A Review on 4D Visualization

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In the field of scientific visualization, the term "four dimensional visualization" usually refers to the process of rendering a three dimensional field of scalar values. While this paradigm applies to many different data sets, there are also uses for visualizing data that correspond to actual four-dimensional structures. For example 4D visualization of medical data, which entails the addition of time as the fourth dimension to 3D data, is fast gaining ground as a tool for diagnosis and surgical planning by medical practitioners. The purpose of 4D visualization is to graphically illustrate scientific data to enable scientists to understand, illustrate, and glean insight from their data.

Keywords —*4 Dimensional space, Concept of 4D Visualization*

I. INTRODUCTION

The display of four-dimensional data is usually accomplished by assigning three dimensions to location in three-space, and the remaining dimension to some scalar property at each three-dimensional location. This assignment is quite apt for a variety of four-dimensional data, such as tissue density in a region of a human body, pressure values in a volume of air, or temperature distribution throughout a mechanical object.

While there exist a number of methods to approach the visualization of three-dimensional scalar fields, there are few methods that are effective on true four-dimensional data, where the data do not represent a three-dimensional scalar field.

II. WHAT IS A DIMENSION?

Before we get started, let's be clear what we mean by a dimension. As a simple definition, adimension is a measure of extent. The dimensions of an object – no, not a plain old object, buta monkey with Rainbow-colored fur, so this won't read like some boring math textbook –refer to different directions in which an object extends. The monkey has height (how tall she is– of course she's a girl, what else would she be?), breadth (how wide she is, shoulder to shoulder), and depth (front to back, or nose to tail); she is three-dimensional (3D).However, there are different kinds of dimensions, like space and time – or if you want to getexotic, we can talk about the dimensionality of your thoughts or even your body odor. Weneed to explore the concept of a dimension a little further, so that you'll know exactly whichtype of dimensions we are discussing in this book.

Let's begin with a simple geometric example. An infinitesimal point has zero dimensions (0D; that's "zero dee," not "oh dee") – it doesn't extend in any direction. (Yeah, infinitesimal. Like that word? Surely you know the word infinity – the largest number, right? Wrong! If it were a number, you could add one to it and find a larger number. Infinity represents the concept that you can keep counting forever. Infinitesimal would be the smallest nonzero number, except that if you divide it by two, you get something smaller. So this definition is just as wrong as thinking of infinity as being the largest number. But sometimes an incorrect definition expresses the concept more clearly than a technically correct one.) That long parenthetical remark actually has a purpose. Say what? Yep: We spent a lot of time getting nowhere, just like the zeroth dimension! A line is one-dimensional (1D) as it only extends one way – like this sentence, which you can only read forward or backward. A plane is two dimensional (2D); it has length and width. A block is three-dimensional (3D); it has length, width, and depth.

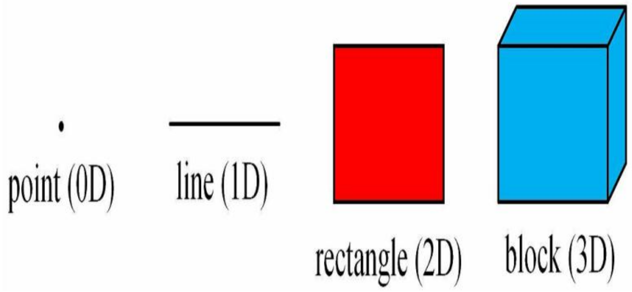


Figure 1: Illustrate the example of 0D, 1D, 2D and 3D.

If you want the previous picture to look less boring, you have to use your brain and imagine that it consists of – from left to right – a monkey's thought, a monkey's tail, a monkey's shadow, and a monkey. Our universe appears to be 3D because we can only move in three independent directions – north/south, east/west, and up/down. Any other direction is a combination of these. So that's why we think of space as being 3D.

Space appears to be 3D, but space-time is 4D. Time is a dimension in the sense that it is also a measure of extent – it is a duration. But time is clearly a different type of dimension than length, width, and depth. In this report, we're interested in a fourth dimension of space. That is, a fourth dimension that is very much like length, width, and depth, but not a combination of these (i.e. not like northeast). String theory actually predicts that our universe has more than just three dimensions of space. Our universe might actually have 9 dimensions of space.

III. DIMENSIONS ZERO AND ONE

Let's begin with the zeroth dimension. A 0D object is just a mathematical point. A single object in a 0D universe would take up all of the space. Motion wouldn't be possible. It would be the ultimate prison, where you could only "do time," as the saying goes. You couldn't do anything physical in 0D, but it might suffice for a purely philosophical or spiritual world. The first dimension could be a line, but it could also be a curve like a parabola or a circle. Curves are effectively 1D because any object living in such a space would have the same limited freedom that a line has: You can only go forward or backward.

IV. THE SECOND DIMENSION

A plane is 2D, but a 2D world doesn't need to be flat; it could be curved like a sphere or a cylinder. A monkey in a plane could move in two independent directions – north/south or east/west. Similarly, a monkey confined to the surface of a sphere (so just like the monkey in the plane, she can't go up or down) could only travel north/south or east/west. Walking around in an open field is a largely 2D human activity. Notice that two lines intersect at a point and two planes intersect at a line. We can use patterns like this to predict what the fourth dimension might be like. For example, by analogy, if two 3D universes (hyperplanes) were to intersect, they would meet at a plane. A 2D world would actually be quite unlike 2D drawings that we often draw on paper. When we draw a 2D picture on a piece of paper, we often draw the surface of a 3D object that we see with our eyes.

V. THREE-DIMENSIONAL SPACE

We ourselves have a few difficulties visualizing the third dimension, and we live in it! We see a 2D image of 3D objects with our eyes, and we draw 2D representations of the third dimension on paper. Trying to draw the third dimension on a plane creates some ambiguity.Mathematically, we can graph 3D using a coordinate system. If you stand in the corner of a room and look at the corner on the floor, this can help you to visualize a 3D coordinate system, with *x*-, *y*-, and *z*-axes. We usually draw 3D coordinate systems with two of the axes lying in the plane of the page and the other axis coming out of the page.

VI. FOUR DIMENSIONAL SPACE

A fourth dimension of space is a direction that you can't point toward, let alone move along, because you're a 3D being living in a 3D world. (Perhaps a genius is a 4D mind confined to a 3D body.) The best way to try to understand the fourth dimension conceptually (i.e. opposed to writing down a bunch of math) is to consider analogies and patterns with the lower dimensions. So let's briefly recap and see what the pattern suggests:

1. A bead sliding back and forth along a monkey tail in 1D. Moving just north/south is 1D.
2. A monkey running around in an open field is 2D. Moving along combinations of north/south and east/west is 2D.
3. A monkey swimming underwater in a pond is 3D. Moving north/south, east/west, and up/down is 3D.
4. To experience 4D motion, a monkey would have to be able to move in a new direction that's mutually perpendicular to all three of these directions – north/south, east/west, and up/down. Even though we can't move in that direction, we do have a name for it. The fourth direction is calledana, and its opposite is called kata.

In order to visualize the fourth dimension, you must think outside the box, literally! Actually, in 4D space, you could even walk outside the box! More precisely, if a monkey were standing inside of a cube-shaped room with no windows or doors in 4D space, the monkey could easily walk outside of it. In contrast, in 3D space the monkey would be trapped inside of the cube.

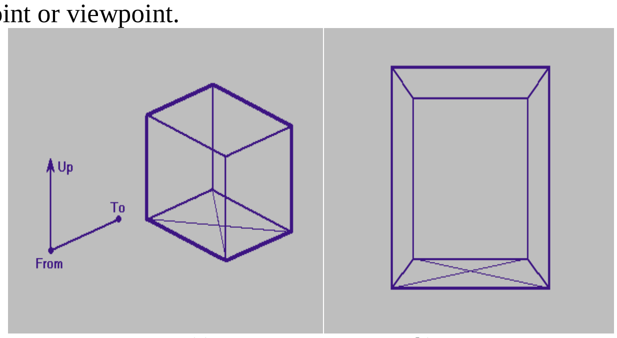
VII. CONCEPT OF 4D VISUALIZATION

In the field of scientific visualization, the term "four dimensional visualization" usually refers to the process of rendering a three dimensional field of scalar values. While this paradigm applies to many different data sets, there are also uses for visualizing data that correspond to actual four-dimensional structures. Four dimensional structures have typically been visualized via wire frame methods, but this process alone is usually insufficient for an intuitive understanding. The visualization of four dimensional objects is possible through wire frame methods with extended visualization cues, and through ray tracing methods. Both the methods employ true four-space viewing parameters and geometry. The ray tracing approach easily solves the hidden surface and shadowing problems of 4D objects, and yields an image in the form of a three-dimensional field of RGB values, which can be rendered with a variety of existing methods. The 4D ray tracer also supports true four-dimensional lighting, reflections and refractions.

The display of four-dimensional data is usually accomplished by assigning three dimensions to location in three-space, and the remaining dimension to some scalar property at each three-dimensional location. This assignment is quite apt for a variety of four-dimensional data, such as tissue density in a region of a human body, pressure values in a volume of air, or temperature distribution throughout a mechanical object.

Viewing in Three-Space

The first thing to establish is the viewpoint, or viewer location. This is easily done by specifying a 3D point in space that marks the location of the viewpoint. This is called the from-point or viewpoint.



(a) (b)

Figure 2: a) 3D viewing vectors form to points, b) Resulting view from figure 2.a.

The next thing to establish is the line of sight. This can be done by either specifying a line-of-sight vector, or by specifying a point of interest in the scene. The point-of-interest method has several advantages. One advantage is that the person doing the rendering usually has something in mind to look at, rather than some particular direction. It also has the advantage that you can ``tie'' this point to a moving object, so we can easily track the object as it moves through space. This point of interest is called the to-point. Now to pin down the orientation of the viewer/scene, a vector is specified that will point straight up after being projected to the viewing plane. This vector is called the up-vector.

Since the up-vector specifies the orientation of the viewer about the line-of-sight, the up-vector must not be parallel to the line of sight. The viewing program uses the up-vector to generate a vector orthogonal to the line of sight and that lies in the plane of the line of sight and the original up-vector.

If we're going to use perspective projection, we need to specify the amount of perspective, or ``zoom'', that the resultant image will have. This is done by specifying the angle of the viewing cone, also known as the viewing frustum. The viewing frustum is a rectangular cone in three-space that has the from-point as its tip, and that encloses the projection rectangle, which is perpendicular to the cone axis. The angle between opposite sides of the viewing frustum is called the viewing angle. It is generally easier to let the viewing angle specify the angle for one dimension of the projection rectangle, and then to tailor the angle of the perpendicular angle of the viewing frustum to match the other dimension of the projection rectangle.
The greater the viewing angle, the greater the amount of perspective (wide-angle effect), and the lower the viewing angle, the lower the amount of perspective (telephoto effect). The viewing angle must reside in the range of 0 to pi, exclusive.

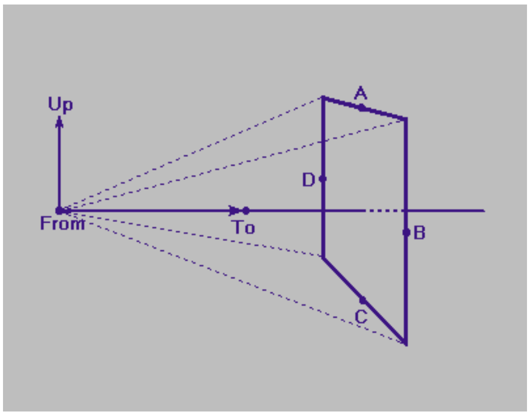


Figure 3: The 3D Viewing Vector and Viewing Frustum.

The angle from D to From to B is the horizontal viewing angle, and the angle from A to From to C is the vertical viewing angle.

To render a three-dimensional scene, we use these viewing parameters to project the scene to a two-dimensional rectangle, also known as the viewport. The viewport can be thought of as a window on the display screen between the eye (viewpoint) and the 3D scene. The scene is projected onto (or ``through'') this viewport, which then contains a two-dimensional projection of the three-dimensional scene.

Viewing in Four-Space
To construct a viewing model for four dimensions, the three-dimensional viewing model is extended to four dimensions.
Three-dimensional viewing is the task of projecting the three-dimensional scene onto a two-dimensional rectangle. In the same manner, four-dimensional viewing is the process of projecting a 4D scene onto a 3D region, which can then be viewed with regular 3D rendering methods. The viewing parameters for the 4D to 3D projection are similar to those for 3D to 2D viewing.

As in the 4D viewing model, we need to define the from-point. This is conceptually the same as the 3D from-point, except that the 4D from-point resides in four-space. Likewise, the to-point is a 4D point that specifies the point of interest in the 4D scene.

The from-point and the to-point together define the line of sight for the 4D scene. The orientation of the image view is specified by the up-vector plus an additional vector called the over-vector. The over-vector accounts for the additional degree of freedom in four-space. Since the up-vector and over-vector specify the orientation of the viewer, the up-vector, over-vector and line of sight must all be linearly independent.

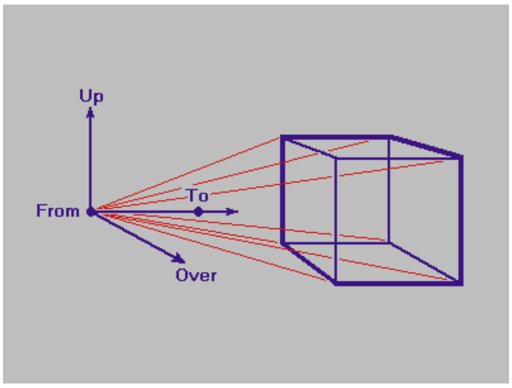


Figure 4: 4D Viewing Vectors and Viewing Frustum.

The viewing-angle is defined as for three-dimensional viewing, and is used to size one side of the projection-parallelepiped; the other two sides are sized to fit the dimensions of the projection-parallelepiped. For this work, all three dimensions of the projection parallelepiped.

VIII. IS IT POSSIBLE TO VISUALIZE 4D?

Some believe that it is impossible for us to visualize 4D, since we are confined to 3D and therefore cannot directly experience it. However, it is possible to develop a good idea of what 4D objects look like: the key lies in the fact that to see N dimensions, one only needs an (N-1)-dimensional retina.
Even though we are 3D beings who live in a 3D world, our eyes actually only see in 2D. Our retina has only a 2D surface area with which it can detect light coming into our eye. What our eye sees is in fact not 3D, but a 2D projection of the 3D world we are looking at.

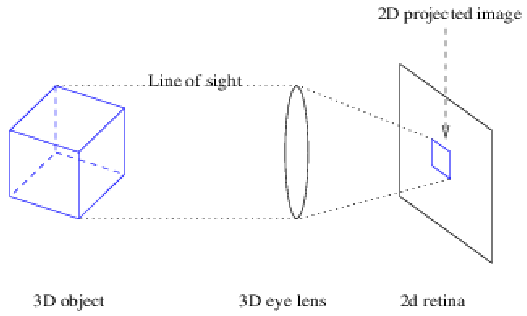


Figure 5: Schematic of 2D projection of 3D object.

In spite of this, we are quite able to grasp the concept of 3D. Our mind is quite facile at reconstructing a 3D model of the world around us from the 2D images seen by our retina. It does this by using indirect information in the 2D images such as light and shade, parallax, and previous experience. Even though our retina doesn't actually see*3D* depth, we instinctively infer it. We have a very good intuitive grasp of what 3D is, to the point that we are normally quite unconscious of the fact we're only seeing in 2D.
Similarly, a hypothetical 4D being would have a 3D retina, and would see the 4D world as 3D projections.

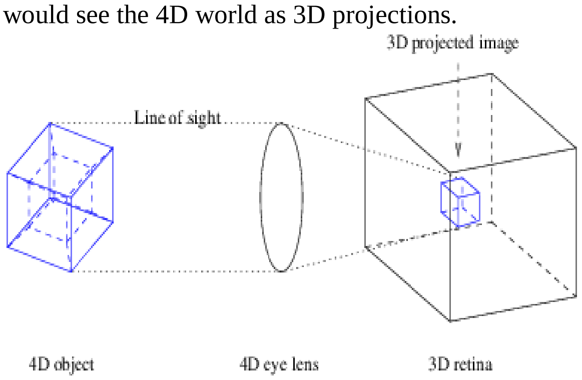


Figure 6: Schematic of 3D projection of 4D object.

It would not directly see the 4th dimension, but would infer it using indirect information such as light and shade, parallax, and previous experience.
The key here is that what the 4D being sees in its retina is *3*-dimensional, not 4-dimensional. The 4th dimension is inferred. But since we have a good intuitive grasp of 3D, it is not that difficult to understand what a 4D being sees in its retina. From there, we just need to learn how to infer 4D depth.
The rest of this document will describe in detail the basic principles of 4D visualization, as well as provide a number of examples of 4D objects. We shall take a purely geometrical approach and treat all 4 dimensions as spatial dimensions.

IX .METHODS OF VISUALIZING 4D

4D visualization methods include: dimensional analogy, cross-sections, and projections.

Dimensionalanalogy

Dimensional analogy is a method of inferring things about higher dimensions by seeing how lower dimensions relate to our 3D world.
First, we study how things in lower-dimensional spaces such as 2D behave. Then we study the equivalent things in 3D, and compare the two, finding out how something in 2D generalizes to 3D. Then we apply the same principle to infer what would happen if we generalized from 3D to 4D.
Dimensional analogy is a very powerful tool that enables us to understand things that happen in 4D by comparing them to analogous things in 3D.

Cross-sectionmethod

The cross-section method takes a 4-dimensional object and intersects it with our 3D world, similar to how we might take a 3D object and intersect it with the 2D plane to see what the shape of its intersection is. By taking many such intersections of the same object, we can derive some useful information about it.

Projectionmethod

The projection method takes a 4-dimensional object and projects it onto a 3D hyper-plane, similar to how a camera captures an image of a scene by capturing light projected from the scene onto the film. By studying such images, we try to reconstruct a mental model of what the 4D object is like.

X.Benefits of 4D Visualization

4D technology has surpassed certain boundaries that came in the way in obtaining real -time medical imaging. With 4D, now physicians can capture the images of the organ, as they move within the body.
Imagery scanned by 4D imagery medical devices like CT scanner are continually updated with every shift in the position of the organ, which enables physicians to monitor treatment and make necessary adjustments accordingly.
In medical literature, 4D images can be used to detect potential problems associated with fetal development. It helps identifying the exact location of the tumor in the cancer patient so that the physician solely focuses on tumor and thereby, sparing the healthy tissues.
Furthermore, the 4D technology has enabled movies to appear more realistic providing jaw-dropping motion effects with every scene in the movie.

XI.EXAMPLES OF 4D VISUALIZATION

4DUltrasound

Acquisition of 4D ultrasound, especially of the heart and of the fetus is gaining popularity. 4D visualization is powerful in that it reveals the complex 3D geometry and the motion of the object under scanning. 4D ultrasound is a medical ultrasound technique, used in medical field. Ultrasonic phased array system is used for the scanning of the object. Computer based program is used to visualization of 4D images.

Figure 7: 4D ultrasound images of fetus.

Radiotherapy

A major goal in radiation therapy is to deliver a high radiation dose to the perceived tumor volume while minimizing the dose to surrounding uninvolved tissues. Although radiation therapy cures a large fraction of patients treated with this modality, the incidence of local failure remains a problem and the radiation-induced side effects impact the quality of life for many cancer patients. One of the reasons for local failure and increased side effects is the assumption commonly made in radiation therapy that the geometry of the patient's anatomy is invariant relative to what is obtained at the time of the initial 3D imaging (usually Computed Tomography or CT) performed for treatment designs. With the availability of novel imaging techniques, tumor volume and normal structures can be defined in "4D" images, i.e sets of 3D images acquired at specified intervals of time, the interval being dependent upon the specific radiotherapy problem.

XII .CONCLUSION

4D visualization now days getting popularities in many field especially in medical field. It helps the medical practitioner to diagnose the patient's problem in better way. Computer based program is very useful in the visualization of 4D images.

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