From Physical Space to Visual Image Space

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1 Introduction

Virtual reality (VR) is a form of human-computer interface (HCI)\(^1\). And now it is a major branch of computing, covering a broad spectrum of human interaction with computers. It ranges from the interaction with real environments to that with synthetically generated worlds\(^2\). Usually, in the interactive process, one of the main outputs of computer is graphics on the screen. The graphics are the main information source received by human from the computers. To human, vision is the most important organ to gain information from the natural world. So the level of graphic representation on the monitor affects the cognition to information from computer.

We see that real three-dimensional (3D) graphics can be used to represent the information in digital world. VR creates a 3D environment from the data and provides a more common way of interacting with data. In the VR system, especially, users become a part of the data set. The experience of being part of the data, called “immersion”, can be enhanced by the use of stereoscopic three-dimensional images, sound and real-time interaction\(^3\).

2 Space and space simulation

If we use VR as an interface for human-computer, then the characteristic of “immersion” is very important. How does the immersion produce? As we know, immersion is related closely to the human’s spatial experiences. It is because of such spatial experiences that a person can feel like “entering” the virtual environment provided by VR. So Virtual Reality is based on the concept of space.
specially the vision functionality. In order to understand the virtual reality, firstly, it is necessary to discuss the spatial concepts.

2.1 Spatial concepts

The spatial experience is different from the spatial concept. There are two different concepts. One is instinctive, and expresses the people’s awareness about the variety of spatial relationships in the real world. The other is an abstraction to different kinds of spatial experiences, and depends on how people understand the physical world. Spatial experiences include orientation experiences and distance experiences and so on.

The spatial experience is complicated and of diversity. The following are three kinds of the spatial experiences that can directly indicate spatial concepts:

1) The experiences about location, or place. When we say that the object exists, it certainly means that it is at somewhere. In other words, the object that is not at a certain place does not exist.

2) The experiences about emptiness or vacancy. All of us know that there exists the "empty" state. For instance, when the persons all leave a room, explicitly the room is empty. Another example is that, if nobody sits a chair, the chair is free, or "empty".

3) The experiences about occupation. It is known that any object on the ground has its size and shape. The different objects have different occupation in length, width and height.

Any type of spatial concepts tries to unite spatial experiences above. Next we will discuss the modern spatial concepts. Due to the effects from Newton’s theory, the modern spatial concepts have differences from old spatial concepts like Greece’s spatial concepts. For distinction, the modern spatial concept is calleds concept of space.

"Space" is an unphysical thing different from material objects. It exists independently. All objects use it as the reference background of movements. The material is in movement and of diversity, but space is still. Space is a container or framework to all material objects. Also space can be seen as an extension to pure geometry: continuity, infinite expansion, three dimensions, uniformity and measurable.

In fact, the word “space” has different meanings in different disciplines. Space means the spatial occupation in philosophy. It is objective and independent on persons’ awareness. To cosmos, space is infinite in size; but to individual object, space is limited. According to astronomy, space is the part of continuous spatio-temporal system. In geography, geographic space means the distribution modes and situation of matter, energy and information in state, process and function relationships.

Physical space is a real extension of multidimensional space where human lives. On the physical viewpoint, physical space can be viewed, observed or modelled. Corresponding to physical space, there exists the space which can be perceived by human—the cognitive representation of physical space—the cognitive space.

The concepts of space include absolute space and relative space. For instance, the geographic space in geography is defined as two modes, absolute space and relative space. The absolute space is the integration of spatial positions with attribute description and composed of a group of spatial coordinates at different positions. The relative space is the integration of objects with spatial characteristics and composed of spatial relations of a group of objects. We consider that the spatial concept in physics emphasizes on the description about the physical space and the spatial concept in geography emphasizes on the description about the cognitive space.

In general, the most important characteristics of space are its background reference and geometric features. The physical space is the framework of all objects and is like a contain-
er. When an object is put at a certain place, the object occupies a part of the container. If the object is moved away, the part occupied by the object before moving still exists, but is “empty”. In space, not only objects are measurable, but also “empty parts” are measurable. In the virtual reality, one of our main objectives is to establish such a virtual space.

2.2 Space of earth surface

The space of the earth surface is closely related to our life. As mentioned above, the space of the earth surface is a physical space. It is one of the main objects explored in geo-information science, and consists of the earth surface and near-earth part of space within certain range. There are varieties of physical, chemical and biological phenomena in the space of the earth surface.

If we want to represent the space of the earth surface in the virtual reality, firstly, we should investigate the characteristics about the space. Undoubtedly, the space of the earth surface can be described by use of characteristics of physical space that include both geometric and attribute characteristics. The characteristics reflect different aspects of the space. The description of the space can be completed through the description about the spatial objects distributing in the space framework. Actually, we do perceive spatial existence of the real world by the perception of spatial objects and their spatial relations in the real world. The geometric characteristics of spatial objects include location, shape, size, orientation and so forth, while attribute characteristics include all non-geometric properties. In this paper, the description of space means both the description of the geometric characteristics of the spatial objects and that of the attribute characteristics at each geometric point of the spatial objects.

2.3 Visual image space

If there is a “digital copy” for earth surface (physical space) on computer, on the basis of our experiences, we can view this “virtual space” in the virtual reality system. Furthermore, when we see “the virtual space” in the real 3D mode, our vision seems to see the real world. We can create “the explicit images” in our brain. The space perception depends on our feelings, including vision, touching, etc. The space perception is under our perception space, and it is a “copy”, “graphic” or “image” corresponding to the physical world in the perception space.

With respect to our visions, the transformation from the objects in the physical world to “space image” is realized through vision. Clearly, in our brain a correspondence of the natural world through vision is created. As the real objects are in the physical space, the correspondences to the real objects are in a “virtual space”. We call the virtual space in our brains visual image space. The visual image space is related to vision. The visual perception is based on the space. If there is no visual image space, there is no visualization. For instance, even a graphic is displayed on computer screen, if we close our eyes, we cannot perceive anything. So we think that the essence of visualization is to translate the information to the visual image space and to reconstruct the models in it.

2.4 Space simulation

The concept of space can be used to understand or explain spatial experiences, which are helpful to support people in the exploration of the real world. When we establish the representation of the physical space, the world around us, with the help of the concept of space, we can produce a virtual environment on computer to enhance the spatial experiences of humanity.

To represent the physical space on computer is a problem of space simulation. The representation on computer can be seen as the “digital image” of the real space, or the “digital copy”. As we can take a picture for a
scene, we also can take a digital image for a physical space with the help of the transformation of space.

Supposing $A$ and $B$ are two data sets, according to a corresponding rule, if each of the elements in $A$ is corresponding to one certain element in $B$, then the corresponding rule is called a transformation or mapping from $A$ to $B$. If $A$ and $B$ are spaces, the transformation between $A$ and $B$ is defined as the transformation of space.

For example, from the earth surface to map is a series of transformation of space. In this case, the entities in 3D space of the earth surface are transformed into the map, a 2D plane.

In fact, by using the general spatial concepts, the earth surface is considered as a multi-dimensional space. From the geometric viewpoint, the earth surface is in a 3D geometric space; from the viewpoint of dynamic change, the surface is in time series (one-dimensional temporal space); from the attribute viewpoint, the surface is in a multi-dimensional feature space (e.g. multi-spectral feature space).

When a spatial problem is discussed, there is need to clarify the true meanings of space. There are different representations and different transformations in different spaces. In geometric space, the geometric transformation, as perspective transformation, can be done. We can also complete the feature transformation in the feature space, e.g. the radiometric transformation in the multi-spectral feature space.

The same as the camera system establishes the relationship between the natural world and photographs, the vision system sets up the corresponding relations between the natural world and the visual image space. Our visual perception to physical space is completed in the visual image space. The visual image space is related to the real world with the help of the electric-magnetic wave and the vision organ, and is a framework, location or place of the visual image for the natural world.

In the virtual reality system, to vision functionality, the main task is to realize a series of special space-transformations in order to obtain the corresponding spatial images in the visual image space to the real objects in the real world. It is a procedure of space simulation in vision (Fig. 1).

![Fig. 1 Space simulation in vision](image)

There are many methods for completing the space simulation in vision. Because the physical space is three-dimensional, so the simulating space of it should be three-dimensional as well. The real space may be either visible or non-visible. In the visible spectrum, the natural world is visible to us. This is to say, our eyes transform the real scene to the visual image space, and make us perceive the existence of the real space. In this sense, we say that, the images in the visual image space are visible. The objective of data visualization just is to simulate objects in the visual image space. The graphic rendering on the screen is only the median result in visual procedure. The destination for the visual representation is the visual image space but not the screen.

In visual perceptive sense, people explore the real world through the visual image space. The formation of the visual image space derives itself from the visual stimulation of the characteristics of the physical space. With this stimulation from the real space, we can feel "the space" before us. If we receive a similar stimulation not from the real space but from the simulating devices, we can also feel "the same space" before us. Simulating stimulation is the basis of establishing the real 3D environment in the virtual reality system (Fig. 2).

### 3 Experiment and discussion

According to the discussion above, a prototype
system based on spatial data, called SMVR (surveying & mapping virtual reality), was developed. The SMVR system was used to transform the space of the earth surface to the visual image space, and to complete the space simulation for the earth surface. In our experiments, the space of the earth surface was digitized through remote sensing. And then the spatial data was gained. The spatial data was properly processed and a digital space was formed on computer. This is a procedure from the physical space to the digital space (Fig. 3).

The digital space is used to describe the characteristics (geometric and attributive) of the physical space (the space of the earth surface in our case) in the digital mode. The representation of the digital space is coded data. Before visualization, the data is stored in codes, and is invisible and, therefore, difficult to understand.

In order to represent and explore the spatial data in the digital space, it is necessary to visualize the coded data. Here the essence of visualization is transforming the digital space to the visual image space. The procedure can be realized through different projection modes (Fig. 4).

From Fig. 4, it can be seen that different images can be gained from the same digital objects through different projections. The stereo images can be formed in the visual image space by use of stereoscopic projection. By using both the central projection (or perspective projection) and the stereoscopic projection, the SMVR system can complete the space simulation from the digital space to the visual image space. Fig. 5 and Fig. 6 individually show different simulating results to a city space by use of the SMVR system. Fig. 5 is the simulating result of the perspective image on computer screen. Fig. 6 is the simulating result of stereo image. When viewing Fig. 6 on the screen wearing stereo glasses, we can perceive "a true 3D space" before us.
tem, it is allowed for more than one person to view the situation of the earth surface in the stereo mode. The system not only has some basic functions such as zoom, roam and measurement, but also can drape designing data and textures interactively to realize "the virtual construction". In this way, the designers can put their plans over "the virtual environment" so as to estimate the aspects of their designs. The functions of the SMVR system currently include: modeling and displaying the 3D landscape of the earth surface, executing the different topographic analysis and the visualizations of results based on DEM, viewing or flying through the virtual landscape, querying geometric measurements like coordinates, length, area, volume and so on, and the attribute feature query in the visual mode, etc.

Currently, the SMVR system which is based on the spatial data has been used to complete the simulation of "the digital earth" of small areas. In order to process the spatial data of the earth surface of larger areas, it is necessary to develop a series of related theories and techniques for the management of huge data, fast parallel computation, 3D stereo display in high quality, the representation of spatial objects, etc. The targets of our next research are: (1) facing the special features of the spatial databases and the complexity in management and huge data, developing the interface techniques which are connected with spatial databases, so as to extend the virtual environment based on the data of small area to that based on the spatial databases capable of managing huge data; (2) developing the interface techniques connected to the modeling databases of analysis methods to provide a virtual environment platform for different 3D analysis; (3) by use of Internet technique, developing the virtual geographic environments (VGE) system.

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