

CyberGIS: Empowering the Synthesis of Computational and Spatial Thinking

Shaowen Wang

University of Illinois at Urbana-Champaign

Spatial thinking and associated geographic approaches, supported by geographic information systems (GIS), play essential roles in solving scientific problems and improving decision-making practices of significant societal impact. Fulfilling such roles is increasingly dependent on the capabilities of synthesizing spatial and computational thinking (Wing 2006) enabled by cyberinfrastructure. Cyberinfrastructure promises to revolutionize how science and engineering are conducted in the 21st century as computation has become the third pillar of science and engineering (along with theory and experiment) (NSF 2003). CyberGIS represent a new GIS modality comprising a seamless blending of cyberinfrastructure, GIS, and spatial analysis capabilities to empower computational and spatial thinking and, thus, promise to transform geospatial problem-solving and decision-making while advancing cyberinfrastructure.

Recent research and development in cyberinfrastructure and geographic information science (GIScience) have demonstrated the benefits and possibilities of CyberGIS from individual perspectives. These efforts span the realm of Internet-based GIS, geospatial middleware, spatial analysis based on high-performance computing approaches, geospatial problem-solving environments and portals, sensor webs and networks, geospatial ontology and semantic web, and volunteered geospatial information.

To effectively establish and exploit CyberGIS, however, requires the treatment of CyberGIS as an integrative framework of synthesizing cyberinfrastructure, GIS, and spatial analysis capabilities (Wang 2010). Moreover, past experiences in bridging cyberinfrastructure and domain sciences suggest that participation of domain application researchers is crucial to increasing the effectiveness and impact of cyberinfrastructure (Wang and Zhu 2008; Wilkins-Diehr 2007). The experience of the NSF TeraGrid GIScience Gateway based on the GISolve Toolkit (www.gisolve.org) has proved the feasibility of a CyberGIS prototype (Wang and Liu 2009), and demonstrated that experiences gained from experiments with a functional CyberGIS are extremely valuable to approach the science and applications of CyberGIS. Significant research and education challenges remain to be tackled with the following three listed as some examples:

- 1) *How to represent, evaluate, and resolve the computational intensity of spatial analysis and modeling?*
- 2) *How to facilitate collaborative spatial problem-solving and decision-making through virtual organizations, and conversely, how can spatial thinking approaches contribute to the development and improvement of virtual organization capabilities?*
- 3) *How to effectively and securely share and integrate decentralized spatial data, information, and analytical capabilities to develop and sustain evolving geospatial cyberinfrastructure and knowledge?*

To tackle these challenges requires application-driven approaches and the synergy of computational and spatial thinking by capturing spatial characteristics inherent in geospatial applications that affect the applicability, functionality, interoperability, and performance of CyberGIS. For example, such characteristics may be related to the properties of spatial

distribution and dependence within a massive dataset that needs to be divided, distributed, and analyzed in a collaborative fashion.

Regarding key characteristics, CyberGIS need to be user-centric, and represent high-performance, distributed, and collaborative capabilities for seamlessly integrating geospatial data handling and semantic synthesis with analysis and simulation. Data handling and spatial analysis must continue to be transformed from sequential to parallel, distributed computing environments to harness the massive power for unprecedented multi-scale geospatial inquiries accessible to individual researchers and the general public. Conventional approaches to data and information sharing and integration need to be reexamined to adapt to this transformation. Furthermore, the advancement of geospatial semantic web is needed to address the challenge of scalable knowledge sharing and participatory computing. As CyberGIS will enhance coordinated knowledge development capabilities, the explicit consideration of workflow and provenance will be crucial to the management of massive data and distributed complex workflow logic involved.

In addition, service-oriented architecture and virtualization design (aka cloud computing) combined with open standards, such as those developed by the Open Geospatial Consortium, can help assure the extensibility and interoperability of CyberGIS. Service infrastructure and interoperability remain to be difficult issues, the investigation of which requires experimental approaches to building and testing cutting-edge technologies.

Education and Workforce Development: Though tremendous opportunities are recognized with respect to CyberGIS, especially in the context of bridging cyberinfrastructure and GIScience, computational science and engineering have not yet been adopted as a mainstream in GIScience and geographic research. Conversely, spatial thinking approaches remain to have a great potential to contribute to the development and use of cyberinfrastructure. Consequently, the tight integration of research and education is crucial to the success of CyberGIS. It is therefore imperative that we create a highly educated, diverse workforce of educators, researchers, and practitioners who can become a critical mass to approach and advance the science and applications of CyberGIS.

Intellectual Merits: As the size of spatial datasets and complexity of spatial analysis and modeling increase, and the need for collaboration between cyberinfrastructure and GIScience research and education becomes compelling, the transformative research to establish CyberGIS becomes ever more important and timely. The intellectual merits of CyberGIS stem from the complexity of the challenges, the profound need to develop solutions that will benefit many fields of societal relevance, and the next generation GIS with synergistic high-performance, distributed, and collaborative capabilities.

Broader Impacts: CyberGIS hold a great promise to advance cyberinfrastructure and GIScience while helping solve many challenging scientific and societal problems (e.g., disaster response, energy, environment, national security, and transportation, to name a few), thus generating tremendously positive and broad impacts on billions of people across the globe. Engagement directly with communities, universities, national agencies, and international partners will be crucial in order to provide avenues for exploration of alternate theories, development of innovative technologies and applications, investigation of adoption barriers, and assessment of impacts. This engagement will make common CyberGIS platforms that can be shared by many application communities, to develop customizations for seeking broad-impact science, engineering, and societal solutions.

References

- NSF, 2003. *Revolutionizing Science and Engineering through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure*. Available at: http://www.communitytechnology.org/nsf_ci_report/ (accessed January 2010).
- Wang, S. 2010. A Cyber-GIS framework for the synthesis of cyberinfrastructure, GIS, and spatial analysis. *Annals of the Association of American Geographers*, forthcoming in July.
- Wang, S., and Liu, Y., 2009. TeraGrid GIScience Gateway: Bridging cyberinfrastructure and GIScience. *International Journal of Geographical Information Science*. 23 (5): 631-656.
- Wang, S., and Zhu, X.-G., 2008. Coupling cyberinfrastructure and geographic information systems to empower ecological and environmental research. *BioScience*, 58 (2), pp. 94-95.
- Wilkins-Diehr, N. 2007, Science gateways - Common community Interfaces to grid resources. *Concurrency and Computation: Practice and Experience*, 19 (6): 743-749.
- Wing J. M. 2006. Computational thinking. *Communications of ACM*, 49 (3): 33-35.