Virtual Geographic Environments

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[5377].

Abstract

The geographic environment in which we live is a comprehensive and dynamic system. Geo-featured processes and phenomena are very complex and challenge the usability of traditional geographic analysis and experimental tools. Virtual worlds have potential for scientific research in many fields. Virtual Geographic Environments (VGEs), which are characterized by their support for geographic simulation (geo-simulation), geographic interaction (geo-interaction), and geographic collaboration (geo-collaboration), play an important role in geographic research. The evolution of VGEs is reviewed according to the various stages of their development, and the framework and components are introduced. The contributions of VGEs that have been and are expected to be achieved are illustrated based on former discussions of geographic questions, geographic knowledge, and the future tendency of geographic research. Future studies that may develop and promote a more practical VGE are suggested.

Main Text

1. Introduction

After Michael Batty first used the term ‘virtual geography’ in 1997 (Batty 1997), the term ‘Virtual Geographic Environments’ (VGEs) was formally proposed by Lin and Gong as a concrete study object of the discipline of virtual geography (Lin and Gong, 2001). The term VGEs stems from two other well-known terms: geographic environment and virtual environment. A geographic environment refers to the portion of Earth’s surface on which creatures (especially human beings) live. It consists of natural (e.g., water, air, and soil) and social (e.g., human behavior) factors related to this geographic space, and it is continuously changing as a dynamical system. The virtual environment, which is also called a virtual world, digital world, or electronic environment, is widely used to describe these virtual spaces that are built based on visualization and virtual reality (VR) technologies; recently, many of these spaces have been developed through the Internet. Users can participate or become immersed in these virtual environments by ‘feeling’ and ‘exploring’ spaces that do not exist in real life or that cannot be reached at the local time and location. Although many types of virtual environments are rooted in game playing, they have potential usefulness for scientific research (Bainbridge 2007). Many applications have been appeared in various fields, such as house design, urban planning, and social network analysis.

Combined with the two terms above, a VGE can be regarded as a typical virtual-based geographic environment that allows users to ‘feel the geographic scenarios in person’ and ‘know the geographic laws beyond reality’ (Lin et al. 2013b).

In this context, over the past decade, more researchers began to consider the study of this new branch of Geographic Information Science (GIScience) from a theoretical perspective or technical perspective (Lin et al. 2013a, Lin et al. 2013b). Although the main concept remains the same, the development process indicates that VGEs have experienced a gradual evolution in terms of their content and functions. Overall, three primary stages are apparent.

(1) The period from 1998 to 2002 can be regarded as the embryonic period of VGEs. Before being formally proposed, the term of VGEs was coined at a conference and later appeared in related processing articles (e.g., Gong and Lin 1998). However, no clear definition was given at the time. After three years of consideration, the term was formally presented in Lin and Gong’s article called ‘Exploring Virtual Geographic Environments’ (2001). They described VGEs as ‘environments pertaining to the relationship between post-humans and 3-D virtual worlds’. Five types of space (i.e. internet space, data space, 3D geographic space, personal perceptual and cognitive space, and social space) are defined to characterize VGEs. The authors also mentioned the ‘georeferenced virtual environment’ to ‘allow distributed users to congregate virtually on the Web and interact with 3-D graphical worlds to explore the Earth’s geographic phenomena and processes in an immersive or semi-immersive way’. In their opinion at that time, a ‘georeferenced virtual environment’ was a component of VGEs. Although their idea of VGEs was slightly clearer than the former concept, it appears that the meaning was so broad that it was difficult to understand the main purpose of providing such a VGE. A gap still existed between VGEs and geography. In contrast, the definition of ‘georeferenced virtual environment’ suggests that it has a use for the exploration of geographic phenomena and processes on Earth. It is easy to understand and appears to focus on solving geographic problems.

(2) The following 6 years (until the year 2008) are regarded as a continuous exploration stage. During those years, to detect the relationship between VGEs and geography, scholars interpreted VGEs from the perspective of geographic language, which is a basic tool to represent geo-spatial information that is related to both the physical and social aspects of an environment. In term of this, considering multi-dimension expression and multi-channel interaction as typical characteristics, VGEs were regarded as the result of the evolution from verbal language through

text, maps, and Geographic Information Systems (GISyetems). This evolution is a continual improvement of spatial information communication (Lin and Zhu 2006). Accordingly, studies on VGEs then focused on how to provide a virtual environment that corresponds to the real world to allow users to better understand through a visual or immersive experience. In this stage, a VGE is similar to the previous 'georeferenced virtual environment'. Although the objective of VGEs was narrowed, its contribution to geographic problem solving emerged. This concept is more practical for today's development of VGEs.

(3) The most recent five years (2009-2013) are regarded as the explosive stage of VGEs, as an increasing number of scholars conduct research on VGEs in this period. For example, Goodchild (2009) proposed that volunteered geographic information (VGI) could be an important data collection mode for the development of a VGE, Mekni (2010) discussed the use of agents to simulate human behavior in VGEs, Priestnall (2012) highlighted that VGEs can be employed for school education and geographic learning, and Konecny (2011) summarized the challenges in the study areas of VGEs. Although the different perceptions were linked to various research approaches and achievements, these five years clearly clarified and concentrated the conception of VGEs. To provide a summary of the previous research over nearly one decade, Lin et al. (2013a, 2013b) re-described their proposed VGEs as a new generation of geographic analysis and computer-aided geographic experiment tools. VGEs are 'a type of typical web- and computer-based geographic environment' built 'by merging geographic knowledge, computer technology, virtual reality technology, network technology, and geographic information technology', and 'with the objective of providing open, digital windows into geographic environments in the physical world, to allow users to 'feel it in person' by a means for augmenting the senses and to 'know it beyond reality' through geographic phenomena simulation and collaborative geographic experiments'. Thus, a VGE will 'contribute to human understanding of the geographic world and assist in solving geographic problems at a deeper level' (Lin et al. 2013b). Compared with the ideas in the former two stages, the latest definition of a VGE has a closer relationship to geography. The construction of a VGE is currently targeted to geographic understanding and problem solving through not only geo-visualization and human immersion but also geo-simulation and geo-collaboration. To some extent, this definition has provided an answer to one of the 'big questions' proposed by Cutter et al. (2002), namely, 'what role will virtual systems play in learning about the world?' The definition also coincides with

three of Goodchild's five future points about GIScience: multi-dimensional visualization, dynamic phenomenon simulation, and public participation (Goodchild 2010, Lin et al. 2013).

2. Structure and components of VGEs

To achieve a better understanding of real geographic environments through VGEs, the features of real geographic environments should be addressed. Three keys characteristics are noteworthy: (1) a geographic environment is a comprehensive system consisting of natural factors (e.g., soil and water), social factors (e.g., human), and their interactions; (2) it is a dynamic system because geographic processes change over time; and (3) in this environment, there are generally two types of geographic objects, discrete objects with boundaries (e.g., a tree or building) or continuous fields without boundaries (e.g., the air). These characteristics require substantial detailed functions of VGEs. Thus, to date, a VGE must support (1) geo-visualization and human immersion to assist in acquiring a visual image and to foster participation, (2) geo-simulation for reproducing and predicting dynamic geographic processes, and (3) geo-collaboration of experts from various fields to conduct comprehensive geographic analyses and experiments through the Internet.

The current structure of a complete VGE is shown in Figure 1 (modified from Lin et al. 2013b). The foundational technologies are computer technology, VR technology, network technology, and geographic information technology. However, the most important basis is the thorough consideration of geographic knowledge during the building and implementation processes. For example, in some game-like virtual environments, a man can fly everywhere at any instant, which is not possible according to common geographic knowledge in the real world. A VGE is built to solve geographic problems so that these common laws should be integrated in as restraints. Based on these foundational technologies and factors, four components (i.e., the data component, modeling and simulation component, interactive component, and collaborative component) and two cores (i.e., a geo-database and a geographic process model base) should be equipped within a complete VGE. Finally the virtual geographic scenarios are built for the public immersion and providing their spatial knowledge and for the researchers conducting collaborative geographic experiments.

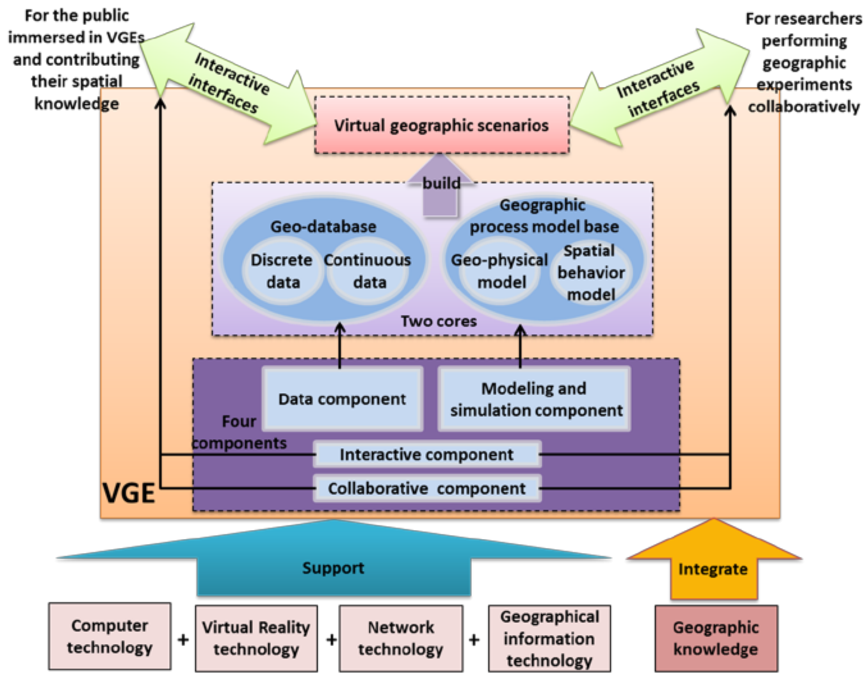

Figure 1. Current structure of a complete VGE (modified from Lin et al. 2013b)

The functions of the four components have been discussed in detail by Lu (2011) and Lin (2013a). A short summary is provided below.

Geographic data (geo-data) are the basic resource for geographical scene expression and geographic problem analysis. The collection, management, and usage strategies of geo-data are always key components of geographic analysis tools. In a VGE, the data component is designed to take responsibility for the geo-data management and organization. Today, with the rapid development of photogrammetry and remote-sensing technologies, mass geo-data from the sky to the underground can be acquired by different professional methods with various tools. At present, more timely social data (e.g., behavior choice) can be provided by the public due to the wide distribution of sensors and the wider availability of natural data (e.g., the temperature and air quality of a location). Although sometimes the accuracy and precision of this type of data are still worthy of discussion, there is no doubt that the data will contribute to the construction of VGEs (Goodchild 2009). Facing mass multi-source and heterogeneous (e.g., differences in data structure, semantic, scale, or coordinate system) geo-data originating from the real geographic environment directly or indirectly, 'setting these data back' into the computer via data integration to form a virtual environment for representation, simulation, and prediction is a significant challenge. Many types of geo-data models in traditional GISystems were designed for visualization (2D/3D) and spatial analysis; thus, a gap still exists between traditional geo-data models and efficient geo-simulation (Lu 2011). If these issues are solved, then the functional geo-database, which is a core base of the VGEs, can be developed and fully utilized as a foundational support to other functions.

The current research priorities of GIScience are changing from static snapshots to dynamic complex processes (Goodchild 2010). A static scenario is easily described, but it is powerless for trend predictions. Geographic modeling and simulation are important for gaining a better understanding of these geographic processes. Studies in this field have produced various geographic process models; many of them have been used for hazard analysis, weather forecasting, and flood warnings. However, except for the developer and owner, other researchers typically have difficulties in understanding and reusing these models, which causes a problem of ‘model islands’. Thus, a type of model reuse mode should be promoted. In daily life, one may need to buy the model resources or related software and deploy them on a server, even for small experiments. This process is costly and inefficient. If these models can be packaged and shared in the network and provided by a unified architecture, then the fee can simply depend on the times that the model users request. Under the precondition that the safety of both the data and model are strictly protected, this approach will not only benefit the model users but also allow the model owners to promote and test their models. The modeling and simulation component in a VGE arms to help the researchers share and reuse the existing model resources in a VGE conveniently without focusing on the configuration of the network and hardware. Thus, it can be regarded a bridge between the geographic process model and distributed model users. Technological problems related to this aspect are under consideration (e.g., Wen et al. 2012), and another core (i.e., the geographic process model base) will be construed based on this component. Thus, in a VGE, one may rent and implement a single model through the Internet after it is packaged and integrated into the geographic process model base, regardless of the user’s budget or technological knowledge of the computer configuration. Combined with the functions that are provided by the data component and interactive component, a VGE can provide the simulation result and corresponding visual or sensible ‘real’ geographic processes that are calculated by the process models. Moreover, due to the complexity and comprehensiveness of the geographic environment, scientific geo-simulation urgently needs the collaborative efforts of multidisciplinary models (e.g., rainfall model, soil erosion model, and evaporation and diffusion model). These models must be coupled in a systematic workspace. According to Lin (2013a), the modeling and simulation component will also provide multidisciplinary researchers an opportunity to create a conception model based on the complex geographic processes in a VGE. Then, different unit models can be linked to conduct a comprehensive simulation to explore a cross-cutting geographic problem. The results can be examined by intuitive feeling and common understanding.

The interactive component of a VGE reflects the design of the tools that support multi-channel geo-interaction. This component is the bridge between the users and virtual scenarios. For the users, interaction can be divided into perception (through vision, hearing, touch, smell, and taste) and manipulation (through a mouse, gesture, or voice). Related research on human-machine interaction (HMI) is increasing in various areas, such as VR and artificial intelligence. Those achievements have been fully referenced in the development process of a VGE. However, specific challenges remains to realizing geo-interactions in a VGE in order to achieve a 'natural' feel and comfortable manipulation. For example, a lake may release different smells when it is polluted by different sources or under different levels. When such a lake is rebuilt in the virtual environment, for an immersed avatar, the various smells may need to be provided to warn the user of the pollution conditions. Another example, a mouse can be used to rotate or zoom in (out) in traditional GISystems. In the VGE, beyond this mode, if the user wants to control his immersed avatar by voice, it is necessary to translate the verbal commands (e.g., turn left, toward the south) into manipulative commands. Moreover, the costs of the related interaction tools must be reduced if more participants are expected to be involved in the geographic exploration tasks using VGEs.

Collaborative work is common in today's scientific research. Geo-collaboration aims to bring different users to work together to contribute their own knowledge cooperatively. This popular approach may be explained by several factors. First, the geographic environment is a complex system that covers various natural and social factors. Thus, the research of the geographic environment requires a closer collaboration of multidiscipline experts. Second, during a task, one person may have basic data only; the suitable process model may be held by another person, whereas another person may know the empirical parameters of a certain experimental area. Collaborative work is also important in such situations. In a VGE, the collaborative component is designed to provide related tools to support such collaboration. When performing collaborative work, the actors of different participants should be defined first, and the total workflow should be designed. Then, every task and sub-task must be clearly divided and assigned to different actors. The necessary tools are requested for each task (e.g., provide the metadata of the original data resource, set the model parameters). Conflict detection and communication strategies are also critical during this process. These issues are the main research topics in the development of a collaborative component of a VGE.

3. Contributions of VGEs

3.1 Geographic experiments and analysis

As mentioned above, the main goal of developing a VGE is to provide a tool, also can be regarded as a workspace, for geographic experiments and analysis. This geo-oriented conception may distinguish VGEs from other digital worlds, such as digital earth and virtual games. Geographic experiments aim to simulate the natural and social worlds under one explanatory umbrella (Matthews and Herbert 2008). Conducting geographic experiments in VGEs will provide the following advantages.

First, although traditional geographic experiments have played an important role in geographic research, they have limitations regarding specific times, environments, and scales. A traditional geographic experiment often employs a fieldwork method or conducts process analysis based on a physical model. For the fieldwork method, it is difficult to control the surrounding environment (e.g., an unexpected rain), and experiments that aim to make predictions are difficult to conduct. For the model-based method, the shortage of field data may affect the accuracy of a simulation. Moreover, if a large region is chosen as the study area, the scale problem also challenges the traditional geographic experiment because it requires a significant amount of money and manpower. A VGE can fill in these gaps to some extent. With a VGE, geographic scenarios may be developed at multiple scales (from global to local). Thus, researchers can ‘zoom in’ or ‘zoom out’ to visit the study areas and perform experiments at various scales. They can add different factors to the study area to view the outcomes under certain assumptions (e.g., set a virtual ‘rain’ or ‘flood’ at a virtual ‘farmland’ or ‘village’). A visual image can be obtained through this low-cost experimental mode through the use of geographic process models at the appropriate scales. Using the tools designed in VGEs, researchers can then adjust the parameters to obtain different experimental results and choose a suitable one to explain the real-world scenario.

Besides, human behavior has been proven to be an important influence on the changing process of the geographic environment. Although human behavior related data may be collected and sorted through questionnaires, surveys, or statistical materials, there is an alternative method to fill this gap. Today, psychologists often test human feelings and behaviors by placing volunteers in small virtual spaces (Bainbridge 2007). This mode can be referenced by geographic experiment as a strategy to involve in human factors. Generally, two types of users are involved with VGEs: professional users (including scientific researchers and decision makers) and public users. Even without professional knowledge, the public users are encouraged to enter into the virtual scenarios through multi-channel interactive tools to obtain personal feelings. In this manner, they can also provide their geographic knowledge and living choices. For example, a virtual polluted small town may be created in a VGE. To conduct a human-environment interactive experiment, one thousand virtual people can be placed into this virtual environment. Among these people, nine hundred may be simulated by ruled agents, whereas the remaining one hundred may be played by invited volunteers as avatars though multi-channel interactive tools. These volunteers can perceive the surrounding environment and attempt to make some personal suggestions through their judgments. Moreover, they may control their avatars to change the conditions in this virtual environment by, for instance, planting virtual trees or reducing the number of virtual cars. Avatars and agents can interact with each other as well as interact with these virtual geographic factors. After recalculation by the corresponding process models, a comprehensive result is identified that considers the natural and social impacts, which will facilitate further comprehensive experiments by researchers (Chen et al. 2013).

Finally, decision makers generally need to have a plan before starting large projects in the real world (e.g., demolishing a dam or building a large petrochemical plant). Traditional decisions may be made based on some documents, reports and figures, but recent tendency is using virtual worlds to assist decision makers to obtain a more understandable image (Bainbridge 2007). Because professional knowledge is required, researchers often conduct some experiments and build various virtual scenarios as proposed solutions (e.g., city planning) beforehand. Then, the decision makers may choose one scenario as the final solution among the proposed solutions. However, limitations still exist because it is difficult for decision makers to comprehend the overall concept proposed by a solution. Thus, the potential problems during the entire process have not been fully identified. With a VGE, decision makers can more easily identify a solution in collaboration with researchers because besides the professional formulas and parameters, they are facing the same virtual environment. Decision makers can directly join in on the experiments and ask the researchers to perform potential actions in the virtual environment (e.g., remove sixty chimneys from the southeast sector of a city or reduce the traffic flow in the northwest sector of a town) to determine the outcome. The results are represented after each step is conducted and re-computed, and the solution can be adjusted in a timely manner. Using this mode, less time is required, and the efficiency of the decision-making process can be greatly enhanced.

3.2 Geographic knowledge sharing

Geographical thinking and reasoning are important ways of exploring the world and its inhabitants. They produce geographic knowledge of the world's natural and social phenomena. Golledge (2002) noted that the nature of geographic knowledge over the last fifty years has evolved from phenomenal to intellectual, such as understanding 'why' and 'how' in addition to 'what' and 'where'. This fact indicates that the topic requires a change from geographic form representation to geographic process analysis.

A main feature of VGEs is that they own a geographic process model base. A geographic process model is an important foundation for geographic simulation. In some words, it can also be regarded as a type of representation of geographic knowledge because the inner mechanism and related formula in geographic process models are generally produced from a summary and induction of former geographic knowledge (Wen et al. 2013). As discussed in section 2, the modeling and simulation component of a VGE promotes a share and reuse mode of geographic process models while performing simulation tasks. When these geographic process models are shared, the inner geographic knowledge can be shared accordingly.

Moreover, comprehensive and complex geographic research requires collaborative works. Thus, process models and geographic knowledge directly from multi-disciplinary experts are needed. One challenge is that different experts often have specific understandings of the problems; they are accustomed to conducting their research under their own thinking and familiar tools. Providing a suitable workspace that can help to achieve a common and familiar understanding is critical. A VGE can provide users with a virtual environment that corresponds to the real geographic world with visual objects and lively phenomena, which is familiar and easily recognized in their daily lives. Compared with tools that use abstract or professional symbols to represent geographic information, the VGE would create a better universal and imaginable understanding that enables multi-disciplinary experts' communication and further knowledge sharing (Lin et al. 2013b). When a collaborative study is performed (e.g., a simulation is conducted through setting different parameters or the model is modified collaboratively), existing knowledge can be shared and new knowledge may be produced. Moreover, a network-based VGE would be convenient for the knowledge-sharing process even if the researchers were distributed across the globe.

3.3 Big Data in GIScience

In 2007, Jim Gary proposed data-intensive science, also known as the fourth paradigm of science, initiating a new chapter in the development of scientific research. Data-intensive science calls for a special data-centered method that integrates the former experiment, induction, and simulation into one process. Researchers are encouraged to explore various phenomena and summarize rules by the collection, storage, analysis and presentation of these big data, which originate from everywhere and at any time. Later, Nature published a special issue on big data in 2008. In 2012, the US government, under the guidance of President Obama, proposed its 'Big Data Big Deal', and the US National Science Foundation (NSF) tried to lead the federal efforts in big data.

Regarding GIScience, the same situation occurs in which mass data can be acquired by various means (e.g., remote sensing, surveying and mapping, global positioning system (GPS), and sensor networks). Although various data are acquired from different tools with different formats, a common feature is that these geo-data are from the real world and can be coded with a real location at a point in time. Accordingly, location can be regarded as a special factor for the gathering and sorting of these big data and is the most important reason for map being used over the years. Today, data are characterized by 3D or multi-dimensions (e.g., time dimension), which require a more powerful tool as the data interface and support further presentation and analysis. A VGE would provide such a workspace because it aims to provide digital mirrors of the real world (Lin et al. 2013b). Based on this background information, all data that exist in the real world can be computerized to form a virtual environment with visible and analyzable information. Specifically, environmental data that are collected by sensors (e.g., air quality, humidity, and temperature) can be inserted into the virtual environment directly through location matching. Using integrated process models and analysis methods, geo-experiment, geo-induction and geo-simulation can be applied to the same virtual environment that is familiar to human beings.

Moreover, social data are also a type of geographic data because the discipline of geography includes both natural and social factors. Social data can now be easily produced by volunteers, (e.g., their travel behavior in a city, their network among friends in different areas, or their evaluation of a shop or a school), and these data can be provided timely though a personal digital assistant (PDA) and smartphones. Examples have appeared in Open Street Map and Google Earth. A VGE can also provide a visual and accessible interface that allows users to enter mass social data (often in real time) into one virtual environment. Combined with data collected by professional methods, these data can be displayed in the virtual environment to reflect the dynamic situation that occurred in the real world. Thus, the data are more useful and understandable, and comprehensive geographic phenomena and rules can also be explored and analyzed in this visual way.

3.4 Potential contributions to some other disciplines

Potential contributions of VGEs to specific disciplines can be established based on the advantages discussed above. Here, remote sensing and global change are presented as examples.

(1) The study of fusing multi-source, multi-resolution remote-sensing data into time-series super-resolution images has become increasingly popular in recent years. These studies explain the natural geographic process using mechanistic models and empirical models. However, remote-sensing images do not yet fully reflect dynamic geographic phenomena due to the fixed resolution and the precision problem of remote-sensing data. To make some progresses, one possible strategy to address this issue is to integrate remote-sensing data with geographic process models. Using a VGE, remote-sensing data and other geo-data can be fully utilized together to form a perceptible environment. Thus, human visualized thinking can be easily introduced to contribute to the interpretation of remote-sensing images. More importantly, a VGE's geographic process model base will provide a bridge between remote-sensing data and geo-simulation, which will enhance the utilization efficiency of remote-sensing information. On one hand, multi-source, multi-resolution remote-sensing data can be used as parameters for geographic process models and as comparative data to assist the optimization and validation tasks during the simulation. On the other hand, after simulation, the results can be used as supplementary information to facilitate the interpretation of geographic phenomena using remote-sensing data.

(2) Global change is a comprehensive discipline involving many aspects, such as natural, social, economic, diplomatic, and legal. Collaboration between multi-disciplines, multi-departments, and various interest groups is urgently needed to perform global change research. However, the situation is not favorable. For example, an earth system model is the most important tool to explain global change and the related impacts of other factors. At present, unique terms are associated with different models and specific simulations, and it is difficult to conduct collaborative research between different research teams. The successful application of VGEs in geographic research can provide an opportunity for the collaboration in global change studies. The critical task is to integrate earth system models into VGEs. Once the geographic process model base is extended to an earth system model base, VGEs can provide a suitable workspace for collaborative global change studies.

4. Conclusion

Along with the development of geographic science and the progress of geographic understanding, the corresponding geographic analysis tools are needed to satisfy the requirements of modern users. Staring from acquiring geographic information to studying geographic objects and their relationships, and then exploring dynamic geographic phenomena and processes, different phases require different assistive tools; thus, an evolution occurred from the use of maps to GISystems and finally to VGEs. Tendency has shown the fact that using a virtual environment for the effective management and analysis of the real world is a workable method (Bainbridge 2007); so as VGEs to geographic analysis and research (Lin et al. 2013b).

Certainly, many tools were approved after several years (or decades) of evolution, including maps and GISystems, VGEs are still evolving. Detailed information and problems have been discussed in previous articles (e.g., Lin et al. 2013a, 2013b). Here, we focus on the expectations for future development. Because a VGE is an integrated workspace based on many theories and various technologies, the critical activity in the future thus may be a better integration of those theories and technologies. Therefore, an urgent expectation is that an increasing number of multi-disciplinary researchers could engage in this meaningful work and provide their contributions. Once various types of knowledge originating from the real world can be seamlessly integrated into the virtual world, VGEs can provide with us a better opportunity to explore and cognize the intriguing world.

SEE ALSO: Big Data in GIScience, Cyberspace, Digital Earth, Geographic information science, Geography and the study of human-environment relations, trends and opportunities in digital and online teaching and learning, Public-participation GIS, 3D Representation, Dynamic complex systems, Cognition and learning, Virtual reality, Visualization, Volunteered geographic information

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Further Readings

Lin, Hui, and Batty, Michael. 2009. *Virtual Geographic Environments*. Beijing: Science Press.

Key Words

Geography, GIScience, Digital Media, Spatial Cognition, Simulation, Geovisualization, Knowledge