Geographic information science in the era of geospatial big data: A cyberspace perspective

Xintao Liu,[1] Min Chen,[2,21,*] Christophe Claramunt,[3] Michael Batty,[4] Mei-Po Kwan,[5] Ahmad M. Senousi,[6] Tao Cheng,[7] Josef Strobl,[8] Arzu Çöltekin,[9] John Wilson,[10] Temenoujka Bandrova,[11] Milan Konecny,[2,12] Paul M. Torrens,[13] Fengyuan Zhang,[1] Li He,[14] Jinfeng Wang,[15] Carlo Ratti,[16] Olaf Kolditz,[17] Alexander Klippel,[18] Songnian Li,[19] Hui Lin,[20] and Guonian Lü[2,21,*]

[1]Department of Land Surveying and Geo-Informatics, Hong Kong Polytechnic University, Hong Kong SAR, Kowloon, China
[2]Key Laboratory of Virtual Geographic Environment (Ministry of Education of PRC), Nanjing Normal University, Nanjing 210023, China
[3]The French Naval Academy Research Institute, 29240 Lanveoc-Poulmic, France
[4]The Bartlett Centre for Advanced Spatial Analysis (CASA), University College London (UCL), WC1E 6BT London, UK
[5]Institute of Space and Earth Information Science, The Chinese University of Hong Kong, Hong Kong SAR, Shatin 999077, China
[6]Department of Civil Engineering, Cairo University, 12613 Cairo, Egypt
[7]SpaceTimeLab, Department of Civil, Environmental and Geomatic Engineering, University College London (UCL), WC1E 6BT London, UK
[8]Department of Geoinformatics, University of Salzburg, 5020 Salzburg, Austria
[9]Institute of Interactive Technologies (IIT), University of Applied Sciences and Arts Northwestern Switzerland FHNW, 5210 Windisch, Switzerland
[10]Spatial Sciences Institute, University of Southern California, Los Angeles, CA 90007, USA
[11]Laboratory on Cartography, Department of Photogrammetry and Cartography, University of Architecture, Civil Engineering and Geodesy, 1164 Sofia, Bulgaria
[12]Laboratory on Geoinformatics and Cartography, Department of Geography, Masaryk University, 61137 Brno, Česká Republika
[13]Computer Science and Engineering, Tandon School & Center for Urban Science + Progress, New York University, New York, NY 10012, USA
[14]School of Humanities and Social Science, Xi'an Jiaotong University, Xi'an 710049, China
[15]Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[16]Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[17]Centre for Environmental Research, Helmholtz Centre for Environmental Research–UFZ, 04318 Leipzig, Germany
[18]Laboratory of Geo-information Science and Remote Sensing, Wageningen University & Research, Wageningen 6708, the Netherlands
[19]Department of Civil Engineering, Toronto Metropolitan University, Toronto, ON M5B 2K3, Canada
[20]School of Geography and Environment, Jiangxi Normal University, Nanchang 330022, China
[21]Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing 210023, China
*Correspondence: chenmin0902@njnu.edu.cn (M.C.); gnlu@njnu.edu.cn (G.L.)

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The advent of information and communication technology and the Internet of Things have led our society toward a digital era. The proliferation of personal computers, smartphones, intelligent autonomous sensors, and pervasive network interactions with individuals have gradually shifted human activities from offline to online and from in person to virtual. This transformation has brought a series of challenges in a variety of fields, such as the dilemma of placelessness, some aspects of timelessness (no time relevance), and the changing relevance of distance in the field of geographic information science (GIScience). In the last two decades, "cyber thinking" in GIScience has received significant attention from different perspectives. For instance, human activities in "cyberspace" need to be reconsidered when coupled with the geographic space to observe the first law of geography.[1,2]

With continuous advances of digital transformation and decentralized and sensor-based technologies, big data are progressively solidified as a major trend, a pillar to revisit, one that sheds new light on GIScience.[3] This commentary introduces a brief narrative review and a framework for the cyber thinking and analysis of challenges and opportunities for GIScience with a specific focus on emerging geospatial big data. As shown in Figure 1, interactions among people, environments, and sensors play a key role in emerging geographic and cyberspaces. Taking these interactions into account, we examine the current research agenda on data contents, data modeling, and data analysis, as we highlight and discuss opportunities and challenges.

GEOSPATIAL BIG DATA IN THE CONTEXT OF CYBERSPACE

A large portion of current big data is geospatial (e.g., GPS-based trajectory data, smart-card data), which faces many challenges in terms of veracity, reliability, data quality, etc., and require intensive research efforts to identify and mitigate the inherent uncertainties. Shi et al.[4] have categorized geospatial big data into Earth- and human-activity observations, and many data are nowadays collected mainly in cyberspace. While cyberspace suggests placelessness, we still propose the following three-class categorization: (1) Earth observations (data collected through aerial and ground sensors), (2) Human activity observations in geographic space (data used to explore human activities and mobility patterns), and (3) Human activity observations in cyberspace (data used to explore human dynamics and semantics based on behavior in cyberspace).

In fact, most human interactions and activities in cyberspace are not isolated; they often influence or are influenced by the events in geographic space. Geospatial big data generated in geographic space and cyberspace in unprecedented spatial and temporal resolutions offer opportunities for a better understanding of human behavior, urban dynamics, human-environment interactions, and many more fundamentally important issues. Nonetheless, geospatial big data face challenges related to their characteristics such as their high-dimensional nature, lacking data standards, data privacy and security, multiple IP addresses, misinformation, and garbage and fake data.

GEOSPATIAL DATA MODELING ACROSS GEOGRAPHIC SPACE AND CYBERSPACE

Current data models do not fully represent the geographic environment and its inherent elements in the context of cyberspace. Hence, new ideas and frameworks must be developed to accommodate data modeling in cyberspace. We identify and organize these into four complementary aspects.

Conceptual models of cyberspace in GIScience. Cyberspace has emerged due to the wide use of network infrastructure. Resembling geographic space, cyberspace consists of virtual places (including identities, websites, and communication platforms) where people interact. Moreover, information flows in cyberspace are of the highest relevance to geographic space. In a conceptual model of virtual geography,[5] much attention is given to modeling "nodes" in geographic space, namely the "land" and "people." In cyberspace, however, we need to understand the structural and dynamic properties of the emerging "nets" indicating human/system interactions and relations.

Conceptual models of integrated physical space and cyberspace. Although cyberspace has distinct features compared with geographic space, we posit that cyberspace cannot exist/function without geographic space. First, human activities in cyberspace depend highly on communications and network infrastructures (e.g., servers and clients) deployed in the geographic world. Second, geographic space and cyberspace include the same essential components, while people themselves must exist and (so far) depend on the real geographic world. Third, many cyberspace services, instead of creating a totally new world, serve as an extension of physical-world activities.

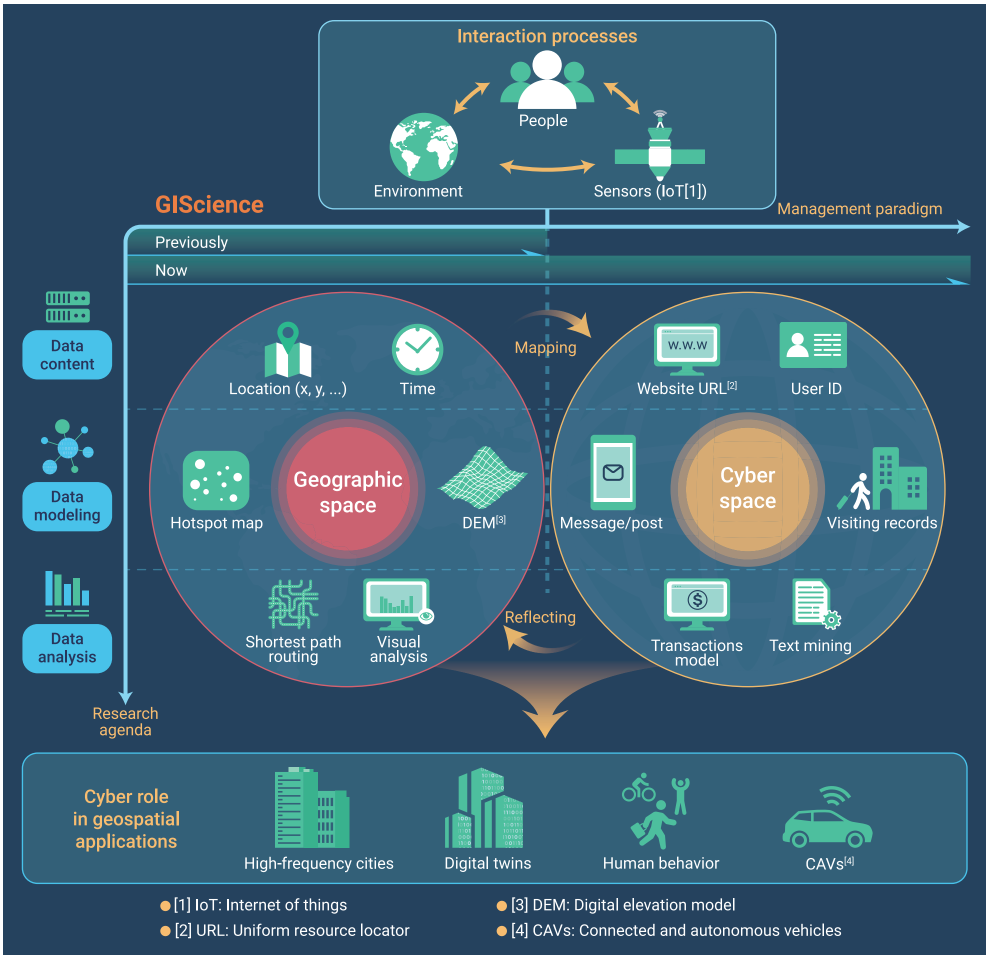

Figure 1. The conceptual view of GIScience from the perspectives of geospatial big data and cyberspace

Cyberspace models in GIScience. Similar to the web-based GIScience framework, conceptual and logical models of CyberGIScience aim to provide reliable solutions to integrate various hardware and software systems and interact with end clients through layers such as cyberspace servers and networking layers. Conversely, CyberGIScience is different from web-based GIScience in its human-centric design and better capability for analyzing massive data volumes. CyberGIScience does not only run on the web system but incorporate complex human activities as well as sensors in cyberspace efficiently and securely.

Spatiotemporal, semantic, and topological modeling of cyberspace data. Big data from cyberspace provide a new lens for observing dimensions beyond geographic space. Attributes extracted in cyberspace should be integrated into a geographic context. Similar models can be adopted to represent activities in cyberspace resulting in digital spatiotemporal trajectories. Modeling semantics is another important aspect of cyberspace data. Diverse types of information beyond spatial location can be utilized in cyberspace, such as text, image, video, website logs, and social media links. Topological structures in cyberspace that are determined by spatio–social relations and flows can provide valuable insights into urban structure in geographic space. Challenges such as data models to represent phenomena in cyberspace should be further researched.

GEOSPATIAL DATA ANALYSIS IN CYBERSPACE

Understanding spatiotemporal patterns associated with natural or human-induced processes has long been on the research agenda of GIScience. Cyberspace-related big data provide new perspectives in spatial knowledge discovery and explore challenges that have not been well addressed so far. Here, we briefly discuss the most important ones among them.

Cyberspace for geo-visual analytics. Various types of cyberspace-related big data enable discovering even more knowledge than that of the geo-social dimensions in previous related studies, an undeniable trend several opportunities allow to simultaneously observe both geographic and cyber systems (e.g., surfed websites record with geographic position). Thus, it appears that high-resolution trajectories in both geographic space and cyberspace are feasible, which has become a target for improving current geo-visual frameworks.

Cyberspace for GIScience infrastructure. In an environment of rapidly evolving technology and data, GIScience technologies must be adapted for data-intensive tasks. The challenges posed by the paradigm shift of activities to cyberspace are attributed to multiple sources of big data and requirements for high-performance computing and new data models to store and represent the complexity of city systems.

Cyberspace for knowledge discovery of relations and interactions. Typically, models of spatial relationships are built from flow data that document the interactions among spatial entities. Cyber-related big data, such as social media data, are normally useful in reconstructing social relations. However, challenges in terms of the convergence of social relations and spatial relations exist in multiple forms, including integrating physical and cyber interactions in the same framework and proactively identifying algorithm-driven behaviors of the major platforms. Meanwhile, effective initiatives that decentralize the power of social media platforms and ensure accountable sovereignty of algorithms should be placed on the agenda that can be helpful to data privacy and security.

Cyberspace for knowledge discovery of classification and prediction. Cyber-related big data have proven to be useful in classifying natural and human-induced spatial structures. Thus, integrating social-sensing big data with remote sensing enables better observations of actual human activities, resulting in more accurate imagery classification results. Another challenging and promising topic lies in the role of compound influences of geographic and cyber human activities for classification and prediction. Therefore, cyber activities may no longer serve simply as additional features in Geo-AI models but must also be integrated with physical activity as a whole.

THE ROLE OF CYBERSPACE IN GEOSPATIAL APPLICATIONS

With the rapid development of the Internet, cyberspace influences most aspects of personal life and society. Moreover, most, if not all, human activities and behaviors that take place in cyberspace will be recorded to produce cyber-related big data that can be harnessed for many GIScience applications and insights. For instance, high-frequency cities, human mobility in cyberspace, digital twins, connected and autonomous vehicles, self-navigation systems, climate change, and emergency and disaster response as well as maritime and aerial mobility forecasting are all features that span geographic space and cyberspace.

REFERENCES

1. Lü, G., Batty, M., Strobl, J., et al. (2019). Reflections and speculations on the progress in Geographic Information Systems (GIS): a geographic perspective. Int. J. Geogr. Inf. Sci. ***33***, 346–367.
2. Goodchild, M.F. (2022). Commentary: general principles and analytical frameworks in geography and GIScience. Ann. GIS ***28***, 85–87.
3. Dangermond, J., and Goodchild, M.F. (2020). Building geospatial infrastructure. Geo-Spat. Inf. Sci. ***23***, 1–9.
4. Shi, W., Zhang, A., Zhou, X., and Zhang, M. (2018). Challenges and prospects of uncertainties in spatial big data analytics. Ann. Am. Assoc. Geogr. ***108***, 1513–1520.
5. Batty, M. (1997). Virtual geography. Futures ***29***, 337–352.

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DECLARATION OF INTERESTS

The authors declare no competing interests.