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

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The advent of Information and Communication Technology (ICT) and the Internet of Things (IoT) have led our society towards 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 phenomenon can be thought of as a paradigm shift that permeates many aspects of modern society. 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, decentralized and sensor-based technologies, big data is 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 offers opportunities for a better understanding of human behavior, urban dynamics, human-environment interactions, and many more fundamentally important issues. Nonetheless, geospatial big data faces challenges related to its characteristics such as its high-dimensional nature, lacking data standards, data privacy and security, multiple IP addresses, misinformation, 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 GIS. 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 the human/system interaction and relations.

Conceptual models of integrated physical space and cyberspace. Although cyberspace has distinct features compared to 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.

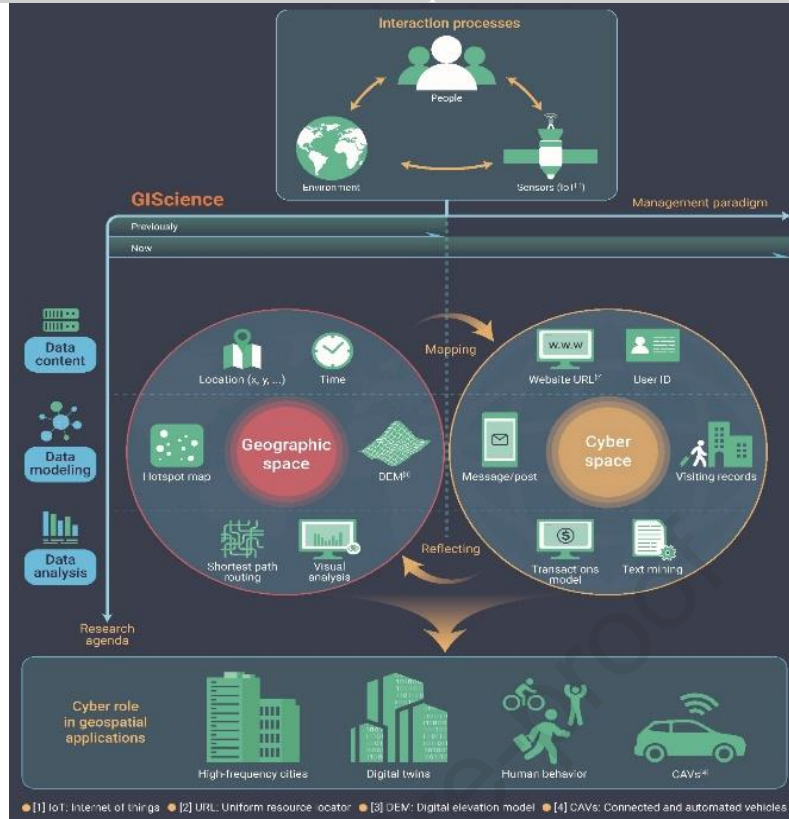


Figure 1. The conceptual view of GIScience from the perspectives of geospatial big data and cyberspace.

Cyberspace models in GIS. Similar to the Web-based GIS framework, conceptual and logical models of CyberGIS 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, CyberGIS is different from Web-based GIS in its human-centric design and better capability for analyzing massive data volumes. CyberGIS 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 provides 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 provides 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 amongst 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 GIS infrastructure. In an environment of rapidly evolving technology and data, GIS 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, is 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 has 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, and particularly satellite-based Internet services, 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 (DT), connected and autonomous vehicles (CAVs), self-navigation systems, climate change, emergency and disaster response, as well as maritime and aerial mobility forecasting are all features that span geographic space and cyberspace.

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DECLARATION OF INTERESTS

The authors declare no competing interests.