Preliminary study on virtual geographic environment cognition and representation

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Abstract: The differences between the geographic environment and the geo-spatial concept of current geo-information technologies, and the characteristics and development processes of spatial cognition of maps and geographic information systems are analyzed. The concept of virtual geographic environment cognition is proposed. The objectives of virtual geographic environment cognition include the cognition of the real world phenomena of surface features, geographic processes, human behavior and their relationships. This paper studies virtual geographical environment cognition from two aspects: acknowledgement and understanding of the geographic space, geographic processes and human behaviors; and then the representation of the real geographic environment in the virtual geographic environment, as well as obtaining and sharing geographical knowledge based on virtual geographic environments to gain insight to the real geographic environment. Representation of virtual geographic environments involves three levels. Research on cognition of virtual geographic environments needs to develop geo-spatial cognition theories and methods of geographic entities and phenomena, as well as cognition and modeling of geographic dynamic processes and the perception of human behaviors. Geographic processes representation and human behavior simulation are focused upon and relevant preliminary study ideas and contents are presented.

Key words: geo-spatial cognition, virtual geographic environment cognition, geographic process representation, human behavior modeling

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1 INTRODUCTION

Geographic Information Systems (GISystems) and Geographic Information Science (GIScience), which is developed as a computer processing technology, a geospatial computing theory and analysis method for geographical data, information and knowledge, are powerful tools for scientific research in modern geography. With the development and popularization of geographic information technology applications and geographic information science research, in mid-1990s researchers began to pay attention to the rationality of understanding and representing geographic space, the scientific nature of modeling and analysis of geographic processes, as well as the intelligence of geographic information system functions and services. In 1995, geo-spatial cognition, geographic concept calculation methods, and geographic information and social science studies were proposed as the three strategic areas in GIScience research by the U.S. National Center for Geographic Information and Analysis (NCGIA) (NCGIA, 1995). In 1996, the University Council of Geographic Information Science (UCGIS) in the United States argued that a major obstacle to the effectiveness of geographic information technologies was the lack of attention paid to the importance of cognition problems, and “geographic information cognition” was listed as one of the ten priority research topics in GIScience (UCGIS, 1996).

Geo-spatial cognition is a foundation for geographic information cognition research and of great significance for understanding and representing geographic information. Geographic information cognition is thus the basic theory of geographic information science. It bridges computer processing technology studies and theoretical analysis and methods research on geographic data, information and knowledge (Lu *et al*., 1998). From

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this point of view, it is a key bottleneck preventing breakthroughs in the advancing geographic information technologies.

In recent years, research on geo-spatial cognition and geographic information representation has gradually expanded and has been encouraged by scholars of related professions, both from China and other countries: such as Peuquet (1988) who suggested that there was a need to establish a unified conceptual framework for geo-spatial representation; MacEachren *et al*. (1995, 2001) who discussed spatial cognition, map graphic models, spatial data visualization, interactive control of dynamic maps and other aspects of spatial cognition; Lu *et al.* (1998, 2005) who proposed the theory of geographic cognition and spatial cognition models; Wang (2001), Gao *et al*. (2004), and Wan *et al*. (2005) who carried out research in the area of spatial cognition, image maps and map cognition theory.

Geography studies the physical environment of the Earth's surface, that is, the interactive region of the "five spheres" (i.e., atmosphere, hydrosphere, biosphere, lithosphere, and soil sphere) (Chen *et al*., 2000). Geographic processes, which involve "five major types of processes" (physical, chemical, biological and cultural processes, as well as the interaction between the 4 given types of processes) that occur in and between the major spheres, especially the interaction between humans and the Earth (that is, "human-Earth relations"), are the driving forces for the formation and development of the geographic environment. Modern geography in particular focuses on geographic process simulation and mechanism analysis of the interaction between humans and the Earth system. At present, research on virtual environments is increasing, not only in the fields related to social, economic and legal aspects of virtual environments, but also in advances in the fields of scientific research. Virtual Geographic Environment (VGE) research, which was initiated by some geographic and geographic information scientists, aims to integrate the virtual reality environment and geography to study the real geographic environment, as well as the phenomena and laws in cyberspace (Gong & Lin, 2001; Lin & Gong, 2002; Lin *et al*., 2003, 2009; Lin & Zhu, 2005). From the perspective of research methods for geographic study, a virtual geographic environment is an integrated virtual environment and working space that can be used for simulation and analysis of complex geographic processes and phenomena, geo-collaborative working, knowledge sharing and group decision-making. In this context, Virtual Geographic Environments need to provide functionalities and mechanisms to support representation of temporal and spatial changes in the geographic processes, as well as the interaction between humans and the Earth, such as geographic representation, organization, management, visualization of space-time processes, as well as expression, management and knowledge extraction and assistance in decision-making on human behavior. Therefore, in this expanding field of Virtual Geographic Environments, research into how to represent and manage geographic processes, and simulate the cognition and behavior of human experience in virtual environments, are not only fundamental theoretical problems, but are also key contents of research methods.

This paper first analyzes development processes and characteristics of the spatial cognition of map and geographic information systems; discusses the concept of a virtual geographic environment; explores virtual geographic environment cognition and representation in two aspects: one is from geo-spatial cognition, geographic processes cognition and human behavior cognition and their representation in virtual geographic environments; the other is from the aspect of geographic knowledge acquisition and sharing, and the impact of virtual geographic environments on human understanding of geography. In addition, we propose some research ideas with focus on geographic process representation and human behavior simulation.

2 DIFFERENCES BETWEEN GEOGRAPHIC ENVIRONMENTS IN GEOGRAPHY AND GEO-SPACE IN CURRENT GEOGRAPHIC INFORMATION TECHNIQUES

Space is the most basic characteristic of things. Space varies with the nature, development progress and the requirements of things. Hu *et al*. (2002) made comparisons of geographic space in geography, earth space in geodesy, map space in cartography, and geo-spatial space in geographic information systems and argue that geographic space in geography is the Earth's surface system (geographic environment) on the basis of the whole earth and its live activities; geographic space in this context thus has universal significance.

In geodesy, rotating ellipsoid mathematical models are used to express geographic space in geography; therefore, the nature of Earth space in geodesy is consistent with geographic space in geography in that they are both three-dimensional space. In traditional cartography, map projections, in which the Earth ellipsoid is flattened to a plane, are used to express map space, in order to thrust the Earth's space into the Euclidean plane space, thus achieving a two-dimensional visualization and measurement of the Earth. Therefore, map space and map information are two-dimensional and just an approximate description of the geographic space. In the field of current geographic information systems, the representation of the Earth surface space is formed by projecting the geodesy space and then making transformations to the Cartesian coordinate system. Therefore, the definition of geographic space in geographic information systems has inherited the concept of space in cartography, and its essence remains the same as the concept of map space.

The foundation of the ontology and epistemology of current cartography and GIS is applying Euclid, Descartes and positivism concepts to understand geographic space and the environment. The basic idea is trying to define the geographic world as a series of spatial units that are represented by clear, continuous and non-overlapping polygons (Pickles, 1995; Sheppard, 1995). However, based on the above understanding, it will be difficult to carry out the "research of dynamics mechanisms and spatio-temporal characteristics of geo-information process and flow" (Chen *et al*., 2000). In addition, the constraints it brings to the development of geography and earth sciences become increasingly evident. Like the relationship of space to things in the world, time is also a most basic characteristic of all things. However, representation of static spatial objects and their analysis are stressed in traditional geographic information systems. In the development process of GIS, the time characteristics of geographic information has been of widespread concern; to some extent, research on the spatio-temporal data model and time GIS has been carried out. On the other hand, on the basis of the conceptual representation of geographic space in traditional GIS, there has been a great limitation when representing those geographical processes that are changing over time and the relationship between geographic factors in geographic environments.

The implication of geographic concepts, like all other concepts, is changing with the experiential and thinking modes, and the changing comprehensive functions of the social world (Liu, 2002). In addition, development of geographic information technologies has had a profound effect on the human objective (experience) world and their social thinking ways. Due to the limitation of conceptual representation of geographic space on the basis of the Cartesian coordinate system in current geographic information technologies, many geographic concepts need to be redefined by researchers, developers and users of geographic information systems in order to meet the constraints and conditions. In geographic information systems, complex geographic space has been simplified to a number of simplified geometric configurations (e.g., points, lines, surfaces, polygons, networks, bounded areas, etc.) that can be strictly classified and are known as geographic entities. However, the geographic environment also includes an integral part of complex and diverse entities and dynamic processes. Compared to the specific and static geographic entities, the implication and classification of the real world that consists of the natural geographic environment and human social organization is much broader and more complex, where geographic phenomena as well as dynamic processes and the relations between them compose an important manifestation of its complexity. Research organizations, researchers and practitioners in geographic information science have begun to reflect and analyze rigorously on the basis of geographic concepts, epistemological principles and theories provided from the perspective of geographic information systems (Sheppard *et al*., 1999; Liu, 2002). The initial research on geographic implications that was proposed by NCGIA also argued that we should study a “geo-spatial perceptual model” based on social theory and cognitive theory to explore the difference of representing geographic implication in cultural ways and in machinery ways, and to explore how to represent the implications of geographic, social and human environments (NCGIA, 1995).

3 SPATIAL COGNITION AND REPRESENTATION IN GEOGRAPHIC INFORMATION SCIENCE

Research in the field of geographic information science and technologies focuses on the theories and methods for collection, description, representation, storage, management and use of geospatial information. By the use of computers, it aims to express, simulate and analyze the phenomena of Earth surface space and spatio-temporal geographic processes, to contain geographic information and transmit geographic knowledge, with support for human access to geographic knowledge, geographic problem solving and decision making. Thus, geographic information technologies, which need to have cognitive science as a base theory, the computer as a tool, and geographic thinking for simulation, analysis and solving geographic problems, is actually an integrated and comprehensive technology platform of geographic data, information and knowledge.

3.1 Cognition, spatial cognition, geo-spatial cognition

The concept of cognition can be regarded in a broad sense as the same as understanding; it is a kind of human mental activity conducted by human brains that reflects the characteristics and relationships of objective things and reveals to humans the meaning and role of these things. Cognition is the general term that describes various processes of a person knowing and understanding the world in which they live, generally including several organic and linked information processing processes, e.g., concept formation, language description, problem solving and individual differences (Wang & Chen, 2001). Through acquisition, storage, conversion, analysis and use of information, human beings can understand the objective nature and laws of things, and form a conceptual world to describe and represent the objective world. Spatial cognition is the capacity and process that people understand of the patterns, distribution of locations, interdependent relations, and changes or trends of various things and geographic phenomenon in the living environment (Gao, 2004). Geo-spatial cognition is a series of psychological processes including human perception, imaging, memorization and thinking processes (e.g., spatial encoding, internal expressing and decoding) on geo-spatial phenomenon and geo-spatial entities, to develop an understanding of geographical space and carry out geographic analysis and decision making (Lloyd, 1997).

Therefore, research into geo-spatial cognition pays more attention to the themes of geographic space (in which people can have many kinds of activity) such as a geo-spatial reference system, geographic implications, relationships, uncertainty, as well as geo-spatial knowledge and human behavior representation that relate to cognition. The study content of geo-spatial cognition is not simply interior space, or desktop space, or abstract Euclidean space. However, the content involves the geographic environment that has prolific geographic implications and semantics. Geo-spatial cognition is a major cross-cutting area of research that integrates psychology, physiology, linguistics, philosophy, computer science and many other disciplines and geography and earth sciences. It studies how people acquire, process, store, transmit and translate geo-spatial information, to understand the environment in which they survive including the location, spatial distribution, dependencies and their changing processes and development laws of various things and phenomena related to the environment.

3.2 Development of geo-spatial cognition and representation

Geo-spatial cognition is a case of the application of cognitive science theory being used in the fields of geography, cartography and geographic information science. Spatial cognition study in geography aims to explore the mechanism of the formation of geographic implications, and how specific geographic reality transforms into geographic implications for human beings. Spatial cognition study of maps is to find the characteristics of maps as a tool for understanding space and to explore how to design a map to achieve the best possible effects for information bearing and transmission. We argue that spatial cognition in the context of geography is the essence of geo-spatial cognition research. However, theory and technology related to spatial cognition research is still very limited in geographic information science, and the patterns currently used mostly follow the mode of map spatial cognition. The development trend is shown in Table 1. For geo-spatial cognition, there is still a need to carry out cross-disciplinary study of psychology, linguistics, philosophy, earth science, computer science and other subjects.

Table 1 Spatial cognition and representation in geographic information science

Class	Representation method	Static ↓ Dynamic
Map	Spatial representation	Static
GIS	Spatial representation + Spatial analysis	↓
VGE	Spatial representation + Spatial analysis + Process simulation	Dynamic

3.2.1 Map spatial cognition and representation

A map is a visual and graphical representation of the Earth surface space and its spatial relationships. During a fairly long period of time, maps have been the main means for people to describe the phenomena and features of the Earth surface, and the map is the most fundamental and common way for representing geographic space. Latitude and longitude lines and map projections are means for the exact expression of the result of map spatial cognition, and the space of the real world is abstracted as map symbols that consist of pure geometric features, such as points, lines and polygons. In the 1970s, Western researchers in cognitive science used maps as a tool for research into cognitive processes, and cognitive processes based maps thus attracted the attention of cartographers and geographers and they began to research map spatial cognition and applied the results of map spatial cognition research to the practice of cartography and mapping. From the point of view that researchers use the maps to access spatial information, understand and memorize the information, and use the information to solve problems and make decisions, map spatial cognition can be divided into four basic processes, i.e., perception process of map space cognition, imaging process, memory process, and thinking process (Wang & Chen, 2001; Zhang *et al*., 2007).

3.2.2 Spatial cognition and presentation in GIS

In traditional cartography, three-dimensional dynamic space in the real world is represented as two-dimensional static images or graphics with plane geometry structures. The development of GIS is an extension of map functions. Cognition in GIS focuses on the locations of geographic features (Where) and the nature of the feature itself (What) (Goodchild *et al*., 1999). From a perspective of GIS design, geo-spatial cognition in traditional GIS is on the basis of map spatial cognition, the main data models still following map-based models in which the real world is mapped as pure geometry features such as points, lines and polygons. In map-based models, although the relationship between feature locations can be described by the topological relationship of the location, a description of semantic relations among geo-spatial entities is lacking, and it is difficult to describe the characteristics of the objective world as a whole. Its limitations are also reflected in the following aspects: the conceptual model of geographic information systems does not define the temporal version and distributed identification of spatial objects, it uses a static single-phase method to organize and manage spatial data, geographic representation is limited to geometric features with static and clear boundaries, and it is difficult to describe dynamically changing processes and their relationships in the geographic environment.

3.2.3 VGE cognition and representation

Virtual Geographic Environment (VGE) is one of the new initiatives of the current development of geographic information technologies. Virtual Geographic Environments aim to describe the true three-dimensional Earth surface space in computer system space and represent the complicated and dynamic geographic processes that are changing over time, thus giving computers the ability to handle the geographic processes that can be perceived and touched by geographic researchers, assist users to access complete and multi-angle information of the studied things through perceiving and understanding the ability of the users, and provide a multi-dimensional virtual platform with which people can naturally interact, that can reproduce the past, predict the future, and repeat experiments. The VGE thus helps people explore the geographic rules; analyze the formation mechanism of geographic processes, solve geographic problems, and carry out planning and decision-making. In the framework of VGE, the research contents of geo-spatial cognition includes not only the locations of geographic features (Where) and the nature of the feature itself (What), but also the development process of how and where the space-time things changed within this framework (How & When) and their relationship with other geographic elements (Why). This framework is similar to the "Integrated spatio-temporal analysis environment" proposed by Peuquet (2009). This so-called "human user in the loop" environment is one where human users are also an integral part and needs to be developed. Therefore, geo-spatial cognition research under the framework of VGE needs to break the schema of traditional map cognition and map-based geographic information system spatial cognition, to reflect the nature of understanding and representation of the geographic environment that owns rich geographic implications and semantic contents. Therefore, the objective of VGE cognition and representation is the geographic environment with geographic implications, which consists of not only static features and phenomena in geographic space, but also dynamic geographic processes and complex human behavior, as well as the relationships between them. VGE needs to explore how human beings transform the conceptual and semantic models of cognition into mathematical or logical models of time and space, integrate the theories and methods of human reasoning and represent these spatio-temporal processes in VGE systems. This approach is therefore the core for implementation and development of a next-generation platform for geographic information representation and processing.

The representational forms of geographic space have appeared as, for example, maps, geographic information systems, to virtual geographic environments. Research into geo-spatial cognition correspondingly advances from map spatial cognition, geographic information systems cognition, to virtual geographic environment cognition. No matter what kind of representational form, on one hand they are the result of human beings carrying out geographic (spatial) cognition research and perceiving and understanding the geographic environment; on the other hand, they are tools for human beings to better understand the geographic environment and to obtain geographic knowledge. Therefore, the geo-spatial cognitive process is not only the thinking process of design and production of maps, GISs, and VGEs, but also the cognitive process of understanding the geographic environment by using these representational forms as tools. In addition, both benefit from each other. For example, analysis of the characteristics of VGE cognition can help in the more effective design of VGE systems and can promote their development, while design and development of VGE systems based on the research in VGE cognition that matches the nature and laws of human being cognition can in turn help users to access geographic knowledge naturally and easily, solve geographic problems and carry out decision-making effectively.

4 VIRTUAL GEOGRAPHIC ENVIRONMENT COGNITION AND REPRESENTATION

A Virtual Geographic Environment integrates geographic quantitative methods, experimental geography science, and information science and technology. It has the characteristics of geo-scientific computing and virtual representation, knowledge exchanging and sharing based on geographic process models, and working patterns of geo-collaboration. It supports representation of geographic phenomena and processes and changing mechanism analysis. It provides a new geography research and geographic knowledge application in interactive ways to carry out geographic study on the complex processes and geographic systems (Lin *et al*., 2009). Therefore, VGE cognition can be understood from two levels: first, perceive and understand the real geographic environment and use the form of VGE to represent it, thus letting humans generate a feeling of “virtual reality” of the real environment; second, study and understand the phenomena and processes that are represented in VGE platforms, and then progress “beyond reality” trend prediction or understanding based on the relevant geographic knowledge. Consequently, the paper discusses issues of VGE cognition and representation from two aspects. First, the characteristics of virtual geographic environment cognition are analyzed in order to help users to better understand the phenomena and processes that are represented in VGE platforms and obtain relevant geographic knowledge; secondly, the characteristics of the virtual geographic environment representation are analyzed and the methods of how to perceive and understand the real geographic environment explored to help abstraction and modeling of the reality and then its representation in VGEs.

4.1 Characteristics of VGE-based cognition

Geographic cognition based on virtual geographic environments can be defined as that with virtual platforms: people understand the geographic environment (natural, social, human environments) in which they survive, including the locations, dependency relationships, changing processes and laws related to various things and phenomena in the environment. Geographic recognition is “a base theory for research on the occurrence, impact, cause and effect, trend analysis of things and phenomena, and an engine for inspiration ideas of image thinking and creative thinking in scientific exploration” (Gao, 2004).

Geographic cognition is a basic function of virtual geographic environments. Cognition is based on one’s perception and experience. Lin *et al*. (2005) argue that compared to geographic linguistic characteristics and functions of VGEs, the abstract representation of the real world in VGE platforms has some more advanced characteristics; for example, multi-modal visual representation with multi-dimension, multi-viewpoint, and multiple details; a variety of natural interaction modalities and geographic collaboration across time, space and scale; and multi-perceived spatial cognitive abilities. VGE can thus support more natural and multi-perceived spatial cognition, abstract representation and analysis-understanding abilities beyond reality. It is an integrated ideographic system that is user-centric, and has the natural communication and representation mode that are closely similar to human beings. In addition, it can be widely used for realistic reproduction of the real physical environment and to provide spatial decision support capabilities. The more attractive application of VGE lies in its ability to simulate those spatial phenomena and geographic processes whose occurrence is difficult or hard to reproduce in the real world, or are difficult for people to perceive directly but only have abstract concepts about those geographic processes, such as visualization of underground structures, simulation of complex spatio-temporal phenomena (such as typhoon evolution, flood, air pollution, etc.), inversion of historical processes, as well as deductions on some future development. With the rapid development and integration of computer technology, communication technology and geo-spatial information technology, VGE platforms lay more stress on interaction, communication, and spread of spatial information and geographic knowledge. Based on VGE platforms, users can obtain knowledge and experience by perception of a sense close to natural mankind and a new form of various ultra-realistic virtual spaces. The characteristics of VGE mainly involve the following:

(1) The nature of intuition and imagery, close-to-the-true perception, interaction, and integration. VGE is an extension of functions of maps and GISs. VGE has not only spatial reading functions of traditional maps and spatial data management, query, calculation, and analysis capabilities of GISs, but also has the feature of process representation and visualization in interactive, immersive, close to the true nature, and augmented reality ways. Therefore, VGEs support the gaining of a more comprehensive geographic understanding through multi-dimensional perception and interaction that is beyond reality and closer to the true nature, immersive perception and experience, and knowledge sharing and interaction.

(2) From the perspective of the development of relationships between producers and users (for cartography map producers and users are almost completely separate), the boundaries for geographic information systems between developers and users are getting more and more fuzzy at present, while creators and users of VGE systems will be gradually developed into a very intimate relationship, and both are actively involved. Thus, the hosts of the two levels of VGE cognition are almost unanimous that they are both providers and practitioners of VGE knowledge. Due to geographic cognition being a complex process that involves the interaction of top-down and bottom-up processes (Wang *et al*., 2005), the unity of producers and users promotes VGE to a more suitable means of representing human cognition.

(3) VGE cognition integrates real practice and virtual practice in geography. Virtual practice based on VGEs can be free from the constraints of time and space, in which the cognition hosts can be absent, and the practice can be repeated, exaggerated and even beyond the reality. Virtual practice raises changes of scientific experiments, production practices and the interactive relationships between them. On the basis of virtual practice, people can extend cognition contents, repeat the experiment or obtain experience and cognition in advance. Applying virtual practice to human cognition processes and integration of virtual knowledge from virtual practice and real knowledge from reality can bring about major changes to the ways that humans understand the real geographic world, reduce the cost of understanding, raise the efficiency of awareness, accelerate the development of geographic cognition, and thus affect significantly human beings understanding in geography.

4.2 Representation based on VGE cognition

Language is a thinking medium of cognition in traditional cognition. However, geographic cognition has a mental image as its thinking base in that the nature of geography research contents determines that geographic cognition needs visual thinking operations (Zhai & Lu, 2008). Geographic cognition is a thinking process that is characterized as a base of mental imagery. Mental image (imagery) is a cognitive schemata that resides in one's memory about the geographic world and geo-spatial characteristics and representation of the cognition results of geographic implications. Visualization of the mental image schemata needs special graphical forms, thus flourishes in the new research field of Geo-Visualization (Geovisualization). For example, MacEachren and Kraak (2001, 2005) described the challenges that the Institute of Geo-Visualization faced, and explored some specific research aspects in this field, e.g., spatial cognition, geospatial data visualization, interactive control on dynamic maps, and geographically working together (Geo-collaboration); Ai (2008) analyzed and presented several representation forms of map visualization that are suitable for characteristics of geographic cognition, among which was the cyber map (Cybermap), being the visualization technology for visual representation of the existence of things, phenomena and processes occurring in cyber/virtual space. Through computer and network technologies, VGE is a visual representation form for virtual geographic space and time, which has the ability to make geographers experience and understand natural and human elements of space-time relations in the computer-generated three-dimensional environment, by using quantitative analysis, numerical simulation and other methods, as well as the interactive collaborative technologies to analyze geographic problems in-depth, visualize the geographic environment, simulate geographic phenomena, reproduce and predict geographic climate change and other related issues, and explore the laws of geography. VGE has features of multi-dimensional dynamic visualization and multi-sensing and geographic synergies interaction and geo-collaboration (Lin *et al*., 2009). We argue that VGE is an ideal form for the representation of the geographic environment that matches the nature of human cognition.

4.2.1 Three levels of VGE representation

At present, representational forms for the concepts and implications of geography (space) are diverse, such as the form of map that has a base of latitude and longitude lines and map projection, the form of GIS that focuses on spatial relations, distance and location representation, and the form of VGE that stresses representation of geographic processes. Consequently, research into geo-spatial cognition also leads to a transition from focusing on representation and analysis of spatial relationships and spatial morphology to geographic process research based on representation of the total relationship between temporal and spatial changes. VGE representation aims to represent the real geographic environment in the form of virtual environments, of which the contents involve the geographic environment from the perspective of geography, including not only static features and phenomena in geographic space, but also dynamic processes and complex human behavior and their relationships. Virtual representation in VGE of the real geographic environment can be divided into three levels (shown in Fig.1): representation of basic geographic structures and other infrastructures, such as static geographic features and phenomena; representation of dynamic geographic processes; and simulation of human behaviors that interact with the relevant geographic environment. The first level can be basically regarded as an extended visualization function that traditional GISs extend from two-dimensions to three-dimensions in geospatial representation and visualization. Abstraction, representation, organization and storage of geographic space information are core contents of GIS data management (Menus *et al*., 2000). In geo-spatial data models, data are used to abstract and formalize the real world for geo-spatial description. In traditional GIS abstraction and cognition of the real world, geographic entities are structured as two-dimensional mathematical geometries, such as points, lines, polygons, and grid cells (grid) using hierarchical data organization methods. However, there is a wide gap between this abstractive representation and simplification of the real geographic world and people's natural perception and understanding of the real world. At present, development of three-dimensional data models and three-dimensional GIS research in the field of geographic information are unfolding; meanwhile, research on three-dimensional modeling methods is one of the foremost areas in the current virtual reality and VGE fields. There are two main modeling methods: one concerns Surface Models that focus on three-dimensional surface representation; and the other involves Voxel models that have the capabilities of representing spatial relations within the objects. A Voxel model can be used to represent the three-dimensional position of any point, which can be given properties, methods, and events that can be the same as in the real natural environment; thus it can be used to represent the relationship between the geographic processes that are commonly studied in geography and the geographic variables, and this helps the conduct of mathematical models based on virtual three-dimensional environments for dynamic process representation.

On the basis of representation of three-dimensional geographic space, VGEs pay more attention to representation, organization and storage of geographic processes and the relationships between them and the related geographic factors. Therefore, research on VGE representation requires not only further research on spatial

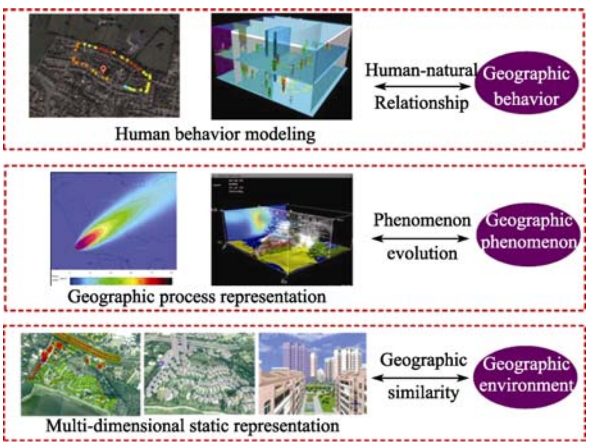

Fig. 1 Three levels of VGE cognition and representation

data models that can effectively carry out the representation of spatial relationships and dynamic access to spatial data, but also research on geographic process management models, in which the system macroeconomic framework, the model organization, and the micro-data structures should be explored for representation, organization and storage of the relationship between geographic variables and geographic factors effectively and capably. Human behavior simulation is a higher level of functionality for a virtual geographical environment. It is a multi-disciplinary cross-cutting research area that combines psychology, cognitive science, artificial intelligence, computer graphics, multi-channel interaction, as well as application areas such as education, military, fire, disaster, and others. Geographic process model management and visualization are important aspects of VGE representation, which integrate and unify effectively multi-disciplinary professional models, such as geographic processes and human behavior models, into a virtual environment. By using VGE, both developers and users can carry out model designing, creation, visual simulation, testing and improvement, as well as conducting real-time control, experience and observation on models. For example, currently VGE integrated applications include fire models and pollution dispersion models; and many applications of human behavior simulation have been used in military training, fire drills and other fields.

4.2.2 Representation of geographic processes and simulation of human behavior

The issues of modeling and spatial data integration are the core of VGE research, which mainly includes representation and simulation of geographic processes and human behavior. Geographic processes refer to the dynamic processes in which geographical things change over time and the associated geographic factors. According to the characteristics of their spatial variation over time, geographic processes can be divided into geographic cycle processes, geographic evolution processes, geographic volatility change processes, and geographic dispersion processes (Li & Yao, 2005). In the Earth surface natural environment, some geographic processes are visible, while others are not. Some common representation forms, including empirical formulae, mathematical models, or descriptions of the probability distributions, are used by earth science researchers to describe and indicate the dynamic evolution process over time and in space of the studied geographic variables or factors. Geographic process models thus contain some basic facts, concepts, principles, laws and other knowledge of the studied spatio-temporal object as well as the relationship with other relevant geographic factors; that is, a geographic process model is the knowledge of some specific geographic process.

Scale is a key concept in geographic process representation. Geographic process representation is highly dependent on the scale, for example, with different scales a geographic mosaic feature has different spatial morphology and functions and the relationship is complicated. Therefore, deduction and conversion of geographic processes with different scales are rather difficult. Research into geographic processes across spatio-temporal scales is a difficult problem in research of spatio-temporal dynamic simulation modeling and analysis of space and time in geography theory and practice. Correspondingly, current awareness and understanding of VGE still mainly focuses on three-dimensional visualization of geographic space, and query and retrieval of geographic data, while research in multi-scale geographic process representation and analysis of dynamic geographic processes has not yet been started. Further development of VGE needs a breakthrough that involves construction, representation, and management of three-dimensional geographic models that aim to describe the spatial distribution and the specificities of geographic processes (Li & Yao, 2005). To achieve the construction and management of a geographic process model library in VGE, establishing conceptual models to describe geographic phenomena and geographic processes is first of all needed; then on the basis of this, the method of logical modeling to deal with the conceptual model should be studied, and the approach to implementation of modeling for storage and management of the geographic process database needs to be established. Visualization of geographic processes can be achieved based on such data architecture.

Human behavior modeling and simulation is a formal description for human thinking, reasoning and other aspects of human behavior. All human behavior is dominated by the activities of thinking; therefore, human behavior simulation needs to simulate human brain thinking for the establishment of flexible and adaptable models of human reasoning and behavior. Due to the inherent diversity and complexity of human beings and the lack of research on human behavior variables and existing theories, it is very difficult to sort out clearly all possible actions that promote human reasoning, complex interactions, and related knowledge. Behavior modeling scientists believe there is still a long way to go before a model that can fully describe human behavior can be established (Boland, 2007). On the other hand, in the long run, the benefits of human behavior simulation are obvious in that it can assist human beings to carry out a variety of production and living activities, harm reduction, cost savings, and improvements in efficiency.

There are many forms of human behavior, such as human behavior in particular geographic environments (e.g., awareness of the involved environment, psychological evaluation of geographic features and phenomena, etc.), the behavior of different human activities (such as shopping, communication activities, etc.), and the behavior relevant to location selection, population migration, the spread of disease, human behavior in traffic, and so on. At present, human behavior simulation is still in its initial stage, and much work remains to be carried out. Currently domestic research involves virtual human walking, sitting, bending, twisting and other physical movement simulation (Qin *et al*., 2002). But this research is limited to simulation of movement of the human body and lacks a study on the most critical activities of human beings: thinking and intellectual activities. More research has been carried out to simulate behavior in a specific environment, such as evacuation behavior simulation of a fire escape (Wen *et al*., 1998), driving behavior simulation of autonomous intelligent virtual humans (Qin *et al*., 2003), simulation study on entity conduction in military exercises (Yang *et al*., 2004), etc. These studies are of very important practical value when referring to specific issues. Behavior simulation in specific environments thus becomes an important aspect in current human behavior simulation research in the VGE field. There are some typical applications that have been developed, such as virtual fire drill, virtual training, and virtual battlefield training. Social interaction simulation is becoming an important area of human behavior research. Currently, the most popular distributed virtual environment applications are 3D online virtual worlds, providing a good simulation platform for humans having a virtual community life and social interaction.

Research of model representation and simulation in VGE needs to be carried out on modeling methods referring to geographic process representation, simulation and analysis. Priority efforts should be given to these aspects: analysis of geographic processes and the behavior, establishment of geographic processes and behavior based representation and simulation models; studies on approaches to spatial-temporal processes that are more consistent with human understanding logics and semantic-driven representation. Rather than the issues of available data formats and structures, we suggest that classification of processes and human behaviors can be conducted first, then organization and processing of geographic data and process knowledge from the three levels of data, information, knowledge to build a corresponding data model, information model and knowledge model and a comprehensive dynamic integrated model framework. For the issue of multi-dimensional visualization and representation, interactions between users and the virtual environment in the visual, auditory, and tactile need to be considered. One of the most important contents in current VGE research is the establishment of an interactive, perceivable multi-dimensional VGE model, which is oriented to geographical process representation and behavior simulation.

5 CONCLUSIONS

VGE is a mapping and virtual representation of the real geographic environment in computer space. VGE aims to reflect the geographic space systems, geographic processes and social systems using a natural way that is amiable to human beings. As a next-generation platform for Earth system research, compared to the past tools of geographic information processing, VGE cognition and representation have new contents and features.

This paper analyzes the differences between the real geographic environment and the geo-spatial concepts of current geo-information technologies. We believe that such differences are barriers to the development of geographic information theory and technology. Virtual geographic environment cognition and representation concepts are proposed and analyzed. The contents of VGE cognition and representation include geographic features and phenomena, geographic processes, human behaviors and the relationship between them in the real world. Characteristics of VGE cognition and representation are analyzed. We argue that VGE represents the real world from three levels: Earth surface features and phenomena, geography processes, and human behaviors. Research into VGE cognition and representation needs to carry out not only development of geo-spatial cognitive theory and methods; at the same time, it needs to expand cognition and representation on dynamic geographic processes and human behavior. Therefore, to develop and realize VGE systems, which is a next-generation platform of geographic information representation and processing, the key issues consist of how to establish conceptive models of cognition of the geographic environment, how to transform the conceptual and semantic cognition models into mathematical and logical models, how to integrate the concepts and methods of spatial-temporal process reasoning and representation into VGE systems, and how to establish interactive, perceivable multi-dimensional VGE models of geographic processes and behavior-oriented expressions that can be an interactive, multi-channel-aware model, which is oriented to geographical process representation and behavior simulation. Currently, related research is still being explored.

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虚拟地理环境认知与表达研究初步

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摘　要： 分析了地理学的地理环境与当前地理信息技术中的地理空间两者概念之间的差异，探讨了地图与地理信息系统空间认知的发展及特点，初步研究了虚拟地理环境认知与表达的对象、特征与主要内容。从基于虚拟地理环境的地理认知和基于地理认知的虚拟地理环境表达两个层面分析了虚拟地理环境的认知与表达；指出虚拟地理环境的认知与表达研究不仅需要进一步发展地理空间认知理论和方法，还需要拓展对地理过程及人类行为的认知与表达理论和方法研究；并着重探讨了地理过程的表达和人类行为的模拟，指出当前虚拟地理环境认知与表达研究的关键内容。

关键词： 地理空间认知，虚拟地理环境认知，地理过程表达，人类行为模拟

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1　引　言

地理信息系统与地理信息科学作为地理数据、信息、知识的计算机处理技术和地理空间计算理论与分析方法，是进行现代地理学科学研究的有力工具。20 世纪 90 年代中期，随着地理信息技术社会化应用的广泛发展以及地理信息科学研究的深入，人们开始关注地理信息系统对于地理空间理解与表达的合理性、地理过程建模与分析的科学性、以及地理信息系统功能与服务的智能性。1995 年美国国家地理信息与分析中心(NCGIA)提出地理空间认知模型研究、地理概念计算方法研究、地理信息与社会研究作为地理信息科学的三大战略领域(NCGIA, 1995)。1996 年美国地理信息科学大学研究会(UCGIS)认为，地理信息技术有效性的一个主要障碍是对认知问题重视程度的不足，并将“地理信息认知”列为十大优先研究主题之一(UCGIS, 1996)。

地理空间认知是地理信息认知研究的基础，它的研究对于地理信息的理解与表达具有决定意义。地理信息认知则是地理信息科学的基础理论之一，它的研究可成为地理信息、知识的计算机处理技术研究与地理学理论分析和方法研究之间的桥梁(鲁学军等, 1998)，是突破地理信息技术发展瓶颈的关键。

近些年来，对于地理空间认知与地理信息表达的研究逐渐展开，如 Peuquet (1988)提出需要建立一个表达地理空间的统一概念框架；Mac Eachren 等(1995, 2001)对空间认知、地图图解模型、空间数据可视化、动态地图交互式控制等多方面进行了论述；鲁学军等(1998, 2005)提出了地理认知理论、空间认知模式；王家耀(2001)、高俊等(2004)；万刚等(2005)从空间认知、心像地图、地图认知学理论等方面对这一领域开展了研究。

地理学研究的地理环境位于地球表层，是大气圈、水圈、生物圈、岩石圈和土壤圈“五大圈层”之

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间交互作用的区域(陈述彭等, 2000)。地理过程是地理环境得以形成与发展的动力，其表现为发生于各大圈层之间的物理、化学、生物和人文“五大过程”以及五大过程之间的相互作用，且集中表现在人地相互作用即“人地关系”上。现代地理学尤为注重地理过程模式阐述与地理系统人地相互作用机制与机理分析。当前，国际上对虚拟环境的研究如火如荼，不仅涉及虚拟环境中的社会、经济和法律方面，更进一步探索虚拟环境在科学研究领域的应用等(First International Conference on Facets of Virtual Environments. http://www.fave-conference.org/)。虚拟地理环境(VGE)研究最初由地理学和地理信息学者提出，旨在通过集成虚拟环境和地理学以研究现实地理环境及赛博空间的现象与规律(龚建华 & 林珲, 2001; 林珲等, 2002, 2003, 2005, 2009)。从地理学研究手段的角度，虚拟地理环境是一个可用于模拟和分析复杂地学过程与现象，支持协同工作、知识共享和群体决策的集成化虚拟地理实验环境与工作空间。虚拟地理环境需要提供对于地理过程时空变化以及人地相互作用机制的表达，包括对地理过程时空模型的表示、组织、管理、可视化以及有关人类行为的表达、管理与知识提取并辅助决策等功能。因此，针对地理过程在虚拟环境中的表示与管理、以及人在虚拟环境中的认知感受及行为模拟开展研究，在虚拟地理环境研究领域既是一个基础理论问题又是一个核心研究方法。

2 地理学的地理环境与当前地理信息技术中地理空间概念之差异

空间是事物的最基本特性。空间随事物的性质、发展和要求的不同而有所变化。胡鹏等(2002)比较了地理学的地理空间、大地测量学的地球空间、地图学的地图空间以及地理信息系统的地理空间的不同，指出地理学的地理空间是以整个地球为着眼点的活动变化着的地球表层系统(地理环境)，其具有普遍意义。

大地测量学采用旋转椭球体数学模型来表达地理学的地理空间，因此，大地测量学的地球空间与地理学的地理空间本质上是统一的，它们是三维空间；传统地图学采用地图投影来实现地图空间的表达，将地球椭球体展平到平面上，其主旨是将地球空间纳入欧氏平面空间，以实现地球信息的可视与度量的二维一体化，因此地图空间是对地理空间的二维近似描述；当前地理信息系统是将大地测量空间经过投影变换后放在笛卡尔坐标系中形成对于地球表层空间的表达，因此，地理信息系统对于地理空间的定义承袭了地图学的空间概念，其本质仍为地图空间。

构成当前地图学与 GIS 的本体论与认识论的基础是应用欧几里得、笛卡儿和实证主义概念来认识地理空间与环境，基本理念是力求把地理世界分成由明确定义的、连续的、不重叠的多边形表达的空间单元 (Pickles, 1995; Sheppard, 1995)。然而，上述的认识基础将很难开展“研究地学信息流程的动力学机理和时空特征” (陈述彭等, 2000)，其对地理学、地球科学发展的束缚日趋明显。与空间性质一样，时间也是所有事物的最基本特性。但是，传统地理信息系统强调对于静态空间对象的表达与分析。虽然在其发展过程中，地理信息的时间特性受到了普遍关注，关于时空数据模型和时态地理信息系统等方面的研究也有所开展，但地理信息系统的空间概念表达在对地理环境中动态变化的地理过程及其与地理要素之间关系的表达方面有着极大的局限性。

地理概念的意义与其他所有概念一样，随经验世界与社会思维模式和综合作用的变化而不断变化(刘妙龙等, 2002)。而地理信息技术的发展对于人类客观(经验)世界及其社会思维方式产生了深远影响。人们应用地理信息技术对地理空间的笛卡尔坐标体系描述导致对地理环境概念表达能力的限制，很多地理概念只能由地理信息系统的研究者、发展商与使用者自行重新定义，以符合其约束条件。在地理信息系统中，复杂的地理空间被简化为一些可以进行严格分类的、简单的几何构形(点、线、面、多边形、网络、有界区域等)，称为地理实体；但是，地理环境的组成部分还包括了复杂多样的运动实体和动态过程，与所谓的确定的、静态的地理实体相比，自然地理环境和人类社会组成的现实世界的分类与意义要广义、复杂得多。其中，地理事物与现象的动态变化过程以及它们之间的相互关系是其复杂性的重要体现。地理信息科学领域的研究组织、研究者与实际工作者们已经开始对为地理信息系统提供基础的认识论原理与地理概念论进行严格的反省与分析 (Sheppard 等, 1999, 刘妙龙等, 2002)。NCGIA 提出对地理概念进行基于社会论和认知论的“地理空间感知模型”的研究，其重要目的就是要探索地理概念、社会概念广义化的表达方式，探索地理概念人文表示与机械表达之间的差异(NCGIA, 1995)。

3　地理信息科学的空间认知与表达

地理信息科学与技术的主要研究面向地理空间信息的采集、描述、表达、存储、管理及运用的理论和方法，其目的是借助计算机来表达、模拟与分析地表空间现象和地理时空过程，承载地理信息、传输地理知识，为人类获取地理知识、解决地理问题及辅助决策服务。因此，地理信息技术应以认知科学为基础，以计算机为工具手段，运用地理思维来模拟、分析、解决地理问题，是地理数据、信息和知识统一的综合性技术平台。

3.1　认知、空间认知、地理空间认知

广义上的认知与认识可视为同一概念，是人脑反映客观事物的特性与联系，并揭示事物对于人的意义与作用的心理活动。认知是一个人对其所生活世界的认识和了解的各个过程的总称，是概念形成、语言描述、问题求解、个性差异等有机联系的信息处理过程(王家耀 & 陈毓芬, 2001)。人类通过对客观世界进行信息获取、存贮、转换、分析和利用，认识、理解和掌握客观事物的本质特征与规律，并形成概念世界来描述和表达客观世界。空间认知是人们认识在生存环境中诸事物、现象的形态与分布、相互位置、依存关系以及变化和趋势的能力和过程(高俊, 2004)。地理空间认知是人类对地理空间现象或地理空间实体的感知、表象、记忆和思维过程的编码、内部表达和解码，逐步理解地理空间，进行地理分析与决策等一系列心理过程(Lloyd, 1997)。

因此，地理空间认知关注人们可以活动于其中的地理空间，如地理空间参照、地理概念、关系、不确定性、以及与认知相关的地理空间知识和人类行为表达等主题。地理空间认知的对象不是单纯的室内空间、桌面空间或者抽象的欧氏空间，而是具有丰富地理概念和语义的地理环境。地理空间认知是心理学、生理学、语言学、哲学、计算机科学等多学科与地理学、地球科学相结合的一个重要的交叉研究领域，是研究人们怎样通过获取、处理、存储、传递和解译地理空间信息来认识自己赖以生存的环境，包括其中诸事物、现象的相关位置、空间分布、依存关系，以及它们的变化过程和发展规律。

3.2　地理空间认知与表达的发展

地理空间认知是认知科学理论在地理学、地图学及地理信息学中的应用。地理学研究空间认知是探索人的地理概念形成的机制，怎样从具体的地理实在转化为地理概念。地图学研究空间认知是寻求地图作为空间认知的工具的特点，从而探讨如何设计地图才能达到最佳的信息承载与传输的效果。可以说，地理学意义上的空间认知是地理空间认知研究的本质所在。然而，在地理信息科学中有关空间认知理论与技术的研究还很有限，目前大多沿袭地图空间认知的模式，其发展态势见表1，同时仍有待于心理学、语言学、哲学、地球科学和计算机科学等多学科的交叉研究。

表 1　地理信息科学的空间认知表达

分类	表达方式	静态
地图	空间表达	↓
GIS	空间表达+空间分析	↓
VGE	空间表达+空间分析+空间模拟	动态

3.2.1　地图空间认知与表达

地图是地表空间及空间关系形成的视觉图解表象。地图在相当长的时期内是人们描绘地表地物和现象的主要手段，是表达地理空间的一种最基本最普通的方式。从地图制图学的角度，经纬线和地图投影是地图空间认知的精确表达，并将现实世界空间抽象为点、线和面等纯几何特征的地图符号。20 世纪 70 年代，西方认知科学的研究者把地图作为研究认知过程的工具，基于地图的认知过程引起地图学家和地理学家的注意，开始了地图空间认知研究，并把地图空间认知研究的成果应用于地图制图实践。从地理研究者使用地图获取空间信息、对信息的认识和记忆、利用信息发现问题、进行决策的角度，地图空间认知可分为 4 个基本的过程: 地图空间认知的感知过程、表象过程、记忆过程和思维过程(王家耀 & 陈毓芬, 2001; 张本昀等, 2007)。

3.2.2　地理信息系统空间认知与表达

传统地图将三维立体的、动态的现实空间表现成二维的、静态的平面的图形图像或者几何图形结构。地理信息系统在地图功能的基础上延伸发展，地理信息系统认知着重研究地理事物在地理空间中的位置(Where)和地理事物本身的性质(What)(Goodchild 等, 1999)。从地理信息系统设计的角度，传统地理信息系统的地理空间认知是基于地图的空间认知，其主要的数据模型仍沿用地图将现实世界抽象为点、线和面等纯几何特征，实际上仍是一种基于地图的模型。虽然地物之间的位置关系可以用拓扑关系来描述，但对地理空间实体语义关系的描述缺乏，难以满足描述客观世界的整体特征要求。其局限性还体现在地理信息系统的概念模型没有时态版本定义和分布式对象标识定义、采用静态单时相来

组织与管理空间数据等，普遍意义上的地理环境表达受限于静态的边界明确的几何图形，对其中动态地理过程及其变化关系的描述则难以胜任。

3.2.3 虚拟地理环境认知与表达

虚拟地理环境是当前地理信息技术发展的新方向之一。虚拟地理环境的目标是在计算机空间描述真三维地球表层系统空间、表达纷繁复杂而动态变化的地理过程，使得计算机能够处理地理研究主体所能感受到的、在思维过程中接触到的地理过程，依靠使用者的感知和认知能力全方位、多角度地获取研究对象的信息，为地理学研究提供一个可重现过去、预测未来、重复实验的多维的、可自然交互的虚拟平台，从而帮助人们探寻地理规律、分析形成机理、解决地理问题、开展规划与决策等。在虚拟地理环境框架下，地理空间认知的研究内容不仅包括地理事物在地理空间中的位置(Where)和地理事物本身的性质(What)，还包括事物在空间时间框架下的发展过程(How & When)及其与其他地理要素之间的相互关系(Why)。这个框架与 Peuquet(2009)提出需要发展的“空间-时间集成分析环境”类似，而人类用户亦是这一环境的组成部分，即“人类用户在回路中”的环境。因此，虚拟地理环境框架下的地理空间认知研究需要突破传统的地图认知和基于地图的地理信息系统空间认知，力图体现地理学对富含地理概念和语义的地理环境的认知与表达本质。因此，虚拟地理环境以地理学意义上的地理环境为认知的对象，既包括地理空间中静态的地物和现象，还包括动态的地理过程与复杂的人类行为及其之间关系。虚拟地理环境表达需要探索如何将人类对于地理环境概念的认知模型和语义模型转化为数学或逻辑模型，将人类对于时间空间过程推理和表达的概念和方法融合在虚拟地理环境系统中，这也是实现和发展地理信息表达与处理新一代平台的关键。

对地理空间的表达形式经历了从地图、地理信息系统到虚拟地理环境的发展，地理空间认知研究也由地图空间认知、地理信息系统认知，发展到虚拟地理环境认知。不论是何种表达形式，其自身既是人类开展地理(空间)认知研究、认识与理解地理环境的结果，同时又是人类进一步认识地理环境与获取地理知识的工具。因此，地理空间认知过程既是设计与制作地图/地理信息系统/虚拟地理环境的思维过程，又是使用这些表达方式、把它们作为认识地理环境的工具的认知过程，且二者的研究是相辅相成的。例如，分析基于虚拟地理环境的地理认知特点有助于设计更有效的虚拟地理环境系统，促进其改进和发展，从而充分体现地理学家的逻辑思维及人类的地理感知方式；而开展符合人类认知特点和规律的地理认知研究，基于此基础上设计开发的虚拟地理环境平台，反过来，也更有效地帮助使用者更自然方便地获取地理知识、求解地理问题和支持决策。

4 虚拟地理环境认知与表达

虚拟地理环境融合地理数量方法、地理实验科学和信息科学技术，具有地学科学计算和虚拟表达特征，采用地理模型的知识交流与共享以及地理协同的工作模式，支持对地理现象和过程的发展规律表达和变化机理分析，以全新的地理研究和地理知识应用与互动模式来开展对地理复杂系统的过程研究(林珲等，2009)。因此，虚拟地理环境的地理认知可从两个层面来理解：一是认知和理解现实地理环境并以虚拟地理环境的形式表现之，使得认知主体能够产生“身临其境”之感受；二是借助虚拟地理环境这个载体来认识和理解其所表示的地理现象和过程，甚至对相关地理知识能够获得“超越现实”的推断或趋势预测理解。与之相应地，本文从两个方面对虚拟地理环境的认知与表达问题进行讨论：一是分析基于虚拟地理环境的认知特点，以帮助人们理解其所表示的地理现象和过程，获取相关地理知识；二是分析虚拟地理环境的表达特点，探讨如何认知和理解现实地理环境，以帮助对其进行抽象、建模、表示成虚拟地理环境。

4.1 基于虚拟地理环境的地理认知特点

基于虚拟地理环境的地理认知就是人们借助虚拟地理环境平台认识自己赖以生存的地理（自然的、社会人文的）环境，包括其中诸事物、现象的相关位置、依存关系以及它们的变化过程和规律。地理认知是“对事物和现象的发生、影响、因果、趋势进行分析研究的基础，是在科学探索中启发形象思维、激发创造性思维的引擎”(高俊, 2004)。

地理认知是虚拟地理环境的基本功能。认知的基础是感觉和体验。林珲等(2005)指出，与传统地图和地理信息系统的地理学语言特点与功能相比较，虚拟地理环境对现实世界的抽象表达具有多维、多视点和多重细节的多模态可视表现、多种自然交互方式和跨时间、空间与尺度的地理协同以及多感知的空间认知能力等特征，能够提供更接近自然的多

感知的空间认知和超越现实的抽象表示与解析理解能力的支持，是一种以用户为中心的、最接近人类自然的交流方式与表达形式的综合表意系统；可被广泛应用于逼真再现真实地理环境并提供辅助空间决策功能，其更具有魅力的应用是模拟那些在真实世界里难以发生或者难以重现的、以及人们只有抽象概念而难以直接感知的空间现象和地理过程，如地下结构的可视化、复杂时空现象(如台风演进、洪水淹没、大气污染等)的仿真、历史过程的反演以及未来发展的推演。随着计算机技术、通信技术与地理空间信息技术的迅速发展并互相交融，虚拟地理环境新平台更突出空间信息与地理知识的传播、交互与交流。基于虚拟地理环境认知新平台，人们通过接近于人类已有的自然感知的形式和各种超现实的虚拟空间感知新形式而获得知识和经验，其特点主要表现在:

(1) 直观形象性、接近真实自然的感知与交互性和集成性。虚拟地理环境是地图和地理信息系统功能的延伸，既具有传统地图的空间阅读和地理信息系统的空间数据管理、查询、量算与分析功能，又具有交互式、沉浸式的接近自然和增强现实的地理过程表达与可视化特征。因此，虚拟地理环境支持超越现实而又接近自然的多维感知与交互方式的、身临其境的感觉体验、知识共享和交流互动来获得更为全面的地理认知。

(2) 从制作者和使用者的关系发展来看，地图制图者与地图使用者几乎是截然分开的，地理信息系统的开发者和使用者之间界限呈现模糊化，而虚拟地理环境的制作者和使用者则逐渐发展为不分彼此的关系，且二者主动参与其中。因此，虚拟地理环境两个层面上的认知主体几乎是一致的，即他们既是虚拟地理环境知识的提供者又是实践者。由于地理认知过程是自上而下和自下而上共同作用的复合加工过程(王晓明等，2005)，制作者与使用者的统一使得虚拟地理环境成为一种更适合于人类认知的表达方式。

(3) 虚拟地理环境认知可融合现实地理实践和虚拟地理实践。虚拟地理环境中的虚拟实践可不受时间和空间的制约，可以是不在场的、可重复的、夸张的甚至是超前的。虚拟实践引起人们科学实验、生产实践及相互交往关系的改变，在虚拟实践的基础上可扩展认知对象、进行重复实验或获得超前体验和认知等。虚拟实践运用到人类认识过程中，虚拟认识与现实实践产生的现实认识相融合，将使人们认识地理世界的方式发生重大变革，可减少认识代价，提高认识效率，加速地理认识的发展，从而对人类地理认识产生重大的影响。

4.2　基于地理认知的虚拟地理环境表达

传统认知以语言为认知的思维媒介，而地理研究对象的特点决定了其认知需要视觉思维的操作，要以心理意象作为思维的基础(翟有龙 & 鲁廷辉，2008)。地理认知是以心理意象为表征基础的思维过程。心理意象(心象)是驻留在内在记忆中的关于地理世界空间特征和地理概念认知结果表达的图式。心象图式的可视化需要由特殊的图形形式来承担，由此也使得地学可视化(Geovisualization)这一新的研究领域的蓬勃发展。例如，MacEachren & Kraak (2001，2005) 阐述了地学可视化研究所面临的挑战，针对空间认知、地理空间数据可视化、动态地图的交互式控制和地理协同工作(Geocollaboration)等方面做了诸多探索研究；艾廷华(2008)分析并提出了几种适宜地理认知特征的地图可视化表达形式，其中，赛伯地图(Cybermap)是对赛伯/虚拟空间里存在的事物、发生的现象与过程进行可视化表达的技术。而虚拟地理环境是一种虚拟表达地理时空的形式，是能够让地理学家在计算机产生的三维空间环境中，感受和认识自然与人文要素的时空关系，利用包括定量分析、数值模拟等方法以及交互协同技术对地理问题进行深入分析，对地理环境进行可视化表达，对地理现象进行模拟、对地理环境变化进行再现和预测，探索地理规律的计算机及网络空间的虚拟环境系统。虚拟地理环境具有多维动态可视化表达、多感知交互和地理协同特征(林珲等，2009)，是符合人类认知特点的表达地理环境的理想形式。

4.2.1　虚拟地理环境表达的 3 个层次

当前，地理(空间)概念与意义的表达形式呈多元化发展，如以经纬线和地图投影为基础的地图，注重空间关系、距离和区位表达的地理信息系统，和强调地理过程表达的虚拟地理环境。地理空间认知也从注重空间格局、形态的空间关系表达与分析，过渡到从时空整体变化关系表达出发对地理过程的研究。虚拟地理环境表达旨在以虚拟环境的方式表现现实地理环境，其对象为地理学意义上的地理环境，既包括地理空间中静态的地物和现象，还包括动态的地理过程与复杂的人类行为及其之间关系。虚拟地理环境对现实地理环境的虚拟表达可分为 3 个层次(图 1)：静态地物与地理现象等基础地理结构的表现；动态地理过程的表达；以及与相关地理环境交互的人类行为的模拟。第一个层次的功能基本

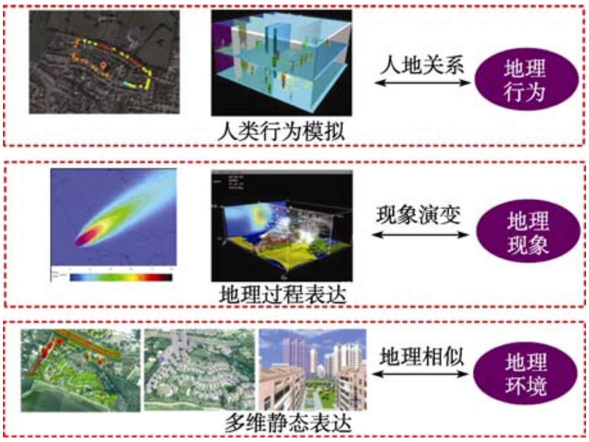

图 1 虚拟地理环境认知表达的 3 个层次

上可以看作是传统二维地理信息系统对地理空间表达的三维可视化发展。对地理空间的抽象、表达、组织和存储是地理信息系统数据管理的核心内容之一(Menus 等, 2000)。地理空间数据模型是用数据对现实世界地理空间进行抽象表达和形式化描述。传统地理信息系统通过对现实世界的地理现象的认知和抽象，把地理实体结构化为数学上二维的点、线、面以及栅格单元(格网)，采用分层的数据组织方法。但是，这种对真实地理空间的简化、抽象的表达同人们对现实地理世界的自然感知与认识之间有着很大的差距。目前地理信息领域对三维空间数据模型和三维地理信息系统的研究发展方兴未艾，三维空间模型建模方法研究也是虚拟现实和虚拟地理环境领域当前研究的热点。注重表达三维空间体表面的面元模型和能够表达空间体内部特征与关系的体元模型是两种主要的建模方法。体元表达模型可对三维空间中的任意点位置赋予与其在自然环境中相同的属性、方法和事件，可用来表达地理学研究的地理过程与地理变量之间的关系，有利于构建基于数理模型的动态过程的虚拟三维环境。

在对三维地理空间的表达基础上，虚拟地理环境更注重对地理过程及与其相关的地理要素之间关系的表达、组织和存储，因此，虚拟地理环境表达研究不仅需要进一步研究能够有效进行空间关系表达和空间数据动态存取的空间数据模型，还需要研究能够有效表达、组织和存储地理变量和地理要素的时空变化关系的地理过程管理模型，探索其宏观框架体系、模型组织和微观数据结构。人类行为模拟是虚拟地理环境更高层次的功能，是一个需要结合心理学、认知科学、人工智能、计算机图形学、多通道交互等，以及应用领域如教育、消防、灾害等多学科交叉的研究领域。模型管理和可视化表达是虚拟地理环境表达的重要方面，它将表示地理过程和人类行为的多学科专业模型高效集成并统一到虚拟环境中，在此既进行模型设计、创建、可视模拟、检验和改进，又可让用户实时控制、体验和观察模型的行为。例如目前实现集成到虚拟地理环境中的应用模型有火灾模型、污染扩散模型等；人类行为模拟已有很多应用于军事训练、消防演练等领域。

4.2.2 地理过程表达与人类行为模拟

模型表达及其与空间数据的融合是虚拟地理环境研究的核心，主要包括地理过程与人类行为的表达和模拟。地理过程是指地理事物随时间的推移和相关地理要素的变化而出现的动态变化过程。根据其在时间空间上变化特征的不同，主要可分为地理循环过程、地理演变过程、地理波动性变化过程和地理扩散过程(李爽 & 姚静, 2005)。在地球表层空间的自然环境中，有些地理过程是可见的，有些则是不可见的。地学研究者通常采用包括经验公式、确定的数理模型或不确定的概率分布描述等表达形式来表示所研究的地理变量/要素在时间空间上的动态演化过程，因此地理过程模型包含了该研究对象在时间空间以及与其他相关地理要素之间关系的一些基本的事实、概念、原理、规律等的知识，即地理过程的知识。

尺度是地理过程表达中的关键概念。地理过程对尺度有高度的依赖性，不同尺度下地理镶嵌体的空间格局与功能不同、关系复杂，地理过程在不同尺度之间的推演和转换存在着诸多困难。因此，对跨时空尺度的地理过程的研究是地理学有关时空建模与时空动态模拟分析理论和实践的难题。与之相应地，当前人们对虚拟地理环境的认识和理解还主要是对地理空间的三维可视化表达及地理数据的查询检索，而对多尺度的地理过程表达及动态地理过程分析方面的研究还未能真正开展。虚拟地理环境的进一步发展需要突破，以描述地理过程为目的、针对地理要素空间分布与地理过程的特殊性的三维地学模型的构建、表示与管理(李爽 & 姚静, 2005)。要实现虚拟地理环境对地理过程模型库的构建和管理，首先需要建立描述地理现象和地理过程的概念模型，在此基础上研究建立表示和处理概念模型的逻辑模型的方法，和地理过程库存储、管理的实现模型，并实现地理过程的可视化表达。

人类行为建模与模拟是针对人类思维推理和人类行为等方面进行的一种形式上的描述。人类所有的行为都依靠思维活动予以支配，因此，模拟人类行为需要对人的大脑思维进行模拟，建立能够表现

人类推理和行为的具有灵活性和适应性的模型。由于人类固有的多样性和复杂性，人类行为的因果变量以及理论缺乏，要将所有促使人类推理和可能行为的那些复杂的交互作用和知识都梳理清楚是非常困难的。行为模拟科学家认为，距离建立一个能够全面描述人类行为的模型还有很长一段路要走(Boland, 2007)。另一方面，长远来看，人类行为模拟研究可辅助人类开展各种生产生活活动，减少危害、节约成本、提高效能，其好处是显而易见的。

人类行为有多种形式，如特定地理环境中的人类行为(涉及如对环境的认知，地物和现象的心理评价等)、不同人类活动的行为(如购物，交际活动等)、与区位选择有关的人类行为、人口迁移、疾病传播、交通疏导中的人类行为，等等。目前，人类行为模拟研究还处于起步阶段，大量工作有待于进一步开展。目前国内的研究方面有关于虚拟人行走、坐立、弯腰、转体等肢体动作的仿真模拟(秦双等，2002)，但这种仿真方式仅限于对人体动作的模拟，缺乏对人类最重要的思维及智能活动的研究；也有较多研究针对人在特定环境下的行为进行模拟，如火灾情况下的避难逃生行为模拟(温丽敏等, 1998)、自主虚拟人智能驾驶行为仿真(秦双等, 2003)、军事演习中实体的行为模拟研究(杨瑞平等，2004)等，这些研究对一些特定的课题有十分重要的实用价值，也是当前虚拟地理环境人类行为模拟研究的重要方面，其典型应用如虚拟消防演练、虚拟培训、虚拟战场训练等。社会交互模拟也正在成为人类行为模拟中的一个热门研究领域。当前最为盛行的分布式虚拟环境应用——三维网络虚拟世界为虚拟社区生活和社会交往提供了良好的模拟平台。

虚拟地理环境的模型表达与模拟研究，需要开展面向地理过程表达与模拟分析的建模方法研究，应该优先考虑地学现象的行为和基于过程的分析，建立面向地理过程和行为表达的虚拟环境表达模型，建立更符合认知逻辑的、语义驱动的时空过程表达方法，而不是优先考虑可用的数据格式与结构。可针对地理过程和人类行为进行分类，从数据、信息、知识 3 个层次组织和处理地理数据和过程知识，建立相应的数据模型、信息模型和知识模型及动态综合的集成模型框架。在模型的多维可视化表达方面，需要考虑用户与虚拟环境在视觉、听觉、触觉等的交互关系。建立面向地理过程和行为表达的可交互、可感知的多通道虚拟地理环境模型是现阶段最主要的研究内容之一。

5 结　论

虚拟地理环境是现实地理环境在计算机空间中的映射与虚拟表达，其目标是以接近人类自然的方式反映现实地理环境所包含的地理空间系统、地理过程及社会系统。作为地球系统研究的新一代平台，相比以往地理信息处理工具，虚拟地理环境认知与表达具有新的内容和特征。

本文分析了地理环境与当前地理信息技术处理的地理空间概念之间的不同，认为这种差异是地理信息理论与技术发展的一个障碍，提出虚拟地理环境认知与表达的概念，虚拟地理环境的地理认知对象是现实世界中的地物和现象、地理学过程、人类行为以及它们之间的相互关系。分析了基于虚拟地理环境的认知及虚拟地理环境的表达特点，指出虚拟地理环境从现实世界中的地物和现象、地理学过程、人类行为 3 个层次表达现实世界。虚拟地理环境认知与表达研究在发展地理空间认知理论和方法研究的同时，需要拓展对动态地理过程及人类行为的认知和表达。因此，如何将人类对于地理环境概念的认知模型和语义模型转化为数学或逻辑模型，将人类对于时空过程推理和表达的概念和方法融合在虚拟地理环境系统中，建立面向地理过程和行为表达的可交互、可感知的多通道虚拟地理环境模型，是实现和发展地理信息表达与处理新一代平台——虚拟地理环境的关键。当前，相关研究仍处于探索之中。

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