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EDITORIAL

Developing dynamic virtual geographic environments (VGEs) for geographic research

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It has been over 15 years since the concept of Virtual Geographic Environments (VGEs) was formally proposed (Lin and Gong 2001). Although the thinking about VGEs never stops since it was born, and the continued development of VGEs has brought about significant achievements resulting from this concept (e.g., Goodchild 2009; Gong et al. 2010; Konecny 2011; Lu 2011; Priestnall et al. 2012; Lin et al. 2013a, b, 2015) as well as related technologies and implementations (e.g., Xu et al. 2011, 2013; Chen et al. 2012, 2013a, b; Zhang et al. 2015a, b; Zhu et al. 2015), there are still some misunderstandings about this 'new' branch of Geoscience. Questions generally are related to two concepts: the first concerns the differences between VGEs and game-like virtual worlds, similar virtual communities and cities, and digital earth; the second asks how VGEs can contribute to geographic research beyond traditional Geographic Information Systems (GIS) and Maps (Aydi et al. 2013; Tung et al. 2013).

The answer to the first question may be found in the term 'geographic environment' which refers not only to the natural surface of the earth, space, or a place, but also involves the social behaviors that interact with natural factors; it is the sphere of direct interaction between nature and society (Kalesnik 1979). An important feature of geographic environments is that they change continuously with time. Although some objects in geographic environments have relatively stable shapes (such as a rock or soils), many exist in constantly changing forms (such as vegetation, air and water), and human beings (both in groups or individual) are active throughout their 'lives'. Given this definition, to build a virtual mirror that can reflect the real geographic environment, only considering the physical part would result only in a one-sided perspective. Moreover, dynamic geographic phenomena and processes require careful attention, a fact often overlooked by traditional systems. Thus, an ideal virtual environment

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should be able to describe both human and natural complexities—not merely where and what they are—but their past and evolution. Avatar-based virtual environments can provide us with live spaces that allow people to communicate and deal, even create objects they want. However, the features that are rooted in game playing often cause conflicts with general rules in the real world, especially some human behavior (Castronova 2007). Therefore, the enhancements necessary to constitute a suitable virtual world for serious research remain in question (Bainbridge 2007). In other words, these game environments often ignore the natural and social rules and knowledge comes from scientific domain, which hampers deep understanding of the changing processes in the real world.

This disconnection raises another issue. The main target of information share-oriented and game-rooted systems is to develop virtual scenarios to attract the users, although the two systems differ in that the latter aims to provide convenient visual methods for data research, expression and understanding, while the latter aims to provide users with vivid scenarios that allow deep perceptions as well as fun. To satisfy the needs of both systems, much work has focused on the fields of scientific visualization of environmental systems and processes (e.g., Rink et al. 2014a, b; Helbig et al. 2014; Liu et al. 2014; Naumov et al. 2014) and Virtual Reality (VR) (e.g., Rauschert et al. 2002; Wall and Brewster 2004; Jansson and Pedersen 2005; Bilke et al. 2014). These efforts have greatly promoted the use of virtual environments to some extent. Although the ability to watch or feel an environment is valuable, the emphasis on these aspects has also caused confusion around what the 'new' VGEs can provide.

Answering this question requires examining the scientific research performed on VGEs to date. The methods of scientific thought include both induction and deduction (Eekels and Roozenburg 1991; Lawson 2005). It is said that through induction, which often involves learning from experience, people are better able to understand patterns, similarities or other regularities (Tidman and Kahane 2003). However, a widely accepted view of science is that it follows a 'hypothetico-deductive' process, in which the deductive consequences of hypotheses, which should be tested by experiment and reasoning, are more important for scientific research (King et al. 2004). In terms of geographic research, an intuitive impression about a place or a geographic process gained through virtual and visual images may be employed for induction. For complex geographic analysis tasks, however, comprehensive geographic experiments (especially computer-aided geographic experiments) and reasoning are still necessary for geographic deduction, where geographic mechanism and rules play more important roles during the entire process. Therefore, specific functions should be equipped with supporting tools.

The first function is *simulation* which has long been regarded as an important approach for development of experiments and theories (Winsberg 2003; Davis et al. 2007). Peck (2004) summarized several key points, noting that simulation can contribute to scientific experiments, but asserting that although simulation is an attempt to mimic complex real-world systems, it can be manipulated in ways that would be impossible, prohibitively costly or unethical in the natural world. When incorporated in models that contain appropriate mechanisms and sometimes involve manual intervention, simulation has made the deductive process operable in scientific research related to the study of the real world. After integration with virtual environments, it will enhance their ability to reason and conduct experiments beyond visualization (e.g., Bilke et al. 2014).

A second issue is supporting *collaborative research* for complex problem solving. The world is a system that involves interacting natural and social factors; thus, geographic phenomena and processes are all related to some degree, and they should not be studied separately. Accordingly, modern geographic research has moved towards integration and a comprehensive perspective on the world, which requires experts from different domains to work collaboratively while not keep their head down. Because of this aspect, on one hand, web-based virtual worlds provide a favorable natural advantage for users to communicate within a same environment; on the other hand, some virtual research environments (VREs) have also supported generic research tasks such as data management (horizontal view) as well as allowing scientists to use their tools and technologies within their particular disciplines (vertical view) (Voss and Procter 2009; Granell et al. 2013). Indeed, there is an urgent need to merge these two types of systems so as to facilitate collaboration based on common cognition (Lin et al. 2013b).

The idea of VGEs conforms to this trend of geographic research, as well as answering the question proposed by Cutter et al. (2002), who asked what role virtual systems will play in learning about the world. VGEs also follow Batty's idea of virtual geography (Batty 1997) in that they are not only limited to providing virtual spaces for users to experience an environment in person, but also allow them to know it beyond reality (Lin and Chen 2015). In this case, knowing an environment beyond reality can be realized not only by experience, but also in experiments. Both the conceptual framework and detailed compositions and functions of VGEs have been illustrated in previous papers (Lin et al. 2013a, b). In this article, we emphasize that VGEs should be built based on knowledge and rules from real geographic environment. In addition to geo-visualization and human participation, we note that the development of VGEs should also focus on their geo-simulation and geo-collaboration functions, which is an important difference between VGEs and traditional systems.

To promote research in the above two areas—simulation as well as collaborative research—and contribute to building dynamic VGEs for scientific research, an international conference was held in Hong Kong November 2014. Several related topics were discussed, such as geographic data organization and model sharing for comprehensive experiments, collaborative simulation and its applications. This Thematic Issue includes 14 articles selected from over 40 talks and is aimed to introduce new ideas that can stimulate current research.

Cognition is an important way for humans to understand concepts, events and the world, and the process of cognition involves the basic channels with which information transfers from objects to the sensory organs and finally forms images or knowledge in the brain. The study of cognition is of great significance because it can help to explore how humans acquire knowledge and rules from external phenomena, and how assistance tools can be built to satisfy cognitive customs and models (Lu 2013). VGEs aim to provide users with integrated tools to understand the world better; thus the issue of human cognition should be considered seriously to make VGEs truly user-oriented. Jia et al. (2015) argued that VGEs should unite geographic information and human cognition, and proposed a formal language for VGEs with the aim of establishing a kind of cognitive linguistic methodology for the construction of VGEs. This proposal is an attempt to extend geographic language from MAP to GIS and now to VGEs.

Before conducting geographic simulation, two types of models should be investigated: data models and geo-process models. Data are the abstraction of real objects and their attributes, and thus data models organize these data in a certain format for computation, storage and analysis (Chen et al. 2015a). Geo-process models are designed to describe geographic phenomena and processes using mathematical formulas; they have been regarded as the foundation for simulation and prediction (Wen et al. 2013; Kolditz and de Jonge 2004; Xie et al. 2006; Bauer et al. 2012). It is obvious that an ideal data model in VGEs should be designed to fully support the computation of complex geo-process models for comprehensive simulation (Kolditz et al. 2012).

Lu et al. (2015) explored the difficulties in building a data environment to express geographic characteristic, processes and mechanisms in a unified framework. As VGEs may integrate information including geometries and graphs, algebraic equations, time series, and information spectrums (Chen et al. 2013b), they argued that it is better to change the foundations of the data environment from a classic cartographic model to an integrated scene model, which can include various different elements and information in a complete model (Lu et al. 2015). Accordingly, they proposed a spatio-temporal unified data model based on the theory of geometric algebra. This model is creative and differs from traditional models because it can support the integration of representation and computation in a universal space–time, thus reducing simulation difficulty and enhancing efficiency.

Regarding geo-process models, to reflect different processes in the real world, both physical models and behavior-related model (including some results caused by social behavior) should be considered because geography has both natural and social facets, and many processes are affected by both factors (e.g., Gutierrez et al. 2013; Servida et al. 2013; Carreno et al. 2014). More specific examples are related to Decision Support Systems (Aminu et al. 2013) and Eco-Environmental Risk Analysis studies (Shao et al. 2014).

Some examples of physical models are as follows. Tang et al. (2015) proposed a plant growth model integrating ontology and artificial intelligence (AI) to explore the growth processes of plants and their relationship with their environment. Guo et al. (2015) designed an adaptive tide numerical model to simulate complex flows in coastal areas. Finally, Jørgensen (2015) presented a type of ecological model called a structurally dynamic model that can capture structural changes in species composition, individual species and their properties. Jørgensen's model is a new geo-process model in the ecological arena and is distinct from traditional methods.

With regard to behavior-related model, Cellular Automata (CA) models are often employed to illustrate human-caused environment changes, such as changing land cover and land use (e.g., Basse et al. 2014; Lin et al. 2014; Al-shalabi et al. 2013; Mao et al. 2013). Agent-based models are normally utilized as effective methods of simulating human behavior in certain environment such as in emergencies (e.g., Vanclooster et al. 2014). Focusing on movement, in this issue, Rybansky et al. (2015) found that modeling the movement of vehicles in open terrain is more difficult because many factors affect vehicle deceleration, including terrain surface configuration, surface roughness, and materials, as well as obstacles in the route. To deliver a proper solution, he designed a method for calculating vehicle deceleration that synthesized corresponding raster cells in an elementary terrain area with influences from geographic factors.

Collaboration is a multi-faceted issue and involves many aspects. First, participants should understand the conceptual ideas and the problems to be solved before undertaking simulation and analysis task. Next, related data and models should be standardized and shared so that users can communicate in a unified way. Collaborative technologies and assistive tools are required to support essential collaborative operation and analysis. Li et al. (2015) explained these stages and provided a framework for collaborative experimentation using flood analysis as a case study.

Among these stages, data sharing and exchange are fundamental for collaboration and have attracted large amounts of attention. Shi (2015) presented an online geo-information service that enables automated real-time and on-demand geo-referenced spatial and attribute data extraction, transfer and fusion. To reduce difficulty of model data preparation and pre-processing for collaborative simulation, Yue et al. (2015) designed the Universal Data eXchange (UDX) model, which describes both the structural format data and the unstructured text data in a uniform way. This model undertakes data exchange tasks well while integrating different geo-process models as well as expressing multi-source heterogeneous data in a clear, visual and formalized way. Similar work was conducted by Hu et al. (2015), providing a Data Format Markup Language (DFML) to describe the data formats of geo-process models using three components: data type, structure and layout.

In addition to providing a data foundation for collaboration, Torrens proposed an integrated strategy for intertwining agents and environments together, thus enabling social and physical factors to work collaboratively for comprehensive simulation in VGEs (Torrens 2015a). It is another important aspect of collaboration, albeit not directly; once human behavior-related models (e.g., Torrens et al. 2012, 2013, 2014) and physical models can functionally interact with each other, the human-environment processes can be simulated naturally and dynamically in a complete VGE (Torrens 2015b). The framework can also offer a seamless transition between data, process, and representation, thus contributing to an actionable understanding. This workflow concept is important to guarantee a continuous analysis processes preventing any loss of information.

Beyond theoretical work, three cases studies are introduced in this issue to help understand different processes. Yin et al. (2015) conducted a visual analysis and simulation of the spatiotemporal processes during dam-break resulting from floods; they use a network environment to support dam-break risk management efficiently. Chen et al. (Chen et al. 2015b) present the design and integration of GeoHydro/DataBase, and a regional hydrologic model for simulating watershed hydrological processes in Meijiang, China. Russwurm and Moore (2015) demonstrate another application of VGEs, featuring non-specific native geography rather than the usual specific virtual environment that is tied to a real location. This application can be regarded as a supplemental work that enables users to experience the geographic environment beyond reality.

Our world is an extremely complex and comprehensive system that undergoes permanent changes. These characteristics place geographic research beyond traditional models and require interdisciplinary investigation, requiring experts from different areas and domains to join together to solve problems. Several multi-disciplinary projects have been proposed, including the International Geosphere–Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP); and the Earth System Science Partnership (ESSP) have been formed. However, there remains an urgent need for powerful workspaces. Virtual environments provide immense potential for certain and separate research, but we are still on a long way from understanding our complex environment fully through these linked virtual mirrors. To date, VGEs are not mature enough to be widely used in geographic research. The functions of simulation and collaboration should be continuously enhanced, enabling VGEs to provide 'real' dynamic environments that obey truly geographic rules and laws. This forms a starting point from which experts from different domains can contribute knowledge for comprehensive understanding of complex environmental processes to improve our abilities for sustainable environmental management.

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