Virtual Environments Begin to Embrace Process-based Geographic Analysis

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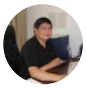
Michael Batty
University College London

Milan Konečný
Masaryk University

Alexey Voinov
University of Technology Sydney



Guonian Lü
Key Laboratory of Virtual Geographic Environ…

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Virtual Environments Begin to Embrace Process-based Geographic Analysis

Virtual environments are computer-based digital spaces that we can observe, participate in, and experience in person. Virtual environments were initially viewed as "mirror worlds" (Gerlenter 2004), although they are being extended as this virtuality broadens to include scenarios that cannot be found in real life. Employing virtual environments as a tool to facilitate scientific exploration is not a new story. For example, virtual worlds, such as Second Life (SL) and World of Warcraft (WoW), have demonstrated the potential for studying social, behavioral and economic issues (Bambridge 2007; DeMers et al. 2013; Messinger et al. 2009), while a wide array of virtual laboratories are being developed to advance research in conventional domains, such as those dealing with chemical and biological problems (Bettenworth and Abbott 2000; Bohil et al. 2011; Yaron et al. 2010).

Similar examples have been reported in the domain of geography. Several three-dimensional geospatially referenced virtual environments (GRVEs) have been developed at different scales to include virtual objects (e.g. terrain, landmarks, and buildings) that correspond to real world representations. With these 'windows' on the real world, users can observe and move in abstract representations of the real places in which they live and work or in unfamiliar places that they have not experienced hitherto. This approach provides a valuable strategy for obtaining images of real geographic scenes or future scenarios, thus facilitating direct perception. However, this strategy does not yet allow for rigorous geographic analysis because a mismatch exists between actual environments and the limited functions that GRVEs can provide (MacEachren and Kraak 2001).

Later developments have revealed a greater potential for using GRVEs as experimental laboratories for geospatial analysis because more theory and analytic functions have been incorporated into their structure. In enhanced GRVEs, spatial databases and indices have been employed so that users can easily query physical geographic objects (such as mountains, lakes, and buildings) and their attached attributes. Three-dimensional spatial analysis methods provide appropriate representations for computing the parameters of navigation that are associated with movement in both real and abstract space as well as various features, such as the average duration over which a building receives sunlight each day and the extent to which land-use activities are patronized by those working and/or living in such environments. Moreover, with the development of three-dimensional physical data models, geographers can perform cross-sectional analyses of virtual geological and geographic structures from multiple directions across many sub-layers. All these achievements focus on the question 'what role will virtual systems play in learning about the world?' (Cutter et al. 2002).

A key driver for enhancing assistive tools must stem from the target itself. Recently, an important research priority in geographic analysis has emerged as researchers shift from identifying static snapshots to exploring dynamic phenomena (Goodchild 2009, 2010). Dynamic phenomena, unlike static shapes, forms, and patterns, include a series of physical or human geographic processes that change across spatial and temporal dimensions. Manipulating, interpreting, and storing information for those changing processes are critical skills and are also

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important for geographic understanding and analyses (Mark et al. 1999). This change in approach covers many aspects, ranging from theories to technologies, and provides new opportunities and challenges for related assistive tools and interfaces, including GRVEs.

New ideas are emerging with the aim of introducing at least three categories of geographic processes that are becoming embedded in GRVEs: historical geographic processes recorded in traditional documents, contemporary geographic processes that currently occur in nature, and experimental geographic processes that are still being explored and discovered.

Historical geographic processes pertain to changes that have occurred in the past, for example, the evolution of a city or the migratory process associated with a family. By adding historical geographic processes to a virtual environment, their historiography can be improved and participants can easily begin to compare temporal changes within a geographic context that embrace culture, the arts and humanities. However, most geographic information related to such processes is recorded in traditional paper maps, paintings, and unstructured texts, which cannot be directly used for GRVEs. Some attempts have been made to build four-dimensional representations (where time constitutes the fourth dimension), such as historical evolutions of virtual cities, e.g. virtual Kyoto (Yasumoto et al. 2012), to draw four-dimensional migration paths of Chinese families (Chen et al. 2013), and so on; but accuracy and precision remain problems for further study.

The perceptual psychologist Gibson argued that a good laboratory must resemble life itself (Gibson 1986). Following Gibson, arguably, a suitable virtual environment should be as life-like as possible (Loomis et al. 1999; Tarr and Warren 2002). One's surroundings that embody physical processes, such as blowing wind, pouring rain, moving cars, and animals in motion, inform our daily life in a dynamic world. Introducing this information into GRVEs will enhance the user's perception of the environment and will enable better feedback and reactions from users (Lin et al. 2013b).

In this respect, accessing up-to-date geographic process data is a major quest. Currently, such process data can be acquired at increasingly faster rates. Environmental data (e.g. mineral and geothermal resources, air and water quality, humidity, and temperature) can be collected by ubiquitous sensors, while social data (e.g. travel behavior, energy use, and spending patterns) can be gathered using various forms of crowdsourcing, which can supplement remote sensing observations. With timely positioning, these data can be an important component of GRVEs, providing facts and connections for the users. For example, in Figure 1, we show how such a virtual environment can be created by importing into a 3-D environment real-time streamed data from travel using smart cards, demonstrating how users of a particular category, i.e. those with a disabled free pass for travel, move around a complex system composed of buildings and subway lines that provide a virtual representation of the real world (Batty 2013).

Apart from this type of visualization, another important goal for geographically referenced virtual environments is their use as an experimental workspace for exploring real geographic phenomena (Bainbridge 2007; Subrahmanian and Dickerson 2009). Focusing on geographic research, computer-aided geographic experiments are quickly becoming a common strategy for simulating and predicting dynamic phenomena, where process models are often employed as basic tools. Geographic process models equip GRVEs with realistic mechanisms that allow users to perform exploratory analysis based on experiences and interactions with visual predictions from geographic scenarios that not yet well understood (Lin et al. 2013a). During such experiments researchers can adjust model-related parameters that pertain, for example, to the objects that comprise a city associated with air pollution (Xu et al. 2013) or the speed and flexibility of people as agent-based avatars interacting with a scene and exploring ways that they might move in such environment (Torrens 2012). Users can then compare different experimental results using straightforward visual perceptions.

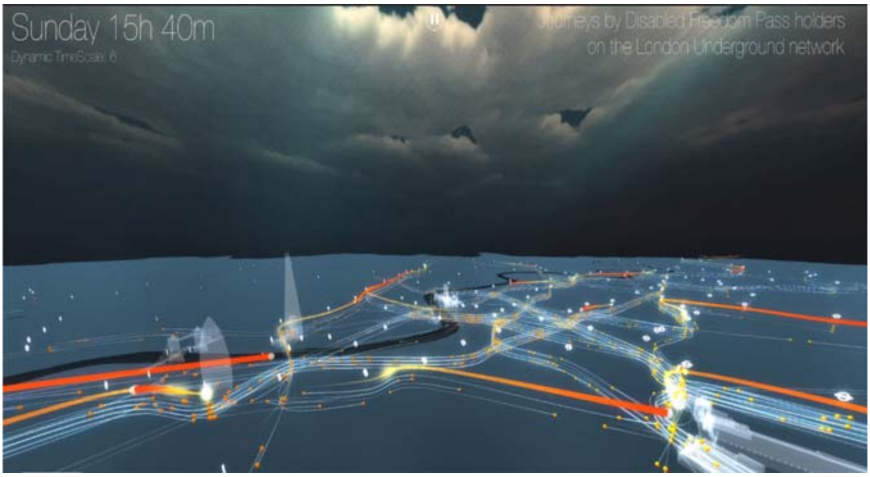

Figure 1 A virtual, geographically referenced environment in which real-time data on movements illustrate flows of a particular class of traveler on London's subway systems (courtesy of Gareth Simons, CASA, University College London: http://vimeo.com/96998519).

Moreover, as a foundation for collective modeling and simulation, technologies related to model management, reuse, and coupling are being explored (Kelly et al. 2013; Wen et al. 2013). By incorporating such technologies, GRVEs can be improved as tools for researchers to share knowledge and gain a more universal understanding of geographic processes (Lin et al. 2013a; Bilke et al. 2014). A lower threshold can be used for comprehensive experiments in a collective mode, such as those being developed for flood-routing (Lin et al. 2010) or air pollution analysis (Xu et al. 2011).

Research has shown that the most effective way to understand an environment is from direct experience (Cutter et al. 2002; Tuan 2001). Massive geographic datasets are becoming increasingly available for representing such environments, while the causality for expressing various processes is becoming better understood when combined with such information and integrated in future analysis. These efforts will provide more realistic and perceptible GRVEs, a holograph for geography so-to-speak, that allow users to explore inaccessible past or future environments or distant present environments, not only through their static objects but through processes that mirror their real dynamics. Ongoing research is challenging because it involves many technologies in the domains of geography, virtual reality and computer science that must be synthesized from both physical and human perspectives. However, these challenges should not obscure the fact that these new research directions will lead to a new synthesis of the virtual and real worlds. Our speculation is that embedding geographic processes into virtual environments holds extraordinary potential for future geographic analysis, which extends well beyond the current state of the art in geographic information systems and geographic information science.

Hui Lin
Institute of Space and Earth Information Science
The Chinese University of Hong Kong; Shenzhen Research Institute
The Chinese University of Hong Kong; Department of Geography and
Resource Management, The Chinese University of Hong Kong

Michael Batty
Centre for Advanced Spatial Analysis
University College London

Sven E Jørgensen
Faculty of Health, Institute A, Section of Environmental Chemistry
University of Copenhagen

Bojie Fu
State Key Laboratory of Urban and Regional Ecology
Research Center for Eco-environmental Sciences
Chinese Academy of Sciences

Milan Konecny
Laboratory on Geoinformatics and Cartography
Masaryk University

Alexey Voinov
Faculty of Geo-Information Science and
Earth Observation (ITC)
University of Twente

Paul Torrens
Center for Geospatial Information Science
University of Maryland

Guonian Lu
Key Laboratory of Virtual Geographic Environment,
Ministry of Education of PRC, Nanjing Normal University

A-Xing Zhu
Jiangsu Center for Collaborative Innovation in
Geographical Information Resource Development
and Application, Nanjing Normal University;
Department of Geography, University of Wisconsin–Madison

John P Wilson
Spatial Sciences Institute
University of Southern California

Jianya Gong
LIESMARS
Wuhan University

Olaf Kolditz
Department Environmental Informatics
Technische Universität Dresden

Temenoujka Bandrova
Laboratory on Cartography
University of Architecture, Civil Engineering and Geodesy

Min Chen
Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing Normal University;
State Key Laboratory Cultivation Base of Geographical Environment Evolution (Jiangsu Province), Nanjing Normal University
Address for correspondence: *chenmin0902@163.com*

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