Voluble: a Space-Time Diagram of the Solar System

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ABSTRACT

Voluble is a dynamic space-time diagram of the solar system. Voluble is designed to help users understand the relationship between space and time in the motion of the planets around the sun. Voluble is set in virtual reality to relate these movements to our experience of immediate space. Beyond just the visual, understanding dynamic systems is naturally associated to the articulation of our bodies as we perform a number of complex calculations, albeit unconsciously, to deal with simple tasks. Such capabilities encompass spatial perception and memory. Voluble investigates the balance between the visually abstract and the spatially figurative in immersive development to help illuminate phenomena that are beyond the reach of human scale and time. While most diagrams, even computer-based interactive ones, are flat, three-dimensional real-time virtual reality representations are closer to our experience of space. The representation can be seen as if it was "really there," engaging a larger number of cues pertaining to our everyday spatial experience.

Keywords: virtual reality, space, design, visualization, astronomy, museum, solar system, agency, time-space, diagram

1. INTRODUCTION

The Voluble interactive visualization is being developed at the Space Visualization Laboratory[i] of the Adler Planetarium in Chicago, as a visualization experiment. Voluble affords visitors the opportunity to explore the speed of the planets' orbits by observing both a three-dimensional model of the solar system and the associated space-time diagram simultaneously. Like a large mobile, the structure of the planets' movement over time is enhanced to understand the relationships between space and time. The structure itself is set in virtual reality to relate the orbits to our ability to move through space.

First we will describe what a space-time diagram is and discuss immersion in the context of an astronomy museum. Then we will describe the motivation of joining this diagram with an immersive experience of the solar system in the context of a museum setting. Consequently we will go over the elements of design involved in articulating the spatial relationships that blend reality and the abstraction of the diagram. In the end, we will describe the space where development takes place, and a n earlierattempt at creating a similar implementation, and finally describe our current implementation.

As a conclusion, we will describe our current work to complete and test the application, as well as the challenges involving both the museum-going public, and the scientific understanding to be reached, and how the application will be evaluated and improved upon in future revisions. The evaluation plan will focus on whether or not users are able to understand that the planets' orbits are not synchronous and look for any misconceptions that the model might elicit.

2. MOTIVATION

2.1 Space-time diagrams

In 1895 in his novel The Time Machine, H.G. Wells wrote "There is no difference between time and any of the three dimensions of space except that our consciousness moves along it." [ii]. This turned out to be a prescience observation … a decade later Albert Einstein published his special theory of theory of relativity deeply linking space and time. This linkage can be described in terms of a four dimensional Minkowski space where the metric distance is defined as:

The Engineering Reality of Virtual Reality 2008, edited by Ian E. McDowall, Margaret Dolinsky,
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 6804, 68040A, © 2008 SPIE-IS&T · 0277-786X/08/$18

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2dt^2$$

The speed of light c, is the fundamental constant linking the dimensions of space and time.

Traditional two-dimensional space-time diagrams collapse the three spatial dimensions onto the x-axis and present time on the y-axis (Fig. 1). In these diagrams light travels along forty-five degree lines. Intervals in this four dimensional space can be divided into two categories: "Space-like" paths where ds < 0 are inclined at angles > 45 degrees on the space-time diagram and represent potential particle paths and "Time-like" paths where ds > 0 are inclined at angles < 45 degrees in the space-time diagram where particles are unable to travel along these paths due to the prohibition against greater than speed of light travel.

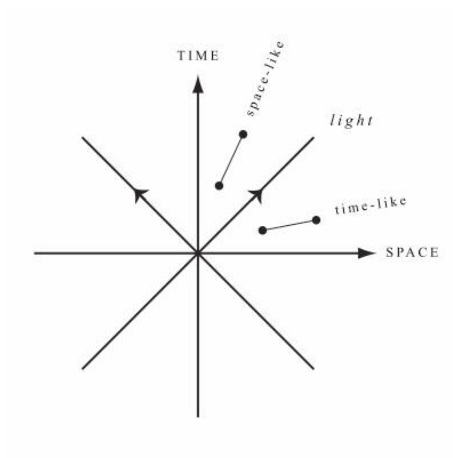

Fig. 1. A two-dimensional space-time diagram.

2.2 The solar system

Isaac Newton's description of gravity provides an accurate description of the motion of bodies in the solar system. The most significant place where relativistic corrections are needed for describing the precession of the orbit of Mercury, yet this precession is quite small, one turn every twelve million orbits. Interestingly enough, while Newtonian mechanics provided a explanation for the nature of planetary orbits, they were accurately described a century earlier by Johannes Kepler's three laws of planetary motion: bound orbits travel along ellipses, a line joining the Sun and a planet sweeps out equal areas in equal times, and the square of the period of a planets orbit is proportional to the cube of the semi-major axis of the ellipse. It is the last two laws that we hope to demonstrate with the space-time diagram of the solar system, namely how the speed and period of an orbit change with orbital distance.

By creating a three-dimensional model of the space-time diagram of the solar system we can display two spatial dimensions rather than just the one typically displayed in traditional flat diagrams. Fortunately, this is not a major problem as the planetary orbits are in nearly the same plane. The inclination of the eight planets to the ecliptic is 7 degrees or less. The inclination of Pluto is 17 degrees, one piece of evidence indicating that it is an outlier. The orbits lie in a plane as a consequence of their formation from the same spinning gas cloud that flattened as it collapsed.

The orbits of the planets are also highly non-relativistic. The average orbital speed of the Earth is roughly one ten thousandth that of the speed of light. Thus to create a useful space-time diagram of the solar system we need to use a different metric, not linking space and time by the speed of light, but with a velocity characteristic of the speed of objects in the solar system.

2.3 Being immersed

The typical museum visitor's understanding of complex spatial relationships is derived from daily activities such as sports and dance. More recently, electronic visualization for non-scientific audiences has begun including stereo vision and tracking manipulation to recreate the experience of navigating space as an act of agency[iii] that is, where we "encounter a world that is dynamically altered by our participation."[iv] In such a space "people can play as opposed to being entertained." [v]

The solar system, as with all astronomical subjects, is well beyond typical human experience. Everything we know about it is based on data collected from observations. When viewing models of the solar system, it is not apparent how the orbital speed of a planet relates to its distance from the sun. Observing the relationship between time and space in both a three dimensional model and a three dimensional diagram in perspective projection may give a better idea as to why the system works the way it does as a mental model that is independent of a particular point of view[vi]. In a museum setting such an experience may bring together different pieces of the puzzle, so the model of how parts of our universe works is appreciated in more depth and can be applied to other learning experiences.

2.4 The museum setting

As a planetarium and museum, the Adler seeks to facilitate understanding of large phenomena that are temporally and spatially removed from embodied human experience. These are things that we cannot immediately experience because they are too far away, too big to see all at once at a detail level that makes them understandable, and they evolve over too large of a time scale.

Since early times, humankind has attempted to understand celestial objects. The Adler collection of historical objects includes charts of the skies which helped people make sense of the universe. Today the amount of data about our knowledge of the universe has increased immensely, and the challenge is to integrate this knowledge into the visitor experience. In the simple case of the time-space diagram of our solar system, we seek to understand and internalize the planets' relationship between distance and orbital speed around the sun.

The application is being developed at the Adler's Space Visualization Laboratory (SVL.) In this working laboratory scientists, technicians, artists, and educators work together to create new ways for people to explore the universe. At SVL people can experience the prototypes of new interactive visualizations that will eventually move into other areas of the museum, and attend presentations by astronomers and related researchers that take advantage of the visualizations. Modern astronomical instruments produce such massive amounts of data that astronomers now rely on a diverse array of tools to properly display and analyze this information. Developing visualizations at SVL further enables scientists and the public to explore and interact with these complex datasets in specialized ways.

3. DEVELOPMENT

3.1 Design

Visualization is a process through which data is represented, integrated, or reduced in such a manner to allow patterns or trends to be more easily observed and understood. We can learn more about our universe by studying patterns in data, aided by visualization. Affordances of different types of media (stereoscopic visualizations and others) allow us to draw attention to or enhance different features within data. In the case of the solar system, we want to draw attention to the dynamic structure of the system and how planets compare in both their distance from the sun and their orbital speed.

Voluble is a three-dimensional real-time experience and not just an animation because the persistence of structure is easier to understand from the multiple angles and real-time interaction. When a model of the solar system and its space-time diagram are joined, slices of time are shown simultaneously with their orbit's motion. Orbital speeds can then be adjusted and visually compared in scale from any point of view better than with a series of animations. This is especially helpful since the planets do not often align as they revolve. Combining a model of a system with a diagram is a challenge for designers, where the goal is to create a space where visitors can intuitively understand the logic of a system by spatially interacting with it.

In Voluble the space-time diagram is added to the plane of the solar system which results in the shape of a helix like an extruded coordinate that shows the orbits over time: the helix is the curve of the planet's orbit in three dimensional space. When the helix is viewed with perspective projection it becomes a spiral very much like the spiral in a snail. Both helix and spiral reflect a cycle as a circle over time is completed, establishing a change in the location of the emerging spiral's origin as the cycle progresses.

One example of navigating a helix in three-dimensional space is climbing "spiral" stairs. In the stairs of the towers in "La Sagrada Familia" (Fig. 2), a work by the architect Antoni Gaudí, the space is that of the helix, with stairs going up inside a very narrow cylinder shape. The stairs have an opening through the center that allows climbers to look up or down the spiral view. Moving through the particular form of the stairs space is not just similar to moving around the helixes, but illuminates the concept of a cycle and the displacement of time it takes to complete it, by having experienced it physically.

While most diagrams are flat, or in the case of interactive ones allow for manipulation and motion sequences, a virtual reality representation can be seen in space as if it was "really there," therefore engaging a higher number of memory cues that pertain to our every day spatial experience. In terms of design structure, the helix looks like a spiral in three-dimensional space when a perspective projection is used. In the case of Voluble, the orbit motions are presented twice in order to emphasize not just the motion, but also the cycle of the planets' orbits: in spinning around the sun and in the space-time diagram. In designing them together, the repetition of the time variable in both the helix and in real-time, reinforces the comparison among orbits, so the system's structure is more apparent.

Fig. 2. Tower stairs in " La Sagrada Familia" Temple. Barcelona, Spain[vii].

3.2 Previous work

Navigating space in a virtual reality environment with complex space relationships was tested with some success in the Round Earth Project[viii] In that project, children collaborate in moving around an asteroid using both a surface and a satellite view. The model of the asteroid is used as a displacement scenario so the concepts realized there are transferred to the domain of their experience of Earth following the cross-domain transfer hypothesis[ix].

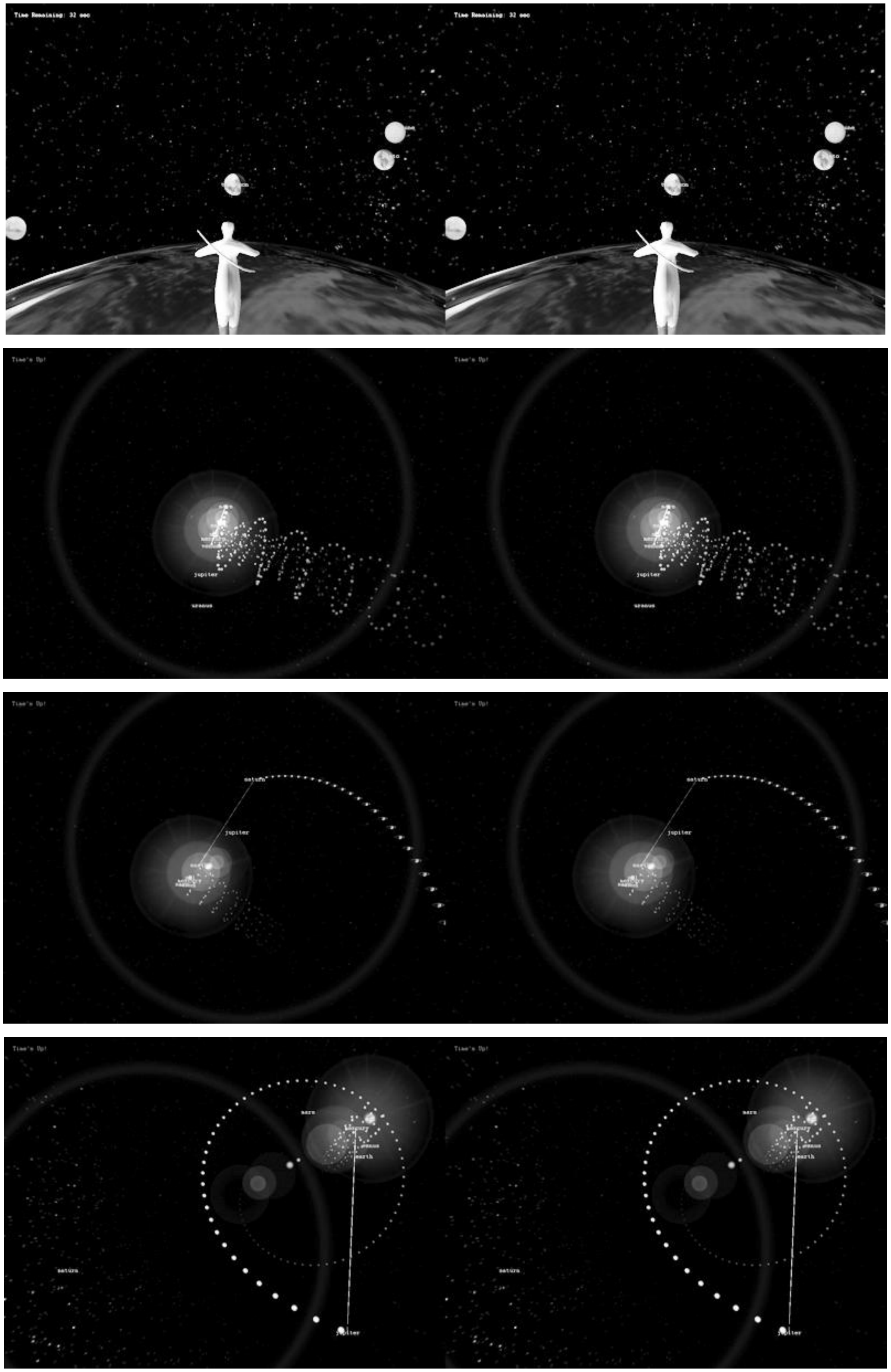

Fig. 3. Stereo screenshots of Arcanius as seen from the Earth's surface, and from a distant point in space

A previous version of the space-time diagram was included in a game called Arcanius[x], developed by Gideon Goldman and Julieta Aguilera at the University of Illinois at Chicago. Arcanius allows users to view the solar system from the different planets, and also from an outside distant point. The program was designed to run in a stereo projection system using Blitz3D. In order to see the helix-like trails, the user has to link three planets by pointing and jumping from the surface of one planet to the next. Once three planets are linked, the user could move to the outside camera and see the helixes left behind (Fig. 3).

Even though Arcanius is an immersive game, the structure of the helixes was approached differently. They were designed as breadcrumb-like trails that are left behind by each planet as a static sculptural form. For Voluble on the other hand, the helixes are continuous and not only reveal the frequency of the orbit, but they retain the spinning motion, further emphasizing how distance affects orbit speed.

3.3 Implementation

In Voluble, models of spirals follow planets' orbits around the axis of the solar system. The nearly circular orbits of the planets become helixes in the space-time diagram and the paths of moons are helixes around the parent planet's helix. The traces of the planets in time are persistent, while the paths of objects in the space-time diagram are animated. The animated planets are represented as flat circles as they represent the position of the object in an instant of time. Because of the small size of objects in the solar system compared to the vast distances between the planets, we need to scale the sizes of the planets up by a factor of a hundred. Likewise, because of the relative scales of the orbital distances and periods between the inner and outer solar system, we create separate scaling factors relating space and time depending on what section of the solar system we are viewing.

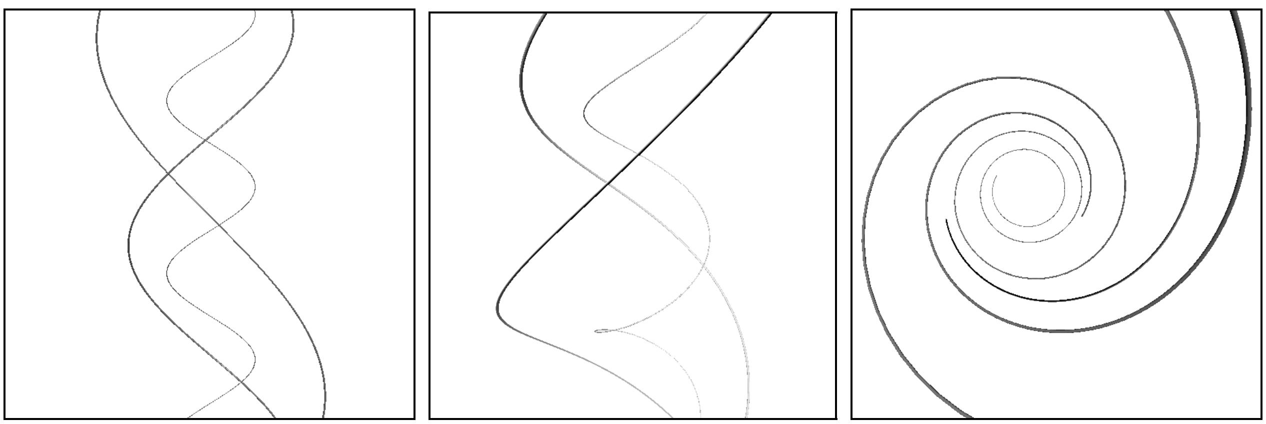

Fig. 4. Perspective screenshots of the helixes of Mercury, Venus and Earth from sides and bottom respectively.

Interaction allows the user to navigate the space within the helix field and proximity, and adjust the relative speed of all the orbits at once, measured in number of earth years, dynamically printed at the bottom of the screen for reference. Helixes of the individual planets can be switched on and off to allow for comparison among particular planet orbits (Fig. 4).

Voluble is being developed using Electro[xi], an application development environment designed for use on both cluster-driven tiled displays and desktop systems. Electro is based on the MPI process model and is bound to the Lua programming language. With support for 3D graphics, 2D graphics, audio, and input handling, Electro provides an easy-to-use scripting system for interactive applications spanning multiple processors and displays. Electro supports Linux, Windows 2K/XP, and Mac OS X. The helixes and planets are modeled and textured in Blender 3D and Maya.

Even though the application is ideally run on a stereo tracked C-Wall system, part of the application is designed to run in the non-tracked stereo GeoWall[xii] at the museum. The GeoWall system consists of two projectors with polarized filters that allow for stereo viewing with the use of corresponding polarized glasses. A handheld device that can be moved in space is used to navigate the virtual reality experience.

4. CONCLUSION

Voluble is a representation of the space-time diagram of the solar system. Like a large mobile, Voluble is designed to use the agency of spatial navigation to help people understand the relationship between space and time in the motion of the planets around the sun. Voluble investigates the balance between the visually abstract and the spatially figurative of an immersive dynamic environment by joining the model of the solar system and its space-time diagram.

In its current state, the application can be navigated in any direction and the system helixes can be seen from any angle. The speed range (in Earth years) has been determined to be one that allows the user to focus on form and the scale of the helixes is enough to allow for comparison. Controls afford the altering of parameters, and support the fact that those parameters are not literal. What remains is being emphasized: the relationship among the objects in the system.

Voluble is to be further refined in collaboration with educators at the Adler using the *Understanding by Design* methodology[xiii] and according to National Science Education Standards[xiv]. The evaluation plan will focus on whether or not users are able to understand that the planets' orbits are not synchronous and look for any misconceptions that the model might elicit.

The questions remains as to "how the increasing use of videogames and more sophisticated virtual environments will change the way people think about and remember space and place"[xv]. At the Adler, visitors have increasing familiarity with tracked interaction in videogames and stereo images in films. At SVL we want to take advantage of such an increase to explore new ways of communicating scientific concepts. Identifying a dynamic environment with our immediate space, and joining relative scale with the time-space diagram as a hybrid environment, may help us become familiar with phenomena that is beyond the scope of human space and time.

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