

c. Major Research Efforts

Geographic Information Science is the basic research field that seeks to redefine geographic concepts and their use in the context of geographic information systems. The latter in turn enable research and applications throughout the environmental and social sciences. As indicated above, the major research themes for our program over the next five years are basic geographic information science, geographic environmental science, and geographic social science. These three topics provide a broad yet intellectually coherent research environment for the continued growth of our program.

c.1 Basic Geographic Information Science

The basic research field of GIScience has many components (Mark, 2003), four of which are strongly represented at Buffalo: ontology of the geographic domain; cognitive geography and geographic cognition; human interaction with geographic information and technology; and geographic information, institutions, and society. These headings provide a framework for discussion of basic GIScience research at Buffalo and the ways in which trainees will be involved in that research. The Institute for Geoinformatics at the University of Münster, Germany, will be the primary site for International Research Internships by students specializing in this topic area.

c.1.1 Ontology of the Geographic Domain

Ontology seeks to define in formal terms the categories of entities and relations exemplified in specific domains of reality. Recently, ontology has become a key topic in information science (Welty and Smith, 2001). As is becoming increasingly clear, the rigorous specification of the ontology of a domain is a prerequisite for the efficient exchange and management of information, especially where this occurs across disciplinary boundaries. A clearly-specified ontology can also contribute to the semantic interoperability of the software and database components of diverse information systems. Much of the work on the cognitive and linguistic foundations of GIScience (cf. Mark and Frank, 1990) is best considered under the banner of ontology.

Ontological investigations in the information sciences have witnessed considerable expansion in recent years—most recently under the auspices of the Semantic Web project (Berners-Lee *et al.*, 2001)—in response to the need for standard reference terminologies to enable the efficient sharing of data resources among different information communities. An ontology describes in rigorous fashion the types of constituents of reality within a given domain and also the types of relations between these constituents. The research at Buffalo blends deductive reasoning, human subjects testing, and formalization (Smith and Mark, 2001). UB researchers are currently in an implementation phase, building prototype ontologies using standard ontology-coding environments as part of the current international effort in ontology standardization. Funds are requested in this proposal to purchase for Rational Rose UML Development software license for use in the next phase of this research.

Ontological research is useful not only in the domain of information fusion and standardization. Its methods can be applied also to the conceptualizations used by human beings and by different scientific disciplines. Ontology in this extended sense already plays a central role in the existing IGERT program in GIScience in Buffalo, where it has facilitated the building of bridges between fields as disparate as archeology, meteorology, geology, soil science, and military data fusion. It thus has already lent strong support to the interdisciplinary nature of our present IGERT program in ways that we believe are unique. ‘It is clear that, while the [current IGERT in GIScience] program has been in operation, Buffalo has become a world center of excellence in a new field of what might be called geographical ontology’ (Hayes, in Hill and Chase, 2002, p. 31).

Multidisciplinary geo-ontological research in Buffalo in the future will draw on the still only partially exploited results of our NSF-funded project (<http://www.geog.buffalo.edu/ngia/ontology>), in which UB IGERT faculty and fellows from a number of disciplines have carried out an extensive series of multi-language and multi-site experiments designed to establish how human subjects

conceptualize geospatial phenomena. The project has produced more than 20 publications over the first three years, and has accumulated a wealth of partially analyzed and as yet unpublished data that will fuel many additional papers and follow-up experiments in the future.

Our current IGERT faculty and fellows are engaged in constructing and testing a powerful formal-ontological framework for the treatment of spatial and temporal phenomena at different levels of granularity. This framework has the capacity to handle not only phenomena captured in the field-based representations used in geospatial sciences but also the objects and geospatial affordances—such as topographical features, land parcels, cities, armies—that are most salient to human beings in a range of everyday and professional activities. It can deal also with geographic processes—with changes and interactions of a range of different sorts and at a range of different levels of granularity—from both a field- and an object-based perspective. Some of the first results of this work are already being applied in Buffalo in work sponsored by defense agencies in disaster relief ontology and in the development of ontology-based visualization tools for what are called Level 3 Abstract Concepts in the military domain, such as *threat* or *opportunity*. Our work contributes also to the current international efforts in ontology development associated with the Semantic Web and related ventures, which seek to exploit ontologies as a means of fostering data integrity and reasoning efficiency in data processing across the internet. We plan to use our theoretically grounded formal ontology of the geospatial domain as a basis for studies of the interactions between geography and other disciplines at geographic scales—including meteorology, hydrology, ecology, transport science, demographics, criminology, and epidemiology. Whereas ontology may seem like an esoteric academic topic, current IGERT Fellows with a background in ontology have already begun to pursue career paths in the intelligence and security industries.

Graduate education and research training are strongly interwoven around the topic of ontology. All of our IGERT Fellows are required to take an introductory course in ontology of the geospatial domain, and many have taken additional ontology courses or seminars. The University at Buffalo has approved the hiring of two new tenure-track faculty members in the field, one of whom will be a specialist in geospatial ontology. Research in this area currently involves cooperation with several other faculty members and researchers at Buffalo, including James Llinas and Eric Little in the Center for Multisource Information Fusion in the Department of Industrial Engineering, Roberto Casati, Randall Dipert and David Hershenov in Philosophy, and Charles W. Dement (founder of Ontek Corporation) and others in the School of Management. Buffalo ontologists, both students and faculty, are also involved in collaborations with the Institute for Formal Ontology and Medical Information Science (Leipzig, Germany), the Laboratories for Applied Ontology (Trento, Turin and Rome, Italy) and the Research Group for Qualitative Spatial Reasoning (Leeds, England). These sites will provide opportunities for International Research Internships for our Fellows.

c.1.2 Cognitive Geography and Geographic Cognition

Buffalo has a long tradition of work on spatial cognition and language. Recent work by Smith (Philosophy) and Mark on elicited ontologies (Smith and Mark, 1999) straddles the line between ontology and cognitive studies. Much of Mark's work under this project involves human subjects testing to establish the nature of human conceptualizations of the geographic domain. Involvement of IGERT Fellows in this work exposes them to the principles and ethics of research involving human subjects. Mark is working with Andrew Turk of Murdoch University, Perth, Australia, on landscape entity type terms used by Australian aboriginal people, work which stands at the boundary between ontology and cognitive studies, and which also has potential to provide International Research Internship opportunities for Buffalo IGERT Fellows.

Four of our current IGERT trainees are specializing in Archaeology within the Anthropology department, under the direction of E. Zubrow and S. Milisauskas. The link between Archaeology and GIScience is mainly through the spatial cognition research topic; the research aims to recover the

spatial concepts and principles that influenced people's lives in the past, using GIS and related software to perform new types of investigations of archaeological sites and of the positions of artifacts within them.

IGERT students interested in geographic cognition will also be able to take advantage of the rich spectrum of research and teaching associated with Buffalo's Center for Cognitive Science. Notable among these is Leonard Talmy (Linguistics), the Center's Director, who is responsible for some of the most important conceptual work on spatial language. David Mark (Geography) continues to work on human navigation and way-finding, geographic categorization, and comparative cross-cultural studies of geographic cognition. J.-C. Thill (Geography) and I. Casas (Geography) work on spatial choice models in the context of behavioral geography. S. Shapiro (Computer Science and Engineering) has supervised research on spatial language and on reasoning about spatial relations.

Lastly, Buffalo is an International Partner of the International Quality Network (IQN) in Spatial Cognition, funded by the German Academic Exchange Service (DAAD). The universities of Bremen, Freiburg, and Hamburg have jointly established a Spatial Cognition Research Center. Under this program that fosters cooperative basic research in spatial cognition, interdisciplinary research training, application-driven investigations, and dissemination of results in seminars, conferences, and publications. It offers visiting opportunities for international researchers. One current IGERT Fellow, J. Galko (Philosophy), will spend summer 2003 in Bremen under this program.

c.1.3 Human Interaction with Geographic Information and Technology

The study of human interaction with geographic technologies and geographic information systems is an important element of GIScience. IGERT participating faculty A. Bisantz (Industrial Engineering) and C. Renschler (Geography) have recently initiated a project to investigate and develop solutions regarding distributed team decision-making in a location-based computer aided environment, where individual decision makers are linked through Heterogeneous Information Portals (HIP). The increasing availability of advanced computer and global positioning system (GPS) technologies has led to new opportunities for teams of decision-makers to collaborate and share information in dynamic, time-critical decision-making environments. In particular, the availability of technologies ranging in scale from wearable computers (in many forms), to hand-held devices, to desktop and large screen displays, to immersive virtual reality environments, along with the software and hardware means for connecting these devices, will allow teams of individuals to work collaboratively while simultaneously relying on very different forms of computer access. These technologies may also allow individual decision-makers to have different views of the same data at different locations and points in time depending on their needs and circumstances. The research will be in collaboration with T. Kesavadas (Mechanical Engineering) and Tom Fulani (Center for Computational Research). Hand-held GPS units are requested in the budget to support this and other IGERT research.

The involvement of Buffalo researchers in projects in human-computer interaction for GIS is well-established, and will continue in the future. D. Mark was co-leader on the NCGIA's research initiative on 'User Interfaces for Geographic Information Systems', and S. Shapiro (Computer Science and Engineering) led a project that developed a prototype multimodal interface for collaborative mission planning. Recently, N. Shiode and D. Mark were involved in a proposal to NSF's International Digital Libraries program that involves usability testing of the interface to georeferenced multimedia data provided by digital libraries. This latter project, which will develop a scientific portal for a multimedia database on the Silk Road through central Asia, continues collaboration with colleagues at the National Institute of Information in Japan, another potential host site for IGERT International Research Internships. The IGERT trainee research in human-computer interaction at Buffalo will be supported by the grant purchase of a SMART Board Interactive Whiteboard.

c.1.4 Spatial Databases

The study of spatial database design is a key part of the research agenda in GIScience, and a foundation of the field. IGERT Trainees in GIScience at Buffalo will be exposed to spatial database principles in their core coursework, and also will have opportunities to be involved in cutting-edge research in this area. UB GIScience researchers currently have several NSF grants involving image databases in a digital library context (Zhang and Mark, 2000; Zhang *et al.*, 2000, 2001). Geographic images acquired from satellites and airborne platforms, digital elevation models, and other data sources provide rich information about objects and patterns on the Earth's surface and have become ideal data sources for a wide range of image database analysis and modeling research. A. Zhang (Computer Science and Engineering) and her colleagues are investigating feature extraction, image statistics, and semantics-based approaches as ways to describe the content of earth images in terms of spatial-dependency (autocorrelation), scale-dependency, and human cognition of content. These approaches will automatically extract various levels of metadata including texture and color features, global statistical features, and high-level semantic keywords from geographic images. These metadata are then clustered and indexed to support effective and efficient querying and analysis on the content of images. In another spatial database project, D. Flewelling (Geography) and J. Chomicki (Computer Science and Engineering) are collaborating on research that will lead to methods for obtaining consistent query results from databases that contain inconsistent information.

c.1.5 Geographic Information, Institutions, and Society

Science and technology have a two-way relation with society—they influence many aspects of our lives and institutions, but they are themselves shaped by societal needs and values (Sheppard *et al.*, 1999). Research is being conducted at Buffalo on several aspects of this topic, under several research paradigms. Some of the research employs standard social science methods such as questionnaire surveys and statistical analysis to examine diffusion of technological innovation and the impacts of GIS technology on organizations that adopt it. Other work, informed by social theory, explores the ways in which information technology shifts power and responsibility within society. Still other efforts examine the interactions between geographic information technology and the legal system, with attention to issues such as privacy, liability, intellectual property, and information access.

The integration of GIS with qualitative research methods is an important research topic. Research in this area will incorporate results of qualitative research into GIS applications and the use of qualitative research to enhance the rigor and reliability of GIS research. It will address epistemological issues that arise when we seek to combine GIS-related technologies with qualitative research methods. Currently the development of research questions in social science is constrained by available GIS software. Part of our efforts in basic GI Science research is designed to provide the intellectual and technical foundations for an awareness on the part of GIS developers of the limitations that the software places on its users, so that future software will afford a more diverse range of applications. M. Cope (Geography) and two current IGERT Fellows working under her direction are conducting research on this topic at UB, which will use NVivo qualitative data analysis software to be purchased through this grant. One of those students co-organized several sessions on the integration of qualitative methods and GIS at the national meeting of the Association of American Geographers, and will co-edit a special issue of *Environment and Planning A* on this topic. In a related project, Cope is examining how children conceptualize urban space, and how we can improve the teaching of geographic concepts in the lower grades (Cope, 2001).

N. Shiode (Geography) is working on a related topic: the ways in which wireless communication is leading to a ubiquitous information society: With the rapid deployment of the high speed wireless broadband communication networks, our ideas of accessibility and opportunity will change dramatically over the next decade. The geography of information will become more compact yet increasingly complex and diverse, reflecting the extent of social and economic activities that take

place within and around such networks. This project will include a series of quantitative analyses on wireless subnetworks and build a simulation model, which would help us understand and predict the newly emerging network spaces.

In additional GI and Society research at Buffalo, one of our current IGERT Fellows (J. Morgan) is conducting a telephone survey examining citizens' concerns about information privacy and possible changes due to increased concern for homeland security; this work is being directed by D. Mark (Geography). Another IGERT Fellow (K. Syfert) is conducting dissertation research on the role of women in the information technology sector in Japan, with particular emphasis on the GIS industry under the direction of C. Frake (Anthropology). These current projects communicate the flavor of projects that IGERT trainees may become involved with in future in this research area.