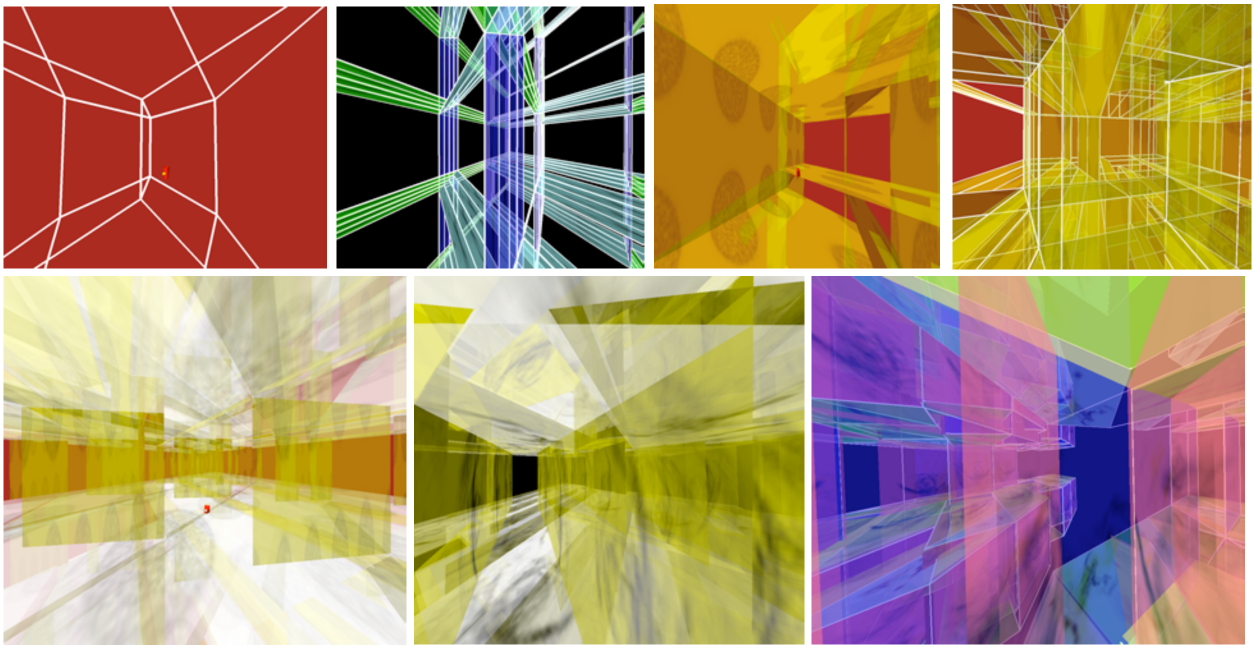

Figure 7: The sequence above shows the evolution of the grid development process, starting with a single unit wireframe, surface texturing of some sides of the tesseract, opacity adjustments and different methods for sorting out the drawn faces when seen though other surfaces.

The pattern produced by the cells of the grid is enhanced by attaching two dimensional textures to the surfaces of the tesseract grid (Fig.7). The perspective projection of the virtual world causes the texture to shrink according to distance, as well as more clearly show the direction each face is pointed to. Textures cycle in sequence (Fig.8 to Fig.13) while the background color changes, evoking the passage of a day, or geological eras where natural phenomena reflect changes in chemical interactions.

Figure 8: Final textures attached to the grid, in the order and reference in which they appear during the cycle. From left to right: title space (night, black), forest (dawn, blue), face (morning, white), sand (afternoon, yellow), light flare (evening, red).
Hand drawn using electronic tablet and imaging software.

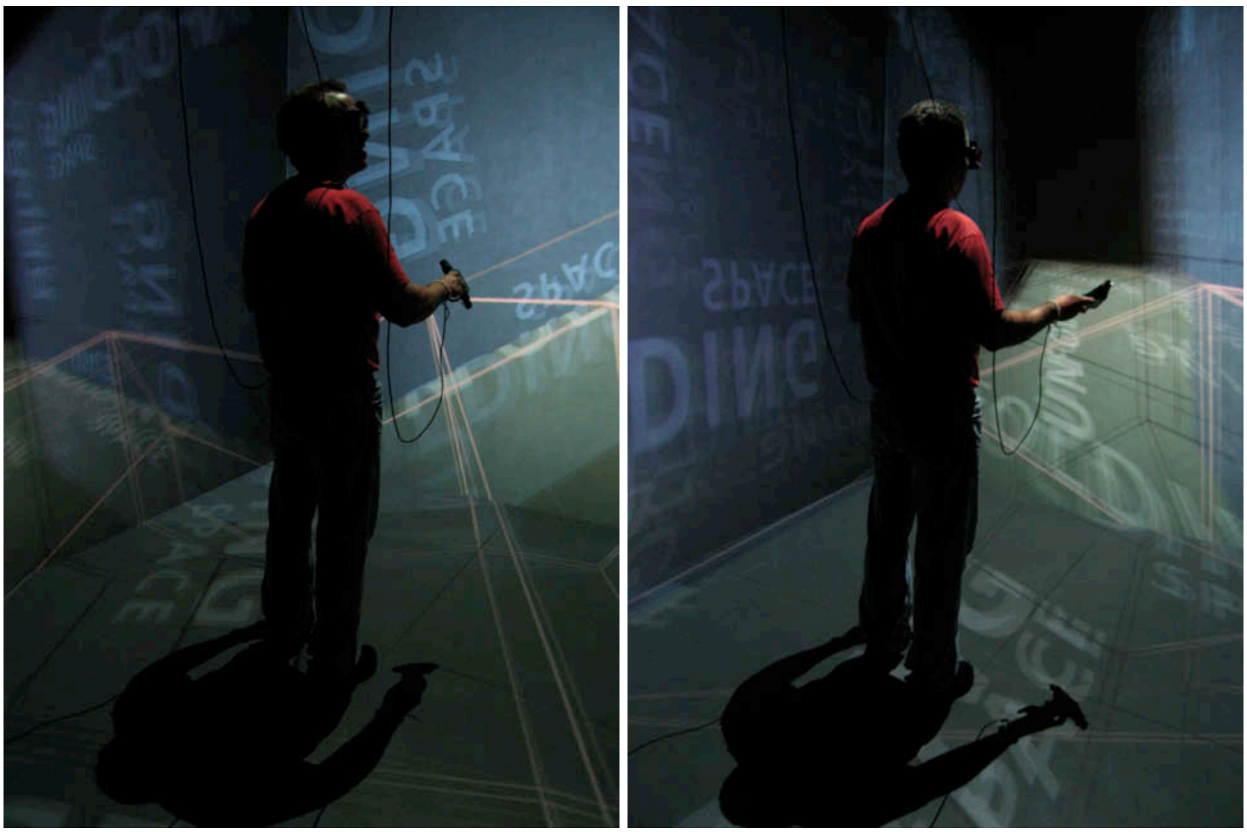

Figure 9: View of the opening of the cycle with title texture in the CAVE. The self-intersecting sides of the tesseract still align with the same sides of the other grid cells, forming corridors when a set of faces is switched off and the corresponding surfaces are aligned to the person's orientation.
Photography by Patricia Ledesma.

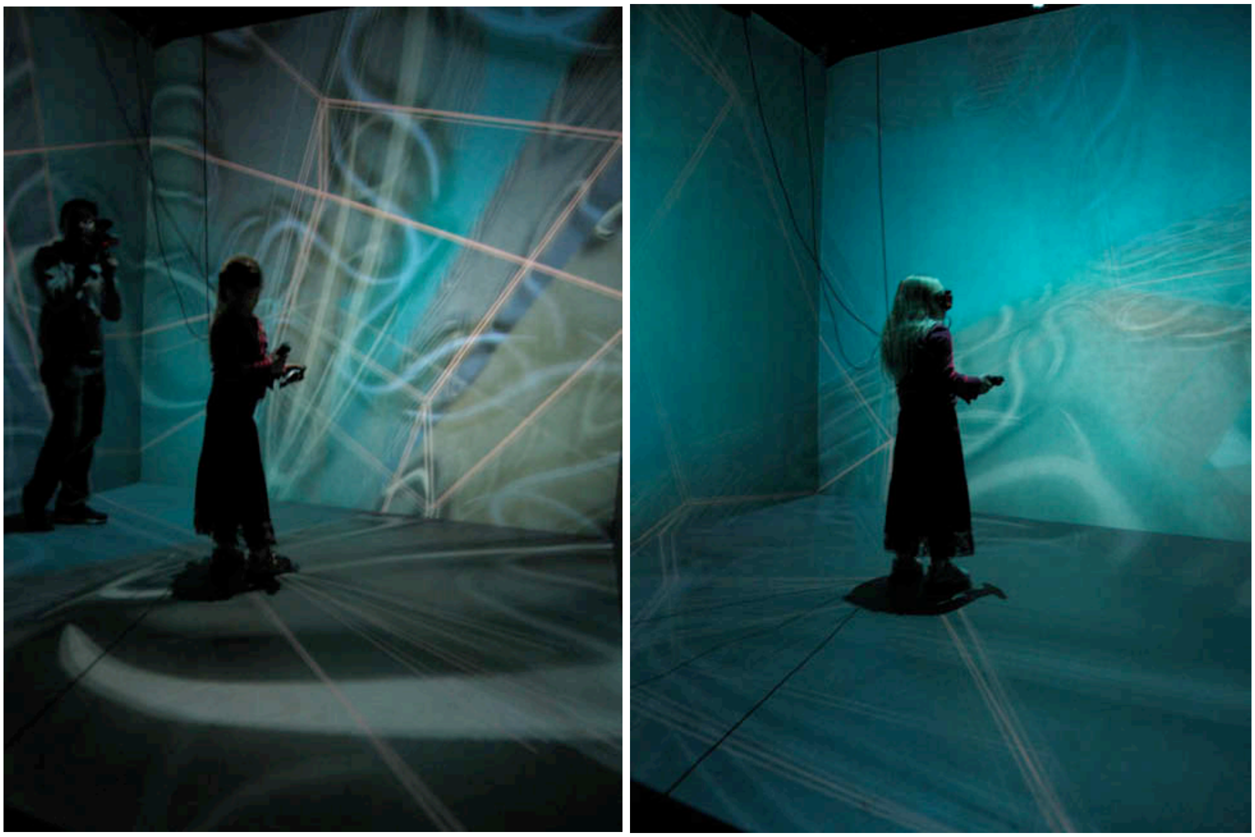

Figure 10: View of the second segment of the cycle in the CAVE. This particular texture tended to be navigated like water. Surfaces start fading into the next segment and color (left).
Photography by Patricia Ledesma.

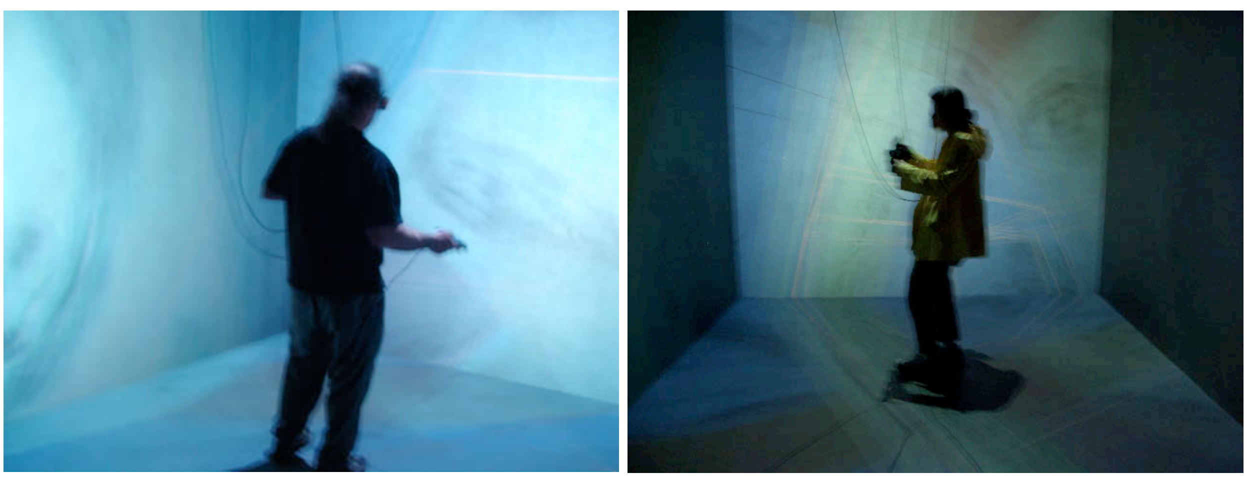

Figure 11: View of the third segment in the cycle: the face. Recognition of the associative pattern of facial features lended itself to be a explored like a mirror with shadows, and evoked a strong response allowing to recognize not only the face but the four dimensional structure, while experimenting with what resulted into a kind of hypercubist dynamic composition.
Photography by (left) Kapil Arora and HyeYun Park, and (right) Daria Tsoupikova.

Figure 12: View of the fourth segment of the cycle.
Photography by Kapil Arora and HyeYun Park.

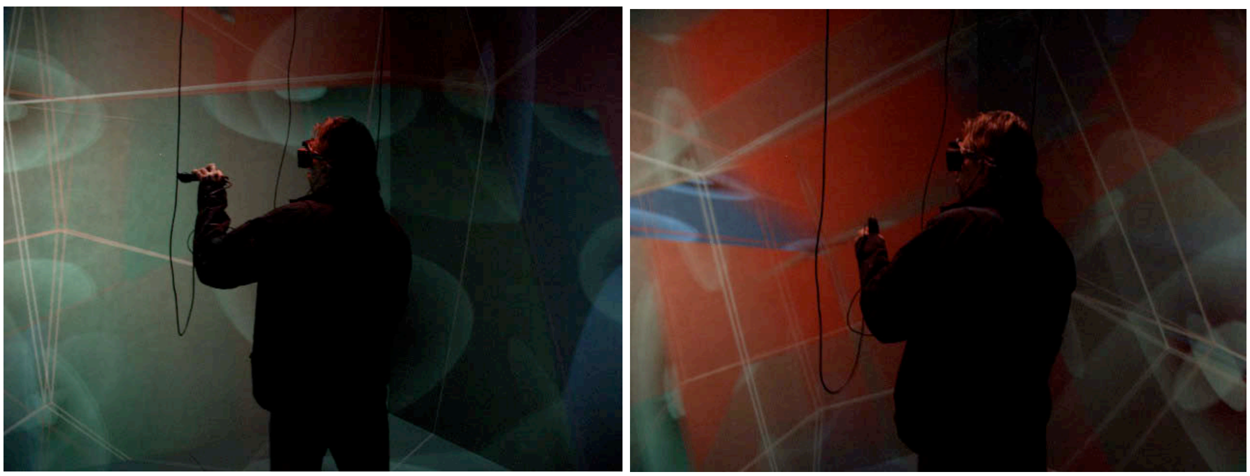

Figure 13: View of the fifth segment of the cycle. Circles drawn around each four dimensional vertex reveal the orientation of each of the surfaces that converge there.
Photography by Daria Tsoupikova.

UNFOLDING SPACE contains four kinds of spatialized sounds which form a triad. The base sound was created in sound software to evoke mongolian throat singing, in order to focus the person in the ground, specially since there is no ground in the environment. This detail was very effective not only in preventing motion sickness, but also slowing down body motion to an attentive pace. The main sound is a soft varying pitch flute-like sequence of intonations, that evokes human voice, as if a long sentence was being repeated to remember certain words. The sentence gets louder as the person gets closer to the screen. A cello single note increases in volume when the right arm is moved away from the center in an opening posture. Finally, a fast flapping sound appears and increases in volume when the arms are raised or lowered away from the center. In this manner, the combinations that result from specific poses and movements of the body work as feedback while giving a tactile —from opaque to reflective- quality— to the surfaces of the tesseract grid.

6. CONCLUSION

In UNFOLDING SPACE, a four dimensional grid is used to augment reality in terms of structure and the relationship among its parts. The result is a tridimensional structure of surfaces that self intersect as the grid is rotated in four dimensions. In order to see the grid and enhance the relative position of its cells, a series of textures are assigned to all the surfaces of the tesseracts, and is set to be semi-transparent. This produces a situation of colors and images being superimposed. The same situation of image intersection and superimposition is familiar to us from similar phenomena we experience in the natural world, specifically when we deal with shadows, reflections and imprints for understanding and navigating space. In the natural world, we can use the pattern and form of what we see for measure and continuity. Therefore, the same design principles we use for designing two and tridimensional worlds is used for higher dimensional navigation.

Interaction with a four dimensional structure is facilitated by using body motion. The limbs of our bodies move as a whole but are capable of moving independently. The degrees of freedom of an arm and hand are used to represent the projection of a four dimensional rotation, and relate the resulting form to the natural experience and intention of the user. The shadow of a tesseract grid is then maneuvered to hide and reveal the surfaces of the structure while maintaining the coherence of a labyrinth, of knowing how much variation to expect depending on how much the position of the body and the arm has changed.

In UNFOLDING SPACE, I explore the medium of Virtual Reality as an entirely different realm where the point of view is articulated by the body as it reaches our eyes.

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