GIScience

GIScience (geographic information science) is a scholarly discipline that addresses fundamental issues surrounding the use of a variety of digital technologies to handle geographic information; namely, information about places, activities, and phenomena on and near the surface of the Earth that are stored in maps or images. GIScience includes the existing technologies and research areas of GIS (geographic information systems or GISystems), cartography (mapmaking), geodesy (measurement of the Earth itself), surveying (measurement of natural and manmade features on the Earth; also called geomatics in the U.S.), photogrammetry (measurement from photographs or images), global positioning system or GPS (precise and accurate positioning on the Earth's surface aided by satellites), digital image processing (handling and analysis of image data), remote sensing (observation of Earth from space or underwater), and quantitative spatial analysis and modeling.

GIScience therefore includes questions of spatial data structures, analysis, accuracy, meaning, cognition, visualization, and many more, and thus overlaps with the domains of several traditional disciplines that are concerned with Earth's physical processes or how humans interaction with the Earth (e.g., geography, geology and geophysics, oceanography, ecology, environmental science, applied mathematics, spatial statistics, physics), as well as disciplines that are concerned with how humans interact with machines (e.g., computer science, information science, cognitive science, cognitive psychology, artificial intelligence). However, GIScience is not central to any of these, representing instead a new kind of scientific collaborative that is defined by researchers from many distinct backgrounds working together on particular sets of interrelated problems; problems that are scientific in nature but also serve the needs of natural resource management, government, industry, and business.

It is important to make a distinction between GIS and GIScience. While GIS is concerned primarily with the hardware and software for capturing, manipulating, and representing geographic data and information (e.g., GIS as a container of data, maps, and software tools), GIScience is essentially the "science behind GIS" or the "science behind the systems." It can be defined further as the scientific research that is done both on and with GIS, ranging from the fundamental issues arising from the use of GIS (such as how to improve the interface to the system, to improve its overall design and usability, or to track error through the system), to the systematic study of geographic information using scientific methods (such as issues of scale, accuracy, and quantitative analysis of spatial data), even to the science that is done with GIS (e.g., the development of spatial models for predicting landslide susceptibility in a region, or of agent-based models for simulating the actions or interactions vehicles in a transportation network, or of a map or table or spatial statistic expressing environmental impacts resulting from the decision to commercially develop a piece of land).

A Brief History of GIScience

The origin of GIScience is traced back to two keynote addresses presented by Michael F. Goodchild of the University of California at Santa Barbara at conferences in Europe: one entitled "Spatial Information Science" to the Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland, July 1990 and the other, "Progress on the GIS Research Agenda" to the Second European GIS Conference, Brussels, Belgium, April 1991. In both of these keynote addresses Goodchild challenged the academic GIS community to move beyond a focus primarily on the technical capabilities of GIS to the more substantive intellectual challenges and scientific questions posed by the use of GIS, or the impediments to its use. This fundamental shift would thereby ensure the acceptance and longer-term survival of GIS within broader academia. These important presentations were later published in 1992 in a seminal paper for the *International Journal of Geographic Information Systems*, a paper that has since defined the field of GIScience. A few years prior to Goodchild's presentations in Europe, the National Science Foundation (NSF) had in 1988 awarded a multi-year, multi-million grant to University of California at Santa Barbara, the State University of New York at Buffalo and the University of Maine to form the National Center for Geographic Information and Analysis or NCGIA. This was the first major consortium of academicians formed to define and conduct research in the field, laying the foundations for current and future scholarly inquiry by way of its Initiatives 1-21 on topics ranging from the accuracy of spatial databases, to visualization of spatial data quality, to the social implications of GIS, to multiple roles of GIS in global change research, to collaborative spatial decision-making. Following on the success of the NCGIA, but seeking to realign its research, education, and outreach agendas on more basic, fundamental issues of GIScience, the NCGIA spawned Project Varenius in 1997. Project Varenius focused on several strategic areas of GIScience deemed among the most fruitful for advancing the field in the new context of 21st century information technology. These strategic areas were cognitive models of geographic space, geographies of the information society (including spatial data infrastructures), and computational implementations of geographic concepts (including overcoming the duality of spatially-continuous fields versus discrete objects). A series of Varenius specialist workshops was held on these topics and publications produced from 1997 to 1999.

In a somewhat parallel effort, in 1990 the NCGIA board of directors recommended that a more broadly based organization be established to engage the long-term participation of excellent researchers beyond the three-university consortium of the NCGIA, thereby supporting and promoting GIScience even further. The NCGIA responded by forming an ad hoc committee of researchers from sixteen institutions with prominent programs in GIS and representing seven different academic disciplines. These individuals gathered sufficient momentum to spawn a national meeting in Boulder, Colorado in 1994 attended by forty-two individuals representing thirty-three universities, research institutions, and the Association of American Geographers. This meeting established the University Consortium for Geographic Information Science or UCGIS as a formal non-profit organization with a charge, as indicated at www.ucgis.org, "to advance the understanding of geographic processes and spatial relationships through improved theory, methods, technology and data, and to promote the informed and responsible use of geographic information systems and geographic analysis for the benefit of society." The UCGIS has since grown to a membership of over eighty (at the time of this writing, seventy-three universities, three professional organizations, and eight corporate, government, and international members). The organization continues to seek ways to unify the academic GIScience research and education communities to speak with a strong voice on matters affecting resources and policies, particularly where the U.S. Congress and federal agencies such as NSF, the National Aeronautics and Space

Administration (NASA), the U.S Geological Survey (USGS), the National Geospatial-Intelligence Agency (NGA), the Federal Emergency Management Administration (FEMA), the Department of Homeland Security (DHS), and the National Oceanic and Atmospheric Administration (NOAA) are concerned. Over the years, the organization has formulated dozens of research and education priorities in GIScience, disseminated these via white papers, brochures, and occasional scholarly monographs, and assessed progress in relation to major federal programs and national interests.

In Europe, a similar effort was launched to form the Association of Geographic Information Laboratories for Europe or AGILE. AGILE was established in 1998 with mission and goals similar to UCGIS, and with an eye toward continuing momentum from the European GIS conference series, as well as new research initiatives developing within the European Science Foundation's GISDATA scientific program. AGILE promotes and develops GIScience initiatives in a manner similar to UCGIS with working groups, research initiatives, and small conferences and workshops for the exchange of ideas and strategic planning on promoting GIScience initiatives.

GIScience as a field of study has now reached a mature level with its own scholarly journals, research monographs, blogs, textbooks, core curricula, degree and certificate programs, research institutes, professional organizations, and conferences. For example, in addition to the UCGIS and AGILE, there are related organizations such as the Cartography of Geographic Information Society, the Open Geospatial Consortium, and the International Spatial Accuracy Research Association, leading peer-reviewed journals such as the *International Journal of Geographical Information Science* (published by Taylor & Francis) and *Cartography and Geographic Information Science* (published by the American Congress on Surveying and Mapping), as well as *Transactions in GIS* (published by Blackwell) and *Geoinformatica* (published by Springer). The GIScience series of conferences (www.giscience.org) has convened biennially since 2000, and several new conferences that have emerged in recent years such as GeoWeb (www.geowebconference.org), the International Conference on Geospatial Semantics and the Where 2.0 and OSCON conferences of O'Reilly Media (conferences.oreillynet.com) now regularly feature GIScience themes and research topics.

Examples of Research Topics in GIScience

Research in GIScience is now represented by literally scores of different topics and specialties, all arising from the questions raised by GIS and the other kinds of geographic technologies mentioned above. For example, there are questions of representation. How to represent the varied and infinitely complex features on the surface of the Earth? What criteria should be used to select a representation? How best to assess a representation in terms of its accuracy, its completeness? How should one store a given representation efficiently – what is the best data model to use conceptually and the best data structure to use computationally? How should extend a representation from the well-known two-dimensions of a flat surface to the three-, four- and n-dimensions needed to capture and understand dynamic processes in the atmosphere, the ocean, and the Earth's surface?

There are research questions in the realm of scale, which refers to the level of detail at which information can be observed, represented, and analyzed. How does changing the scale of data affect our understanding of the processes or patterns generating the data? Do processes always scale linearly or uniformly, and if not, how do we characterize or understand them? What are the best ways to describe scaling behavior? Should one use a fractal dimension or multifractals? Is there scale within the digital world of the computer (i.e., does a cartographer's representative scale for a paper map really matter for data sets that may never exist in paper map form)?

Research questions abound in other areas such as spatial data acquisition and integration, cognition of geographic information, interoperability of geographic information, spatial information policy and privacy, error and uncertainty of spatial data and analyses, and many more. Table 1 summarizes the many interesting areas that have persisted in GIScience and as well as though now emerging. Most of these have been identified and refined by the UCGIS over the course of their summer and winter assemblies of the past decade. Of note once again is that these do not focus on geographic technologies such as GIS, GPS, remote sensing, etc. but on several fundamental issues raised by the technologies, especially those impeding its more effective use. The science done with the technologies is motivated by the need for improved practice, observation, or spatially-explicit problem solving.

TABLE 1 HERE.

Table 1. Examples of high-priority research topics of GIScience. Source: UCGIS, AGILE, and GIScience 2008 (2008).

	Long-term Research Challenges	
Spatial Ontologies	Geographic Representation	Spatial Data Acquisition and Integration
Scale	Spatial Cognition	Space and Space/Time Analysis and Modeling
Uncertainty in Geographic Information	Geovisualization	GIS and Society: Interrelation, Integration, and Transformation
Geographic Information Engineering: Distributed and Mobile Computing	Geographic Information Engineering: Spatial Information Infrastructures	Geographic Information Engineering: Geospatial Data Mining and Knowledge Discovery
	Short-term Research Priorities	
GIS and Decision Making	Geospatial Web Service Interoperability	Location-based Services (including ethical and privacy dimensions)
Identification of Spatial Clusters	Geospatial Semantic Web and Information Semantics	Geographic Information Resource Management
Emergency Data Acquisition and Analysis	Gradation and Indeterminate Boundaries	Geographic Information Security
Geospatial Data Fusion	Institutional Aspects of Spatial Data Infrastructures	Geographic Information Partnering
Geocomputation	Global Representation and Modeling	Spatialization
Pervasive, Ubiquitous Computing and Geoinformation	Geospatial Cyberinfrastructure, including Design of Service-Oriented Architecture (SOA)	Dynamic Modeling
Public Participation GIS	Temporal GIS	Geospatial Visual Analytics

Education in GIScience

As the adoption of GIS technology and the principles of GIScience have continued to increase across academic, government and commercial sectors, there has been an increasing emphasis on ensuring an adequately trained and educated workforce in GIScience. Each year the demand by university students for courses not only in GIS but also in GIScience has increased, as has the demand for this coursework by geospatial professionals. Further, the advances in the technology and the research have spawned a national demand for sequences of courses external to traditional degree programs, hence the proliferation of certificates in GIS, in remote sensing, in surveying, and the like. In the late 1990s it became the view of many professionals within the GIScience community that the time had come to synthesize, articulate, and put into appropriate intellectual context the recent advances of this research for use in the classroom at both the undergraduate and graduate levels. As such, the UCGIS developed a set national priorities to advance GIScience education. Among these was a focus on emerging technologies for delivering GIScience education, including distance education (e.g., the web, multimedia audio and video files, digital libraries, tele-immersion, digital video, Internet2, and distributed classrooms connected by digital audio and video for two-way interactive lecture sessions). Supporting infrastructure to support GIScience instruction was a related priority, covering issues of facilities administration and staffing, design and maintenance, safety and security of labs and classrooms, and financial resources. Other priorities included access and equity issues (e.g., for students with physical or learning impairments or from disadvantaged or disenfranchised groups of society), alternative designs for curriculum content and evaluation, research-based graduate GIScience education, and learning with GIS (emphasizing the use of both GIS and GIScience to help students learn about other subjects such as environmental science).

Soon after developing its national education priorities the UCGIS embarked on an ambitious project to develop visionary model curricula for GIScience, designed to further aid in the development of an adequate supply of well–educated and well–prepared GIScientists and technologists. Desired outcomes a model curricula included: (a) demonstrated skill in integrative spatial thinking and effective implementation of various spatial analysis methods, as well as collaborative learning across several sub-disciplines within the GIScience field; (b) solid grounding in the appropriate application of related geospatial technology (software, data collection instruments and devices); and (c) familiarity with a wide variety of research applications, management and decision-support scenarios, with the capacity to apply knowledge to scientific and management problems at a variety of spatial and temporal scales.

Over an 8-year period (1998-2006), dozens of GIScience researchers and educators participated in workshops and related activities in developing an initial comprehensive inventory of knowledge and skills defining the field. The result was the first edition of the *GIScience & Technology Body of Knowledge* resource book and brochure, published in 2006 and detailing hundreds of topics, thousands of formal educational objectives, all organized into over seventy units within ten major knowledge areas.

The Body of Knowledge serves not only as a resource for course and curriculum planning but also as a basis for professional certification, program accreditation, and articulation agreements between four-year universities and two-year community colleges. Issues of certification where GIScience is concerned, and to a lesser degree accreditation and licensure, will be the subject of vigorous discussion and debate for the foreseeable future. As yet there is still no authoritative body that accredits a GIScience major, minor, or certificate program, as currently exists for engineering, urban planning, architecture, and other professionally oriented programs (keeping in mind that accreditation refers to programs in order to establish professional and ethical standards, whereas certification refers to individuals). This differs still from licensure, which is meant to protect the public from any harm that an incompetent professional may cause (as is the case with the licensing of land surveyors for example). Organizations such as the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, accredit traditional disciplines such as civil engineering and forest engineering. But these organizations are highly disciplinary in orientation and commonly review entire departments or colleges, rather than components of them. The Urban and Regional Information Systems Association (URISA) piloted a national program in 2003 to certify GIS professionals via a new GIS Certification Institute (GISCI), including an ascription to a GIS code of ethics. GISCI produced the first group of certified GIS professionals (aka GISPs) in 2003 and has since certified over 2000 more by way of a non-examination, portfolio-based system. GIScience coursework offered throughout the U.S. is eligible toward this national certification. The American Society for Photogrammetry and Remote Sensing certifies a range of GIScience professionals (mapping scientists and technologists in GIS/land information systems, remote sensing, and photogrammetry) via a peer-reviewed application and written examination.

Dawn J. Wright

See also 3-D Data Models, Analytical Operations in GIS, Cartography, GIS Design, Geocomputation, Michael Goodchild, History of GIS, Spatial Analysis, Spatial

Data Models

Further Readings

Association of Geographic Information Laboratories for Europe. [Online]. Retrieved June 1, 2008, from http://www.agile-online.org

DiBiase, D. DeMers, M., Johnson, A., Kemp, K. Luck, A.T., Plewe, B. and E. L. Usery (Eds.). (2006). *Geographic Information Science & Technology Body of Knowledge*, 1st edition. Washington, DC: Association of American Geographers and University Consortium for Geographic Information Science.

Goodchild, M.F. (1992). Geographic information science, *International Journal Geographical Information Systems, 6(1)*, 31–45.

Goodchild, M.F. (2006). Geographical information science: Fifteen years later. In P.F. Fisher (Ed.) *Classics from IJGIS: Twenty Years of the International Journal of Geographical Information Science and Systems* (pp. 199-204). London: Taylor & Francis.

Goodchild, M.F. (2006). GIScience ten years after *Ground Truth*, *Transactions in GIS, 10(5)*, 687–692.

Kemp, K. (Ed.), *Encyclopedia of Geographic Information Science*. Thousand Oaks, CA: Sage Publications.

McMaster, R.E. & Usery, E.L. (Eds.). (2004). *A Research Agenda for Geographic Information Science*. Boca Raton, FL: Taylor & Francis-CRC Press.

Wilson, J.P. & Fotheringham, A.S. (Eds.). (2007). *The Handbook of Geographic Information Science*. Malden, MA: Blackwell Publishing.

Wright, D.J., Goodchild, M.F., and Proctor, J.D. (1997). Demystifying the persistent ambiguity of GIS as “tool” versus “science,” *Annals of the Association of American Geographers, 87(2),* 346-362.

University Consortium for Geographic Information Science [Online]. Retrieved June 1, 2008, from http://www.ucgis.org