

Cartographic Animation in Three Dimensions: Experimenting with the Scene Graph

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Abstract

Cartographers have made a shift from pen and ink to digital production methods; but the digital revolution remains unfinished. Two important methods that digital production makes possible are the use of animation, and the use of three-dimensional representation. Animation, here, is considered to involve the use of motion, especially motion without continuous user input, while three-dimensional representation means the simulation of three dimensions in a two-dimensional display.

The combination of these two computer graphics techniques has the potential for increasing the power of both; the two approaches are complimentary. A three-dimensional scene can be made to carry a higher density of information by using animation to vary the light source or perspective, for example, by highlighting components of a three-dimensional scene that are of particular interest. Elements unique to animation, such as rate of change and order of appearance, can be combined with elements unique to three-dimensional display, like fog, lighting, and texture.

However, although these elements can be combined, current cartographic theory and tools do not make it easy to do so. An addition to cartographic theory that will aid in the creation of novel combinations of three-dimensional scenes with animation is described. This addition is a categorization of possible visual variables generated by three-dimensional scenes, and ways these variables can be integrated with animation in a geovisualization context. A technical solution for combining three-dimensional display and animation, presented here, is the use of software components that can be linked together in a visual programming environment. The software used, *GeoVISTA Studio*, enables data sources, data transformations, data analysis, and data display, to be linked together along with user controls for these components. *GeoVISTA Studio* eases the creation of experimental three-dimensional animated maps.

1 Introduction

Using three-dimensional (3D) scenes for geographic representation has been an interest of cartographers for some years (Moellering 1980; Kraak 1993; MacEachren and Kraak 1997). However, there are still many conceptual and technical hurdles to be overcome for 3D representations to be exploited to their fullest extent in the service of geovisualization. One of the barriers is that conceptualizations of how data may be represented in 3D scenes have been based more on what the current technology permits easily than on what all the possibilities are. In this paper, we offer a description of “visual variables” that could be used in 3D animated geovisualization. Visual variables, after Bertin (Bertin 1981; Bertin 1983), are fundamental building blocks of the 3D scene to which data can be “mapped”. First, the static visual variables made possible by 3D scenes are described. Then, some of the uses of these variables in combination with animation are detailed, including how *GeoVISTA Studio* can aid in the creation of experimental 3D animated maps.

2 Composition of 3D scenes

A 3D view can be described by three elements: the scene composition, light sources, and camera or eye view (Badler and Glassner). We can describe multiple visual variables for each of these elements. In this paper, we will focus on the possibilities for visual variables that can be used to render a scene that displays information about georeferenced elements by assigning some visual variables to geographic coordinates and other visual variables to other information about the phenomena represented. Additionally, in this section, we will consider only the static aspects of a 3D scene, deferring dynamic variables until a later section.

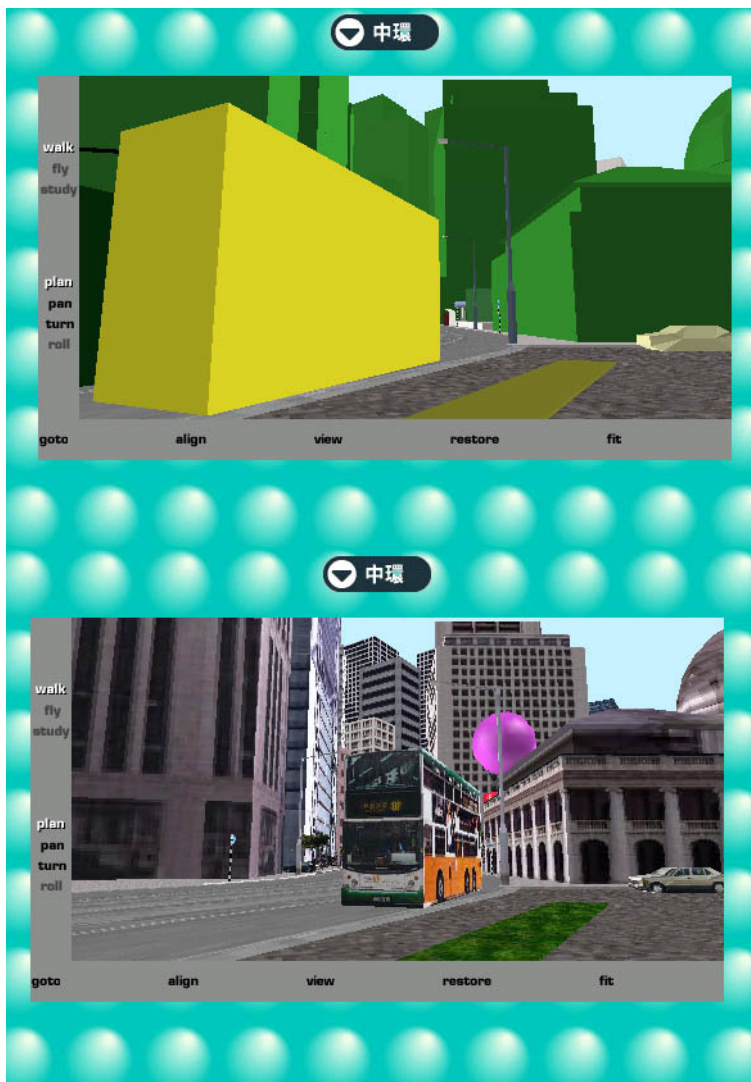


Figure 1: Using visual texture (eHongKong 2001)

shape, size, location, and orientation of the objects. The shape of an object in a 3D scene can be as simple as a cube, or as complex as a digital elevation model (DEM) comprising of thousands of faces. The size objects relative to each other can carry information as well. One issue with using size in a 3D scene is that

2.1 Scene elements

A 3D scene description consists of at least one, but possibly very many, elements. Each object in the scene can vary by many visual properties. The visual appearance of a scene element can be completely described by specifying all the visual variables for each of its elements. These visual properties can be divided into seven properties, which can be further divided into two kinds. First, “tactual” properties that a person could detect if she was able to “feel” the objects, include the shape, size, location and orientation of the elements. Second, “purely visual” properties that could be detected by the eye, but not even theoretically by touch, include color, visual texture, and transparency.

“Tactual” properties

The tactual properties are arguably the ones that define the reality of an object. If we imagine an object, such as a car, that we can feel but not see, we would describe the object as an invisible car. If we can see the car but not feel it, we would call the object an illusionary car. The tactual properties of objects in a three dimensional scene include the

the size of an object represents both the volume of the object at its distance from the viewer, so it might be difficult to distinguish a nearer, smaller object from a larger, more distant one. Location and orientation can be described in terms of the Cartesian x , y , and z coordinates. Location can be given relative to an origin within a scene, or as georeferenced coordinates. Orientation can be given as rotation around x , y , and z . For some shapes, different orientations cannot be distinguished. For example, the orientation of spheres cannot be determined in any axis, while the orientation of a cube could be distinguished in some orientations but not others.

“Purely visual” properties

The purely visual properties of elements in a 3D scene include color, visual texture, reflectance, and transparency. All of these properties can vary over the extent of the element. Thus, fog could be described as a stochastically varying, semi-transparent white element. Color in 3D can be used to code objects in a variety of ways as is done in conventional cartography, e.g., by coloring objects with a greater quantity of some characteristic more darkly. Visual texture can be used in two distinct manners for 3D data visualization. As shown in figure 1, visual texture can be used to make elements appear complex, or realistic, without using complex polygons. The polygons in the two scenes are identical, but the second one has images, or textures, over the polygons.

Visual texture, however, need not be limited to literal images. A great variety of textures can be created and used as a means of encoding information. Three possible dimensions for visual texture are contrast, orientation, and size (Ware 2000). A simple texture can be described by Gabor functions, which are a combination of a cosine function and a gaussian one. The strength of the cosine element specifies the contrast value, a rotation matrix for the cosine function specifies orientation, and the rate of decay of the gaussian function, along with the period of the cosine function, specifies the size of the function. The parameters that control contrast, orientation, and size can all be tied to numerical values to enable mapping information onto the textures of the objects. Beyond Gabor functions, a great range of computer generated textures are possible. See Figure 2 for some examples of possible textures. These textures would be more suitable for nominal data, while the Gabor functions would be more suitable for interval or ratio level data.

For 3D scenes, reflectance of objects must also be considered, and could potentially be used as another visual variable. Reflectance is the amount of light that strikes scene elements that is then emitted from the object. It is distinct from color because it reacts with the light sources and other objects in the scene in a way that simple color does not. An object with total reflectance would be a mirror; one with no reflectance would be black no matter how much light was striking it. Similarly, transparency could vary from invisible to entirely opaque (the usual default). As suggested for 2D depiction (MacEachren 1995), transparency might be an effective means of communicating uncertainty values for 3D scenes.

2.2 Light sources

While many of the variables in the previous section are also similar (or identical) to those previously defined for depiction in two-dimensional scenes, the issue of light sources is not, unless some kind of 3D effect is being attempted, as in hill-shading. Light sources have a number of aspects that could be systematically varied to communicate information. It may be most appropriate to map global, not individual, aspects of a data set to lights. For example, the mean or variance of a particular variable could be mapped to the color or brightness

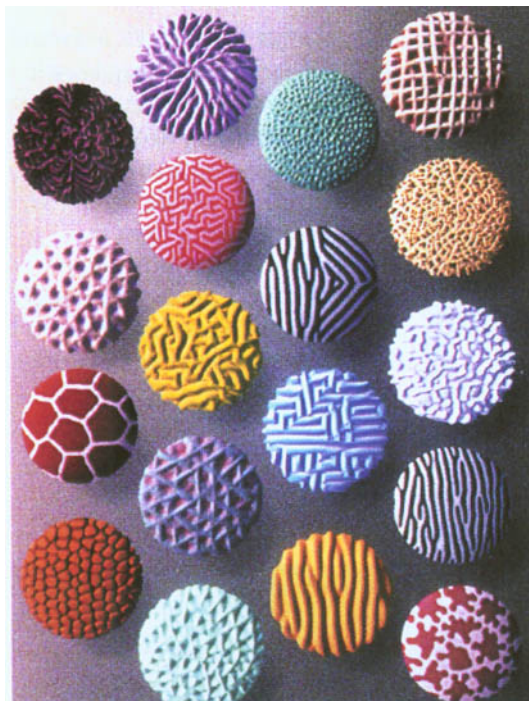


Figure 2: Computer generated textures (Witkin and Kass 1991)

of particular light sources. We can divide these aspects of light sources into spatial and non-spatial ones.

Spatial aspects of light sources

The spatial aspects of light sources include the location, direction, and size of the lights, as well as the width decay and distance decay for the lights. The location and direction of lights can be specified by x, y, and z. The meaning of these variables is affected by the size of the light, as an infinitely large light will not have a location or direction. It is possible to combine partially or completely opaque scene elements with light sources.

The decay aspects of light sources affect the degree to which the strength of the light decreases beyond the normal squaring of the distance relationship. Distance decay simulates an atmospheric effect. Direction decay defines the difference between the tight beam of a spotlight and the diffuse glow of a shaded lamp. Directional decay can be defined by a simple linear or gaussian function.

Non-spatial aspects of light sources

The non-spatial aspects of light sources include their color hue, intensity (value) and saturation. A possible approach to mapping these visual aspects to data is to have different colors mapped to the global means of a few variables, and have their intensity change according to the variance of those variables. A factor that will limit the number of variables that can be employed in this manner is that the values for light sources are only apparent via their interactions with objects, which have their own visual properties. Since at any one point there can only be a single color, even assuming an observer with infinite observational capacities, overloading light sources, transparency, color etc. will result in visual appearances for objects that are ambiguous in their interpretation.

2.3 Camera, or eye location

A 3D scene with no observer, or camera, is a meaningless construct. The camera in a 3D scene has three static components, a location, a direction, and a viewing angle. The location and direction are defined in x, y, z space, like other spatial variables in 3D space. The viewing angle is the size of the “window” onto the 3D world. One use of these variables in the context of geographic information visualization would be to provide the user with multiple views of the data landscape to show the statistically outlying values, or other values of interest. This is analogous to the “grand tour” in exploratory data analysis (EDA) (Tukey 1977).

3 Animation

Animation, in the context of this paper, includes all representations in which the visual scene changes without any direct input from the user. To understand how animation might be employed in three dimensional cartographic scenes, we will first consider what animation variables have been identified for two dimensional cartographic animation, then how the scene element, light source, and camera variables might be utilized in an animated context, and finally how the visual programming environment *GeoVISTA Studio* enables exploration of these questions in a novel manner.

3.1 Cartographic animation in two dimensions

When someone is composing a static map, he or she should consider how to effectively employ visual variables, like size, color hue, and shape of symbols. When creating an animated map, in addition, the appropriate type of animation should be considered. As a complement to delineation of these visual variables (that remain relevant for dynamic maps), our visualization group at Penn State identified three fundamental design elements or “dynamic variables” – scene duration, rate of change between scenes, and scene order – through which animated maps can represent information (DiBiase, MacEachren et al. 1992). We later added three more dynamic variables, display date, frequency, and synchronization (MacEachren 1995).

Scene duration can be thought of as the length of time between two identifiable states (MacEachren 1995). These states can be either individual images or cycles of images or colors. Rate of change refers to the degree of change between scenes. Rate of change could be constant, increasing, or decreasing. The default for map animations depicting time-series data has been a constant rate of change, while (von Wyss 1998) demonstrated that a logarithmic rate of change is effective, when animation is used to zoom from one scale to another. Scene order refers to how the different images are organized in the animation. Customarily, for time-series data, the scene order has been chronological, but this need not be the case. For example, data can be reordered, or “reexpressed” (DiBiase, MacEachren et al. 1992) according to some attribute. Display date refers to where a particular element in an animation appears in the context of the whole animation (and is, thus, the complement of the visual variable “location”). Frequency and synchronization both relate to multiple entities interacting over time. Frequency relates to interaction that is spatially integrated, while synchronization refers to spatially separated but temporally linked map features (MacEachren 2001). Other researchers have found that using synchronization, i.e. multiple animations running simultaneously (with the ability to adjust time lags between them), can be helpful for understanding certain types of temporal data (Blok, Köbber et al. 1999), and that animating transitions in a data analysis space aids in keeping the user oriented.

3.2 Animating 3D visual object attributes

Changing visual object attributes over time or some other variable is likely to be the mainstay for 3D cartographic animation. Arbitrary shapes that are used to communicate information, including directional information, are often referred to as “glyphs”. When we come to considering the visual properties described above – the “tactual” properties shape, size, location and orientation, and the “purely visual” properties color, visual texture, and transparency – it is apparent that these properties vary in how effectively they could be used to communicate information in an animation.

The “tactual” properties all have histories of use in conventional two dimensional and paper cartography, as they are suitable for pen and ink rendering as well as 3D scenes. We will consider here only those factors particular to 3D animation. Changing shape and size are phenomena that happen in the natural environment (real, non-virtual world), but not as frequently as change in location, so it may not be the best carrier of information visually. In fact, change in size might often be interpreted as a change in location, that is, that the object is growing closer or further away, instead of bigger or smaller. Even if the correct interpretation is made, inaccuracies in quantity estimation that have been found in relation to areal and volumetric quantities would probably reappear with a vengeance if viewers are asked to estimate rates of change in volume.

Changing location and orientation, by contrast, often do happen in the natural environment, and as such might be better carriers of information. Changing location has the difficulty that the most natural mapping for latitude and longitude on the earth’s surface is x and y in the virtual scene, and changing location is not compatible with phenomena that do not move. One way around this would be to use “local motion” or agitation. Making scene elements move back and forth in x, y, and z could provide good visual separation between classes. Changing orientation, that is, rotating around some combination of the three axes, could achieve the same effect. These six types of motion, that is, absolute position in x, y, and z, and orientation in x, y, and z, form the foundation of spatial change in 3D scenes.

Animations of color, visual texture, and transparency could be very powerful or very distracting. Indeed, rapid changes in color over large areas of the screen can even make viewers physically ill, as happened in the infamous incident concerning a children’s cartoon in Japan. In a cartographic application, (Monmonier and Gluck 1994) found that users disliked drastic, repeated changes in color hue and value (i.e. blinking symbols) but (Evans 1997) found that users could use “flicker” (alternation between two representations) effectively when the color changes from scene to scene were less drastic ones.

3.3 Animating light sources

Animating light sources is untrammelled ground in cartography. Recall that we divided the possible variables for using light sources into spatial aspects (location, direction, and size of the lights) and non-spatial ones (color and intensity). A possible application for using spatial aspects of light sources in an animation would be to show changing highlights. The observations in the top ten percent in each time step could have highlights on them, calling attention to surrounding values at the same time. On the other hand, non-spatial light source changes could show changes in global statistics, like Moran’s I, a spatial

autocorrelation measure. Changes in light sources would do this by mapping one or more statistics to one or more aspects of light produced.

3.4 Animating camera locations

Animating the location of the viewer treads perilously close to upsetting the “locus of control” that the user must have if they are to feel comfortable manipulating a program (Shneiderman 1998). It can be useful nonetheless. One application would be the “grand tour” mentioned earlier. Without smooth animated transitions, the scenes of interest would merely be blinking in and out of view, and the user would receive an incoherent impression of the phenomena presented. Another application would be to give the viewer a clearer idea of the “total shape” of a phenomena. This has been implemented in some commercial VRML viewers as a “fit scene” command, which brings the entire 3D scene in view, but it could be extended to fly around the data landscape. Because 2D user controls are not always a comfortable fit with the 3D scene, an automated and well controlled fly-around could be a useful tool. An analogous application is the use of rotation in 3D scatterplots to reveal the total shape of a distribution in a way that no static representation can.

3.5 3D cartographic animation using GeoVISTA Studio

Our experiments with 3D animation have been implemented in a software package called *GeoVISTA Studio*, (*Studio* hereafter) which supports coordination between visual and computational analysis techniques (Gahegan, Takatsuka et al. 2000). It is written in Java and provides advantages that are unique to this environment. The visual programming aspects of *Studio* enables us to create custom combinations of controls and visual variables, allow the controls to be reconfigured at runtime, and package the controls and visualization environment up for web deployment. *Studio* can be downloaded from <http://www.geovistastudio.psu.edu/jsp/index.jsp>.

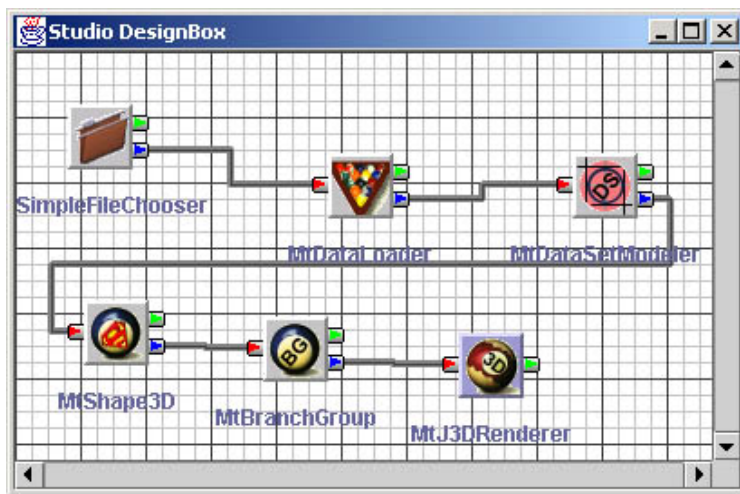


Figure 3: A design in GeoVISTA Studio

process, which will aid in the creation of three dimensional scenes. For example, if an analyst wanted to examine changes in population attributes for enumeration units between census years, she might want to first create a population surface out of the disparate geographies of the different census years. Then, she would need to examine these data for anomalies and remove them, in other words, clean the data. Then she might need to transform the data to remove systematic errors. Finally, she would want to import these data into a three dimensional scene, and animate it across census years.

Different tools available in the current release of *Studio* might be used by our imaginary analyst. Data importation and spatial sampling routines are available as beans within *Studio*. The examination of the data could be done with a 2D map and a parallel coordinate plot, as well as a third-party spreadsheet that has been integrated into *Studio*. Then, the data can be piped out to the 3D renderer shown in Figure 4, and

A *Studio* “design” is shown in Figure 3. Designs are the means by which a new 3D animated environment as well as other cartographic and non-cartographic representations can be constructed without writing any code. 3D display is possible in *Studio* through a 3D renderer included as a core component of the package. Figure 4 illustrates a digital elevation data set (a DGM) depicted using the 3D renderer. Although the DGM represents a surface rather than a volume, the *Studio* renderer can handle true volumetric data.

It is worth noting here that *Studio* can be used for multiple stages of the geovisualization

the analyst would be able to experiment with mapping different aspects of her data onto different aspects of her 3D scene, perhaps by draping color information representing socioeconomic data over height information derived from population counts.

4 Further considerations

Several aspects of 3D animation merit more attention that was possible to devote to them here.

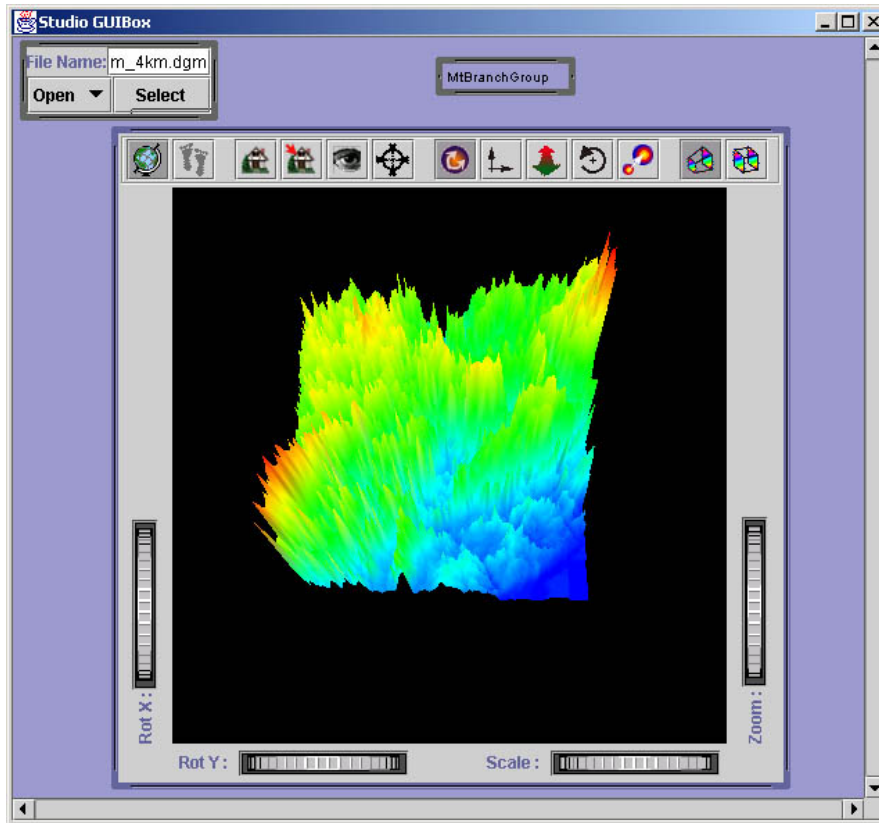


Figure 4: 3D Scene in GeoVISTA Studio

These include interactivity, other senses besides the visual, and the relationship between the visual variables described here and virtual reality (VR). Interactivity in 3D scenes was touched on briefly in this paper, but there is much further to go. We need to consider not only the viewer's interaction with the scene, but potentially the scene elements interactions with each other, and with the viewer!

Other senses, like sound (which is part of the VRML97 specification) and touch could profitably be employed in 3D animated scenes. Sound could help orient users in what can be complicated

spaces, signal critical points in a time series, or help users understand continuously changing scenes. Effective interaction with 3D scenes is dependent upon having six degrees of freedom to move with. The experience of using a mouse on a 2D plane is necessarily difficult for controlling six degrees of freedom, and accounts for much of the awkwardness of navigation that many have experienced in 3D interaction (Fuhrmann and MacEachren 1999).

Many cartographers have been interested in 3D displays as an entrée into virtual reality (VR) (e.g. Fairbairn and Parsley 1997; MacEachren, Kraak et al. 1999; Verbree, Van Maren et al. 1999). The considerations raised in this paper overlap with these questions. The extent to which the experience of virtuality is affected by the use of the visual variables examined here is an open question.

There has been some exciting progress recently in the common format for a standard georeferenced 3D format, GeoVRML (Iversen and Reddy 2001). GeoVRML 1.0 was officially accepted as a Web3D Consortium recommended practice in July 2000. Interest in GeoVRML is likely to grow with the capabilities in commercial software (e.g. ESRI's 3D Analyst extension to ArcView/ArcInfo 8.1) to export information in the GeoVRML format. The GeoVRML group has produced an Open Source Java sample implementation of these nodes.

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