

Geographic Information Science & Technology Body of Knowledge

Edited by David DiBiase, Michael DeMers, Ann Johnson, Karen Kemp, Ann Taylor Luck, Brandon Flewe, and Elizabeth Wentz

UNIVERSITY CONSORTIUM FOR GEOGRAPHIC INFORMATION SCIENCE

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Geographic Information Science and Technology
Body of Knowledge

First Edition

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Edited by
David DiBiase, Michael DeMers, Ann Johnson, Karen Kemp,
Ann Taylor Luck, Brandon Plewe, and Elizabeth Wentz

with contributions by
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and Body of Knowledge Advisory Board

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Foreword

GIS&T: Transforming Science and Society

Former National Science Foundation (NSF) Director Rita Colwell, in her article “The New Landscape of Science: A Geographic Portal” (Colwell, 2004), pointed out that geography and its revolutionary new technologies are “well poised at this watershed juncture to help shape the new landscape of science.” This book marks an important step in that process. Geographic Information Science and Technologies (GIS&T) have today become critical components of the global cyberinfrastructure, both in the university and in society. The integrative capabilities of these and related technologies have extended research frontiers across many fields, in areas ranging from biocomplexity to epidemiology to transportation engineering. Technologies such as geographic information systems (GIS) also have increasingly become the common ground for sharing data across disciplines, or the “glue” which connects large-scale interdisciplinary research, including much that is funded by NSF and other federal agencies.

The *Geographic Information Science & Technology Body of Knowledge* will have application and impact far beyond geography. To the extent that many multidisciplinary research and application projects now depend on the integrative and analytical power of new geographic technologies, many disciplines within the academy are also finding it essential to incorporate spatial concepts and perspectives into their curricula and educational programs (NRC, 1997). The technical expertise and theoretical insights which have been developed over the recent decades within the Geographic Information Science & Technology infrastructure constitutes a Body of Knowledge increasingly necessary to advancing research agendas across the university campus in programs ranging from statistics to biology, from engineering to law, and from sociology to computer science. As Harvard President Lawrence Summers noted on May 5, 2006 at the launch of Harvard's new Center for Geographic Analysis, “By embracing the new geography, I think Harvard is taking an important step today. This is an opportunity to explore vast intellectual territo-

ry...intellectual territory that can now be approached with new perspectives, new tools, and in newly important ways” (Richardson, 2006).

The call for collaborative, cross-sectoral, and interdisciplinary research agendas encompasses a wide array of themes, such as dynamic modeling, change studies, environmental assessments and interventions, complexity studies, assessments of how technologies are impacting lives, evaluations of political processes, and many more. The revolutionary new geographic technologies developed over the past several decades create far-reaching opportunities for individual researchers and collaborative teams in the social sciences, the natural sciences, and the humanities. GIS and related technologies can help to catalyze new research, scholarship, and teaching within these fields, without diminishing traditional methods of research or threatening the richness and diversity of traditional approaches within individual disciplines.

The GIS&T cyberinfrastructure also plays a central role in the larger society. A transformational feature on the GIS&T landscape, and a significant opportunity for our society, for example, will be the widespread continued development and implementation over the next several decades of real-time interactive Geographic Management Systems (GMSs) as core daily operations management networks within most governmental and business organizations (Richardson, 2001; Abler and Richardson, 2003). Currently evolving examples of GMSs range from simple applications, such as real-time management of vehicle fleets or delivery companies, to the continuous interactive management across space and time of the extensive fixed and mobile assets and workforces of highly complex operations, such as those of major electric utility companies, most modern military organizations, governmental emergency response agencies, national park agencies, automated transportation and logistics systems, and international disaster and humanitarian relief operations. GMSs’ dynamic space and time interactive core capabilities create a powerful platform for integrating many other technologies and applications, including wireless communications, environmental sensors, work-order processing, remote sensing and imagery, software agents, econometric modeling, and others.

This book will be an important reference and guide for these existing and future GIS&T infrastructures in science, in society, and in education. Significant credit for the development of the *GIS&T Body of Knowledge* goes to Duane Marble, who both advocated for and pioneered the development of the *Body of Knowledge* throughout the 1990s. Without Duane Marble’s early efforts in this arena, this book would not exist. More recently, the work begun by Marble has been continued by many, including the UCGIS education committee, ably chaired by David DiBiase.

This current work, the First Edition of the *GIS&T Body of Knowledge* is, as it must be, a work in progress. The AAG, as publisher, is committed to working with others to enhance, extend, refine, and continuously update this work in future editions. Subsequent editions will seek to extend the work to curricular implementations, to encompass new and rapidly evolving technologies in the GIS&T fields, and to broaden its focus as the science and technologies themselves become broader and more fully integrated.

The needs to enhance the diversity and build the capacity of the GIS&T cyberinfrastructure within the academic and scientific workforce, and in the larger societal GIS&T workforce, are critical. In fact, the US Department of Labor recently designated geotechnology as “one of the three most important emerging and evolving fields, along with nanotechnology and biotechnology” (Gewin, 2004). Employment opportunities and workforce development needs are growing worldwide as geographic technologies become pervasive in ever more areas of research and the economy.

This process of rapid scientific and technological transformation within GIS&T and in society raises public policy issues as well. The embedding of GIS&T into society is resulting and will result in a broader range of users becoming involved with the GIS&T cyberinfrastructure. These include governments, corporations, workers, consumers, and citizens. Hand in hand with this broadening of participants and applications comes the potential for abuse, raising legitimate concerns about issues such as privacy, data confidentiality, and civil liberties (Armstrong, 2002; Onsrud, 2003). As geographic data become more omnipresent, accurate, and locationally specific, the concerns that arise include a potential lack of public accountability by organizations producing and using geographic data (Pickles, 1995). The *GIS&T Body of Knowledge* also acknowledges the importance of these knowledge areas in a section on GIS&T and Society. Researchers and educators have a key role to play in the future implementation and management of the powerful capabilities of advanced geographic technologies, mediating the risk that is inherent in all technology for potential abuse, and assisting with the development of appropriate legal and regulatory frameworks governing their application. Social scientists engaged in critical analysis of GPS/GIS based geographic technologies—including consumer applications such as the increasingly widespread location-based services (LBS)—can contribute to shaping the future of geographic applications in government and commerce, and in helping to ensure a balance between the benefits and potential misuse of such technologies (Richardson and Solís, 2004).

At the same time, the new geographies engendered by the GIS&T infrastructure offer the promise of better-informed communities, more inclusive practices of government, and greater empowerment of citizens in the decisions affecting their daily lives (Craig and Elwood, 1998; Sieber, 2000). Ultimately, such technologies can present opportunities for enabling democratic processes, enhancing e-government, and promoting social justice. Examples of participatory uses of GIS&T, for example, range from integration of local knowledge into land reforms to collaborative forest management, reclamation of native ancestral lands, and placing the interests of less privileged groups on the broader public agenda (Forbes, 1995; Smith, 1995; Harris & Weiner, 1998; Kyem, 2002).

Of course, neither processes of innovation nor patterns of adoption are spatially uniform. This uneven development offers further potential for social scientists to become involved with the ongoing dynamics of technological change within the GIS&T cyberinfrastructure throughout society. The rapid growth of the GIS&T cyberinfrastructure and the central role it plays in the university and in society challenges us also to increase the participation of currently underrepresented groups by developing meaningful, viable approaches to diversifying the GIS&T research and education workforce, and ultimately the larger soci-

etal GIS&T workforce. This book can be an important resource in the development of specific pathways for diversification of the GIS&T cyberinfrastructure workforce.

Finally, for those of us who have long been engaged in the research and development of the Geographic Information Science and Technology infrastructure, it is gratifying to see this effort to codify the results of this exciting and dynamic field of inquiry into a systematized Body of Knowledge that will support education and continued development of GIS&T in the future. I commend the editors for this important beginning, and look forward to working together with the entire GIS&T community to evolve and update this Body of Knowledge in the years ahead.

Douglas Richardson

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Treasurer and Board Member
University Consortium for
Geographic Information Science (UCGIS)

Introduction

This first edition of the *Body of Knowledge* is one in a series of works produced as part of the Geographic Information Science and Technology (GIS&T) Model Curricula initiative. The initiative has involved more than 70 educators, researchers, and practitioners, coordinated by the Education Committee of the University Consortium for Geographic Information Science (UCGIS). UCGIS was formed in 1994 to provide a coherent voice for the geographic information science (GIScience) research community. With this contribution, UCGIS hopes to foster greater coherence and effectiveness within the GIS&T education community.

The Model Curricula initiative arose from a set of eight Education Challenges identified at the 1997 UCGIS Summer Assembly in Bar Harbor, Maine. One challenge concluded that “improving GIScience education requires the specification and assessment of curricula for a wide range of student constituencies” (Kemp and Wright, 1997, p. 4). A Model Curricula Task Force, chaired by Duane Marble, was formed in 1998. In 2003 the Task Force issued a “Strawman Report” that presented an ambitious vision of national-scale curricular reform for GIS&T undergraduate education in the U.S. Central to that vision is a “Body of Knowledge,” a comprehensive inventory of the GIS&T knowledge domain. The Strawman Report included an initial draft of a Body of Knowledge. The Task Force recommended that the draft be reviewed widely, and expressed hope that a future revised version would be “representative of the views of the majority of the broad GIS&T community” (Marble et al., 2003, p. 27).

This document presents an elaborated version of the *GIS&T Body of Knowledge* that has been revised by a team of seven editors in consultation with a fifty-four-member Advisory Board. The current version includes more than 330 topics organized into seventy-three units and ten knowledge areas. Each topic is defined in terms of formal educational objectives from which instructional activities and assessment instruments can readily be derived. Prior to formal publication as the *Body of Knowledge*, a draft manuscript was made available for public review and comment from mid-November 2005 through January 31, 2006.

The impetus for the Model Curricula initiative was a concern that dated undergraduate curricula were failing to prepare students for the demands of the workplace. The *Body of Knowledge* is intended to serve as a reference work for curriculum planners working at all levels of higher and continuing education. Subsequent developments in the GIS&T field have presented several new and equally compelling uses, however. Professional certification and academic accreditation, for instance, were matters of conjecture in 1998, but now are realities. These and other developments are more likely to be beneficial to the GIS&T field—and to society—if they are grounded in a detailed and comprehensive accounting of the knowledge and skills that characterize educated and experienced GIS&T professionals. With this in mind, the UCGIS Education Committee has elected to publish this first edition of the *GIS&T Body of Knowledge* as a discrete work, rather than to wait until all other aspects of the Model Curricula vision have been realized. As has been the case in allied fields that have developed their own bodies of knowledge, we expect that later editions will account for changes in our dynamic field, and will address the shortcomings that will inevitably be noted in this attempt.

The *Body of Knowledge* represents a community effort and has been subjected to intensive peer review. Contributors to the ten knowledge areas include the editors, Task Force members, Advisory Board members, and other concerned scholars and practitioners who responded to invitations for public comment. The final manuscript reflects the critiques of thirty-one individual reviewers. Not every reviewer will be satisfied with the outcome, of course. Most important among unresolved critiques may be one that objects to the compilation of a body of knowledge on the grounds that it represents an attempt to regulate how GIS&T is taught, and to privilege one way of knowing and thinking about GIS&T over others. But the *Body of Knowledge* is not meant to be an exhaustive consideration of the diverse ways in which GIS&T may be used to enrich individual lives, to strengthen communities, and to promote justice and equity in society. Instead, we aspire to the more modest goal of helping bridge the gap between the GIS&T higher education community and the practitioners, employers, and clients who populate the various GIS&T professions—a gap that is in some cases profound. To the extent that the *Body of Knowledge* fosters this connection, it will advance UCGIS' goal to “expand and strengthen Geographic Information Science education at all levels” (UCGIS, 2002). The *Body of Knowledge* is, we believe, one expression of the coalescence of the GIS&T field, a trend that is both inevitable and, if managed in a participatory manner, desirable.

The document includes six sections. The first scopes the GIS&T domain, identifies its constituent subdomains, and describes relationships to allied fields such as Computer Science and Information Science. Section II, entitled “Why is a GIS&T Body of Knowledge Needed?,” recounts the workforce issues that drive concerns about GIS&T education and training, examines the “education infrastructure” that is responsible for addressing workforce needs in the U.S., and identifies potential benefits of a Body of Knowledge. Section III situates the Model Curricula project and the *Body of Knowledge* within the historical context of GIS&T curriculum development efforts in the U.S. Section IV, “How was the Body of Knowledge Developed?,” describes the Model Curricula vision and explains how the *GIS&T Body of*

Knowledge has evolved since the 2003 Strawman Report. Section V presents the ten knowledge areas that comprise the *Body of Knowledge* itself. Finally, Section VI speculates on the future evolution of the GIS&T domain and the GIS&T education infrastructure, and suggests a timetable for future Model Curricula activities.

On behalf of my colleagues on the editorial team, I wish to thank the Model Curricula Task Force members who volunteered so much time and passion in the service of such a challenging cause. Since 2003, several of these colleagues have continued to serve as editors or as Advisory Board members, content experts, and reviewers. I thank Barbara Trapido-Lurie of Arizona State University, who helped us realize the illustrations that appear in sections I-IV. The editors wish to thank our sponsors, including Intergraph, GE Smallworld, and especially ESRI, which provided financial support that helped to defray volunteers' travel expenses. Thanks also to the National Academies of Science, which commissioned some of the research reported in Sections II and III, and graciously permitted its publication here. We appreciate the encouragement and cooperation of UCGIS officers, Board of Directors, and the Executive Director. We are also grateful to the Association of American Geographers for publishing and supporting the work.

David DiBiase
Managing Editor
Chair, UCGIS Education Committee

What is Geographic Information Science and Technology?

The Domain of GIS&T

Governments, militaries, commercial enterprises, and other interests rely on information about the land and the location and characteristics of people and resources. For centuries, maps have served as the primary mechanism for managing and communicating geospatial information. In the 1960s, computerized geographic information systems (GIS) emerged as a means to manage and analyze such information more efficiently and effectively. Since then, computing power has increased, data have become plentiful, software has become easier to use, and the scope and complexity of questions that GIS is capable of addressing has expanded dramatically. GIS and related technologies are now widely used in government agencies, private businesses, citizens groups, and research institutions. As the demand for these technologies has grown, and as their applications have diversified, the field concerned with the development and use of these technologies has also evolved. Today, GIS software is only one component of a broad domain that we refer to as Geographic Information Science & Technology (GIS&T), which is composed of three interrelated sub-domains (Figure 1). (Some members of the GIS&T community, as well as some important stakeholders, refer to the GIS&T field as simply “geospatial.” Connotations of this term still vary widely, however. See section II below.)

One sub-domain is **Geographic Information Science** (GIScience). GIScience is a multidisciplinary research enterprise that addresses the nature of geographic information and the application of geospatial technologies to basic scientific questions (Goodchild, 1992). Based primarily in the discipline of geography, but drawing upon insights and methods from philosophy, psychology, mathematics, statistics, computer science, landscape architecture, and other fields, GIScientists produced much of the knowledge represented in the ten knowledge areas that comprise the Body of Knowledge.

A second sub-domain is **Geospatial Technology**, the specialized set of information technologies that handle georeferenced data. Geospatial technologies support a wide variety of uses, from data acquisition

(e.g., aerial imaging, remote sensing, land surveying, and global navigation satellite systems), to data storage and manipulation (e.g., GIS, image processing, and database management software), to data analysis (e.g., software for statistical analysis and modeling) to display and output (e.g., geovisualization software and imaging devices). GIScience and applications inform the development of geospatial technologies, but technology development requires contributions from information science and engineering.

The third sub-domain, **Applications of GIS&T**, includes the increasingly diverse uses of geospatial technology in government, industry, and academia. A few examples include near real-time analysis of service outages in electrical networks, applications in military intelligence and operations, homeland defense planning and operations, facilities siting, environmental impact assessment, property tax and land ownership records management, and truck route optimization for solid waste pickup in urban areas. The number and variety of fields that apply geospatial technologies is suggested in Figure 1 by the stack of “various application domains.”

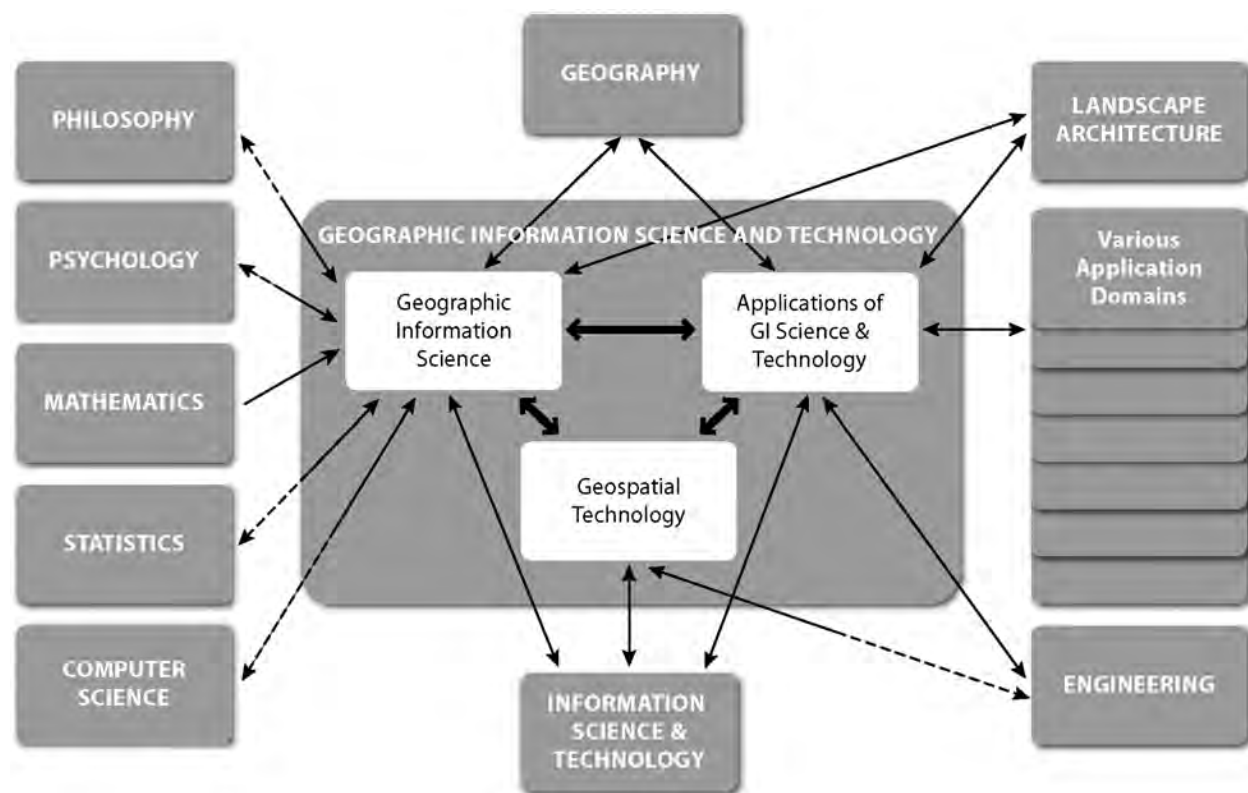


Figure 1: The three sub-domains comprising the GIS&T domain, in relation to allied fields. Two-way relations that are half-dashed represent asymmetrical contributions between allied fields.

The two-way connections depicted in Figure 1 between GIScience, geospatial technology, and applications are significant. Since the early days of GIS, technology users at the application level have challenged geospatial technology developers to provide theoretical solutions and effective tools to deal with complex real-world problems. One example is the set of problems that requires the explicit incorporation

of true volumetric and temporal components into traditional spatial analysis. Problem-induced feedbacks represent an important complement to the traditional science→engineering→users chain.

In addition to the three sub-domains that comprise GIS&T, Figure 1 also depicts contributions to the sub-domains by key allied fields, including philosophy, psychology, mathematics, statistics, computer science, information science and technology, engineering, landscape architecture, and especially geography. Conversely, GIS&T also has contributed to several of these associated fields (for example, the additions of spatial statistics, spatial econometrics, and geostatistics to the general field of statistics).

Unlike other information technology fields, including computer science and information science, there has, until now, been no collective effort by a community of researchers and educators to specify a comprehensive body of knowledge that defines the GIS&T domain. The *Body of Knowledge* is an attempt to fill that void. Like similar documents produced in allied fields, we expect that the *GIS&T Body of Knowledge* will be revisited and revised in years to come.

Why is a GIS&T Body of Knowledge Needed?

Workforce needs

Size of the geospatial enterprise: There is little question that the geospatial information enterprise is large and growing. Absent a standard industry definition, however, estimates of the size of the enterprise have varied. Technology market research firm Daratech (2004) estimated that worldwide sales of GIS software, services, data, and hardware totaled \$1.84 billion in 2003. Daratech predicted that total revenues increased nearly 10 percent in 2004. The American Society for Photogrammetry and Remote Sensing's (ASPRS) survey of the "remote sensing and geospatial information industry" led it to estimate 2001 industry revenues at \$2.4 billion, and to predict growth to more than \$6 billion by 2012 (Mondello, Hepner, & Williamson, 2004). The National Aeronautics and Space Administration (NASA), in consultation with the Geospatial Workforce Development Center at the University of Southern Mississippi, estimated that the U.S. "geospatial technology" market would generate \$30 billion a year by 2005—\$20 billion for remote sensing, \$10 billion for geographic information services (Gaudet, Annulis, & Carr, 2003). This most optimistic prediction, based on an expansive conception of the geospatial information industry that includes remote sensing, GIS, and global positioning system technologies, has since been adopted by the U.S. Department of Labor (U.S. Department of Labor, n.d.).

Size of the geospatial workforce: Because of the varied definitions, broad scope, and rapid evolution of the geospatial enterprise, reliable information about the size and composition of the geospatial workforce is difficult to obtain (Ohio State University, 2002). A few telling estimates do exist, however. ASPRS estimates that about 175,000 people are employed in the "U.S. remote sensing and geospatial information industry" (Mondello, Hepner, and Williamson, 2004). Environmental Systems Research Institute (ESRI), which along with Intergraph accounts for nearly half of the worldwide GIS software market, estimated in 2000 that 500,000 individuals in the U.S. use its software products as part of their jobs, and that some 50,000 individuals work as full-time GIS specialists (Phoenix, 2000). Longley and colleagues

estimate that there are some four million GIS users worldwide, working at some two million sites (Longley, Goodchild, Maguire, & Rhind, 2005). Whatever the actual size of the geospatial information workforce, everyone seems to agree that there are too few qualified workers available to support the industry's growth.

Inadequate supply of geospatial professionals: NASA launched a National Workforce Development Education and Training Initiative in 1997 to address the “serious shortfall of professionals and trained specialists who can utilize geospatial technologies in their jobs” (Gaudet, Annulis, & Carr, 2003, p. 21). ESRI Higher Education Marketing Manager Michael Phoenix estimates that “the shortfall in producing individuals with an advanced level of GIS education is around 3,000 to 4,000 [annually] in the U.S. alone” (Phoenix, 2000, p. 13). The Assistant Secretary for Labor and Training of the U.S. Department of Labor has pointed to survey data indicating that “87 percent of geospatial product and service providers ... had difficulty filling positions requiring geospatial technology skills” (DeRocco, 2004, p. 2). So bullish is the U.S. Department of Labor (DoL) about prospects for growth in “geospatial-related occupations” (Table 1) that it identified geospatial technologies as one of twelve “high-growth” industries. Citing “an immediate and anticipated need to fill tens of thousands of positions,” DoL launched the “President’s High Growth Job Training Initiative” in 2003 (Department of Labor, n.d.). Seeking “alternatives to the traditional pipeline” of four-year degree programs, DoL’s Education and Training Administration is investing up to \$250 million to develop training programs at community colleges (Department of Labor, n.d.). While industry insiders may consider the Department of Labor’s conception of the geospatial industry far too inclusive (e.g., Sietzen, 2004), no one is likely to contest DoL’s analysis that workforce issues have become urgent.

Occupation	2000-2010 Growth (projected)
Cartographers and Photogrammetrists	18.5%
Surveyors	08.1%
Surveying and Mapping Technicians	25.3%
Architectural and Civil Drafters	20.8%
Civil Engineering Technicians	11.9%
Mechanical Drafters	15.4%
Electrical Drafters	23.3%
Electrical and Electronic Engineers	10.8%
Mechanical Engineering Technicians	13.9%
Industrial Engineering Technicians	10.1%
Environmental Engineering Technicians	29.1%
Geoscientists	18.1%

Table 1: U.S. Department of Labor “Geospatial Jobs Outlook” (Department of Labor, n.d.).

Inadequate preparation for high tech roles: Concerns about the preparedness of those who enter the workforce through the “traditional pipeline” of four-year degree programs are less frequently expressed than worries about the quantity of such workers. Such concerns do exist, however. Respondents to the ASPRS industry survey complained not only about the “shortage of trained workers emerging from educational programs,” but also about “the lack of the required skill sets among many of the graduates” (Mondello, Hepner, & Williamson, 2004, p. 13). Since education degree and certificate programs that

specialize in GIS&T are not specifically accredited, it is difficult to judge objectively the educational effectiveness of the traditional pipeline. Even so, a brief review of two critiques is instructive.

1. **Unregulated academic certificate programs:** Ironically, one set of concerns follows from the attempts of higher education institutions to respond to the increasing demand for specialized geospatial education and training opportunities. Some 120 U.S. higher education institutions have developed academic certificate programs that promise to help students to develop GIS-related knowledge and skills and to earn credentials that will help them compete for jobs or advance their careers in the geospatial industry. The proliferation of academic certificate programs is not unique to GIS, of course. The U.S. Department of Education lists over 2,000 post-graduate certificate programs that serve as many as 40-45 million people in the U.S. (Irby, 1999). Wikle (1998) points out that academic certification programs in GIS vary widely in scope, focus, and rigor. Ted Marchese (1999, p. 4), long-time vice president of the American Association for Higher Education, has observed that "...developments in the postsecondary marketplace are quickly outrunning the capacity of existing quality assurance mechanisms to assure fair practice." This "can make it difficult for students and employers to assess the value of these programs" (Lapidus, 2000, p. 7). The lack of standards and accountability for academic certificate programs led veteran GIS practitioner and educator William Huxhold to complain that "today anybody can teach anything and call it GIS education. ... Who knows whether the skills being taught in these programs are needed to become a GIS professional?" (Huxhold, 2000a, p. 25)
2. **Insufficiently rigorous undergraduate programs:** In 1998, Duane Marble published an influential critique of the "low-level, non-technical" character of GIS education in undergraduate degree programs (Marble, 1998, p. 28). "Existing GIS education," Marble claimed, "fails to provide the background in GIScience that is necessary to meet the needs either of the users of GIScience technology or of the scientific community engaged in basic GIScience research and development" (Marble, 1999, p. 31). Unlike students in the early days of GIS education, when the primitive state of the technology necessitated programming skills, Marble pointed out that latter day students and some instructors believe that all one has to do to become a GIS professional is to master the standard functions of commercial off-the-shelf (COTS) software. Thus, graduates are no longer prepared "to make substantial contributions to the ongoing development of GIS technology" (Marble, 1998, p. 1). Advanced knowledge and skills in computer and information sciences are needed more than ever, he argued, to realize the full potential of GIS&T.

Marble identified a "pyramid" of six competency levels that undergraduate degree programs should prepare students to achieve (Figure 2). Public awareness of geospatial technologies constitutes the base of the pyramid. One level above the base is the relatively large number of workers who need to be prepared for careers involving "routine use" of COTS software and related geospatial technologies. A somewhat smaller number of graduates needed to work with "higher level modeling applications" within COTS software must possess knowledge and skills in spatial analysis, computer programming, and database man-

agement systems. More demanding and fewer still are “application design and development” roles that require workers to create software applications rather than to simply use them. Specialists responsible for “system design” require advanced analytical as well as technical skills, including system analysis, database design and development, user interface design, and programming. Finally, the peak of the pyramid represents the relatively small number (perhaps 10,000 or more worldwide) of individuals whose sophisticated understanding of geography, spatial analysis, and computer and information sciences prepares them to lead “research and software development” teams within software companies, government agencies, and in universities. Marble (1998) argued that the base of the pyramid is expanding “at explosive rate while the upper levels have been permitted to crumble” (p. 29).

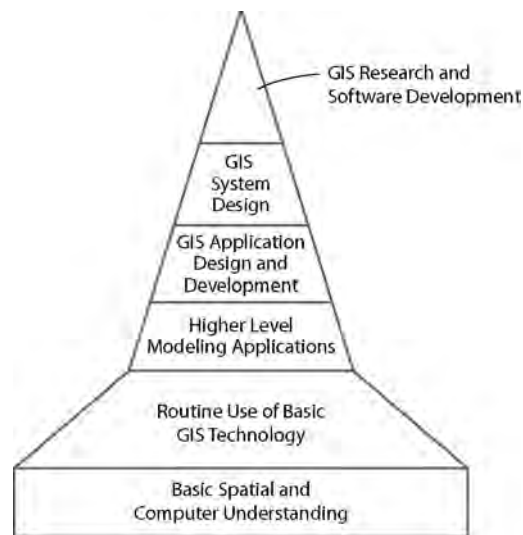


Figure 2: “Pyramid” of roles played by GIS&T professionals. Fewer, but more highly skilled, personnel are needed at the upper levels of the pyramid. (Marble, 1998).

To counteract what he viewed as a failing undergraduate education system, Marble (1998) argued for a “full-fledged examination of the entire spectrum of courses required to support an adequate education at each level of the pyramid” (p. 29). His critique and prescription resonated within the GIS software industry, which subsequently supported efforts to define a new undergraduate curriculum that “immediately reestablish[es] the strong role of computer science education within GIS” (Marble, 1998, p. 29) The resulting Model Curricula initiative, as well as other related efforts, is reviewed in the section on how the *Body of Knowledge* relates to other curriculum efforts.

NASA Geospatial Workforce Development Initiative: Participants in a 2001 “research definition” workshop at the Ohio State University noted that the “nearly complete lack of supply and demand data ... is severely hampering GIS&T development and application in this country ... The Workshop strongly recommends that statistical and other studies of the overall GIS&T workforce ... be undertaken as soon as possible” (Ohio State University, 2002, p. 19). Independently, and motivated primarily by concern

about the U.S. remote sensing industry workforce, in 2001 NASA mobilized a team of workforce development specialists at the University of Southern Mississippi to carry out a study to identify key competencies of geospatial professionals. The Geospatial Workforce Development Center (later reorganized as the Workplace Learning and Performance Institute) convened workshops involving representatives of sixteen leading businesses, government agencies, and professional societies in the geospatial arena. Using focus group and group systems methodologies, researchers asked representatives to identify the key competencies and roles that their employees or constituents were expected to play. The twelve roles identified in the study appear in Table 2.

Applications Development	Identify and develop tools and instruments to satisfy customer needs
Data Acquisition	Collect geospatial and related data
Coordination	Interorganizational facilitation and communication
Data Analysis and Interpretation	Process data and extract information to create products, drive conclusions, and inform decision-making reports
Data Management	Catalog, archive, retrieve, and distribute geospatial data
Management	Efficiently and effectively apply the company's mission using financial, technical, and intellectual skills and resources to optimize the end products
Marketing	Identify customer requirements and needs, and effectively communicate those needs and requirements to the organization, as well as promote geospatial solutions
Project Management	Effectively oversee activity requirements to produce the desired outcomes on time and within budget
Systems Analysis	Assess requirements to produce the desired outcomes on time and within budget
Systems Management	Integrate resources and develop additional resources to support spatial and temporal user requirements
Training	Analyze, design, and develop instructional and non-instructional interventions to provide transfer of knowledge and evaluation for performance enhancement
Visualization	Render data and information into visual geospatial representations

Table 2: Twelve roles played by geospatial technology professionals (Gaudet, Annulis, & Carr, 2003).

Roles were defined as subsets of thirty-nine particular competencies. Competencies rated as “important” by at least 50 percent of role experts were deemed “core competencies.” Competencies appear in Table 3, clustered into four categories. Authors of the study conclude that “For geospatial technology professionals to be successful in today’s marketplace, it is critical to understand that the knowledge, skills, and abilities required for their jobs include a blend of technical, business, analytical, and interpersonal competencies” (Gaudet, Annulis, & Carr, 2003, p. 25).

TECHNICAL COMPETENCIES**Ability to Assess Relationships Among****Geospatial Technologies**

Cartography

Computer Programming Skills

Environmental Applications

GIS Theory and Applications

Geological Applications

Geospatial Data Processing Tools

Photogrammetry

Remote Sensing Theory and Applications

Spatial Information Processing

Technical Writing**Technological Literacy**

Topology

ANALYTICAL COMPETENCIES**Creative Thinking**

Knowledge Management

Model Building Skills

Problem-Solving Skills

Research Skill

Systems Thinking

BUSINESS COMPETENCIES**Ability to See the “Big Picture”**

Business Understanding

Buy-in/Advocacy

Change Management**Cost Benefit Analysis/ROI**

Ethics Modeling

Industry Understanding

Legal Understanding

Organizational Understanding

Performance Analysis and Evaluation

Visioning**INTERPERSONAL COMPETENCIES**

Coaching

Communication

Conflict Management

Feedback Skills

Group Process Understanding

Leadership Skills

Questioning

Relationship Building Skills**Self-Knowledge/Self-Management**

Table 3: Thirty-nine competencies required for success in the geospatial technology profession. Each of the roles outlined in Table 2 above requires a subset of the technical, analytical, business, and interpersonal competencies in Table 3. Boldface type indicates core competencies (Gaudet, Annulis, & Carr, 2003).

The Workplace Learning and Performance Institute’s (WLPI) compilation of geospatial roles and competencies does not align neatly with real job descriptions posted by actual employers. Following earlier studies (e.g., Huxhold, 1991; Dramovicz 1997), the Urban and Regional Information Systems Association’s (URISA) Model Job Descriptions for GIS Professionals (Huxhold, 2000b) identifies six generic job titles for GIS professionals: managers, coordinators, specialists, programmers, analysts, and technicians. Like the roles represented in Marble’s pyramid, these six job titles constitute a ranked list in which each role subsumes most of the knowledge and skills of the roles below it. By contrast, the WLPI’s twelve roles represent unranked, nominal categories. This follows in part from WLPI’s conception of the “geospatial industry,” which is much broader, and thus more diverse, than the conceptions of most practitioners and educators who work in the GIS&T field. More fundamentally, workforce development specialists argue that “today’s fast-changing workplace requires that the basis for recruiting, selecting, and compensating individuals is their competence and skills, rather than a job title. The best approach to develop a workforce is to focus less on specific tasks and duties and more on identifying work-related competencies” (Gaudet, Annulis, & Carr, 2003, p. 22). This first edition of the *Body of Knowledge* adopts the pyramid representation of geospatial workforce roles that is most familiar to practitioners and educators. The units, topics, and objectives that make up the ten knowledge areas presented in section V of this document provide a list of the technical, analytical, and business competencies that are particular to the GIS&T field that is more representative, more detailed, and more useful than the list suggested

by WLPI. Cultivation of generic technical, analytical, business, and interpersonal skills is considered in the following section on the GIS&T education infrastructure.

Many public and private organizations are involved in helping individuals master the knowledge, skills, and credentials needed to contribute to, and advance within, the GIS&T enterprise. Collectively, this constellation of organizations may be conceived of as an “educational infrastructure.” The following section describes this infrastructure, and argues that fostering synergies among its various components is a key objective for national-scale curriculum development efforts.

The GIS&T education infrastructure

As Longley et al. (2000) argue, a diversity of education and training approaches is needed to prepare practitioners in a wide range of fields to realize the potential of geospatial technologies to improve the quality of life. A constellation of public and private organizations provide formal and informal educational opportunities to current and future GIS&T professionals throughout their lifetimes. These organizations include not only educational institutions, but professional societies, private firms, government agencies, and public and private media. In addition to planning, implementing, and assessing curricula, these organizations are concerned with the mobility of students’ academic achievement among institutions (ensured through articulation agreements), accreditation of academic programs, certification of the qualifications of individual practitioners, selection and continuing professional development of employees, and promotion of basic awareness of GIS&T. A body of knowledge produced as a result of the collective effort of a community of researchers, educators, and practitioners has the potential to provide an authoritative basis for increasing the coherence of these activities. Realizing synergies among these organizations and their activities is, the editors believe, key to improving their effectiveness in addressing workforce needs.

Because the field is demanding intellectually as well as technically, and because it is evolving rapidly, educational opportunities in GIS&T must span a lifetime of learning. Opportunities to learn about, and learn with, geospatial technologies are available in many (though certainly not most) primary and secondary classrooms in the U.S., in two-year colleges, and in training sessions provided by for-profit businesses. For learners whose locations or personal situations prevent them from participating in traditional classes, educational opportunities are increasingly available through asynchronous online delivery as well as self-study texts. Furthermore, exposure to geospatial technologies gained through commercial and educational television programming, museum exhibits, geocaching clubs, and other popular media and organizations are indispensable vehicles for fostering geospatial literacy and interest in geospatial careers among the general public. Together, this constellation of educational opportunities constitute what has been called an “educational infrastructure”—an “interwoven network of educational, social and cultural resources” that supports the cumulative process by which individuals learn throughout their lifetimes (St. John and Perry, 1993, p. 60). A description of the informal and formal sectors of the infrastructure follows.

Informal education: The solution to the problem of recruiting, preparing, and retaining competent geospatial technology workers begins with a public understanding of GIS&T and its contributions to society. This challenge is related to the more general problem of recruiting the new generation of scientists, mathematicians, and engineers needed to ensure the nation's economic security. Public understanding of science is also needed to ensure the informed citizenry upon which representative democracy depends. Informal science education fosters public understanding of science both by providing opportunities for learning beyond the classroom and by mitigating the loss of knowledge that most of us experience after completing our formal education (Crane, 1994).

The informal or “free choice” component of the educational infrastructure is “the public's primary source of information about science” (Falk, 2001, p. 10). Experts on informal science education argue that investments should be directed toward increasing the capacity of the educational infrastructure and fostering synergies among its components (e.g., Falk, 2001; St. John, 1998). Specifically, Bybee (2001) claims that, “if the nation is going to achieve science literacy, it will need to recognize the importance of a combined effort of both the formal and free-choice education communities” (p. 47).

Bybee's argument holds for the special case of geographic information science literacy as well. For the same reasons that undergraduate degree programs in Forensic Science are emerging in response to the popularity of the various *Crime Scene Investigation (CSI)* series on primetime network television, applications of geospatial technologies in television programs such as those seen recently in *The District* and *Numb3rs* may prompt young people to imagine geospatial technology careers. With \$1 million of support from the U.S. Department of Labor, a venture called Kidz Online is developing a series of digital video and other resources intended to raise awareness about career opportunities in GIS&T. Geocaching clubs and Google “mashups” engage thousands of enthusiasts nationwide. How might this keen interest in geospatial technology be leveraged to attract future GIScientists? How often are the outcomes of geospatial research and applications highlighted in museum exhibits, or in programs on the National Geographic and Discovery channels? The National Science Foundation's Informal Science Education program supports such projects on a limited and highly competitive basis. Informal education remains the most neglected sector of the geospatial education infrastructure, however. Synergies among formal and informal education are needed to expand public understanding of geographic information science and to recruit talented young people to geographic information studies and geospatial careers.

Formal education: Figure 3 depicts the formal aspect of the GIS&T education infrastructure in matrix form. Four sectors of formal education are represented with columns labeled Primary and Secondary, Undergraduate, Graduate, and Postbaccalaureate and Professional. Six rows represent the levels of expertise that make up Marble's pyramid. A partial inventory of the components of the infrastructure populates the matrix cells. Discussion of the technical, analytical, business, and interpersonal competencies cultivated by the various components at each stage follows.

	Primary and secondary education	Undergraduate education	Graduate education	Postbaccalaureate and Professional education
Research and Development				
System Design			Research universities Government agencies	
Application Design		Four-year institutions Two-year institutions	Software companies Publishers	Four-year institutions Two-year institutions Software companies
Modeling		Software companies Publishers		Professional societies Academic publishers Government agencies
Routine Use		Government agencies		
Basic Understanding	K-12 schools Software companies Government agencies Publishers			

Figure 3: The GIS&T education infrastructure. Columns represent sectors of formal education that span a lifetime of learning. Rows correspond to the roles played by geospatial professionals as represented in Marble's pyramid. Informal education spans the learner's lifetime in parallel with formal education.

Formal education at primary and secondary levels: Geospatial technologies can be effective tools for supporting active and inquiry-based learning in K-12 education (Audet & Ludwig, 2000). Although many exciting innovations at individual schools can be identified, in general the rate of adoption of GIS and related technologies in U.S. primary and secondary schools has been slow (Bednarz, Downs, & Vender, 2002). Teachers' concerns about access to technology, data, training, and curricular materials, combined with the absence of institutional support and professional incentives, conspire to hinder adoptions. Ironically these disincentives persist even as hardware costs decline, educational software licensing is liberalized, free or low-cost curricular materials developed by software vendors, private firms, and government agencies proliferate, and Internet connectivity expands. Federal government emphasis on high-stakes testing associated with No Child Left Behind (NCLB) legislation, combined with lack of funding for geography initiatives under NCLB, also conspire to discourage teacher innovation. The National Research Council's 2006 publication *Learning to Think Spatially* may inspire a new wave of adoptions and innovation. The K-12 sector, combined with informal science education, remains a crucial but underperforming sector for promoting public awareness of geospatial technologies.

Formal education at the undergraduate level—Two-year institutions: According to the National Center for Education Statistics, 42 percent of the 16.5 million U.S. undergraduates in 1999-2000 were enrolled in over 2,000 two-year institutions (in some cases known as "community colleges") (Horn, Peter, & Rooney, 2002). Undergraduates enrolled at public two-year colleges tend to be older, and are more

likely to study part-time, than students at four-year institutions. They are also more likely to seek associate's degrees and vocational certificates.

The success of two-year institutions, and their faculties, is judged primarily by the quantity of enrollments they attract. Thus two-year colleges have a strong incentive to respond to the demand for individuals properly trained for entry-level positions in the geospatial technology industry. One of the most attractive characteristics of community colleges—their low tuition rates—pose challenges for institutions that wish to respond to the demand for geospatial technology education and training, however. Long-established certificate and associate degree programs in geospatial technology at Houston Area Community College, Lansing Area Community College, and Mesa Community College, among others, demonstrate the ability of community-based institutions to overcome such obstacles. Support for development of new programs is available on a competitive basis through the National Science Foundation's Advanced Technology Education program, and, more recently, through the Department of Labor's High Growth Technology Jobs initiative. Institutions that prefer not to develop curricular materials on their own can use licensed materials from commercial vendors (e.g., Digital Quest's SPACESTARS) and from some higher education institutions (e.g., the University of Mississippi's Institute for Advanced Education in Geospatial Sciences). Workforce development goals and programming planning and implementation strategies for two-year institutions are discussed in the report of a workshop sponsored by NSF and the National Council for Geographic Education (Allen, Brand, Beck, Johnson, & Johnson, 2006).

Two-year institutions are well-positioned to prepare students for entry-level positions that involve routine use of geospatial technologies. In terms of the geospatial technology roles identified by WLPI, two-year curricula leading to associates degrees or certificates ought to prepare students for duties including data acquisition, rudimentary data analysis and interpretation, training, and visualization. The institutional incentives and funding streams needed to substantially increase capacity in this sector are in place. However, associate and certificate programs are likely to lack the breadth and depth needed to prepare students for leadership roles in the geospatial industry. One- or two-year programs that emphasize development of technical competencies may necessarily neglect the analytical, interpersonal, and business competencies required for success in geospatial technology roles. While investments in the two-year sector may succeed in expanding the pool of qualified entry-level workers, they are unlikely to “rebuild the top of the pyramid” in the way that Marble and others argue is urgently needed. Innovative baccalaureate, graduate, and postbaccalaureate education and training are needed to answer that challenge.

Formal education at the undergraduate level—Four-year institutions: Very few higher education institutions offer baccalaureate degree programs focused specifically upon GIS, GIScience, or geospatial technologies *per se*. Berdusco (2003) identified about 425 higher education institutions worldwide (about 260 U.S.) that offer formal certificate, diploma, and degree programs in GIS and GIScience. Of the 28 U.S. universities listed as offering undergraduate degree programs in GIS, all but four in fact offer B.A. and B.S. degrees in geography (nineteen programs), Earth science, environmental science, natural resources, or forestry, with concentrations, specializations, tracks, or undergraduate certificates in GIS,

GIScience, cartography, and related topics. For the same reasons that the geospatial workforce is diffused among many industries in every employment sector, geospatial activities tend to be widely dispersed and poorly coordinated on four-year college campuses. Within academic programs, courses involving geospatial technologies are often positioned as intermediate or advanced technical specialties with prerequisites and class size limits that pose barriers to enrollment.

Four-year baccalaureate degree programs provide opportunities to teach and learn subjects at greater depth than in two-year programs. Graduates who excel in rigorous baccalaureate degree programs with specializations in geospatial technology should be well prepared for entry-level positions that involve routine use of geospatial technologies and to apply spatial analysis techniques to address reasonably sophisticated problems in a variety of fields. In addition, graduates of four-year programs should have at least begun to develop the business and interpersonal competencies required for advancement in government agencies and private businesses. In practice, however, too many students who were not exposed to geospatial technologies in primary and secondary schools discover it too late in their college careers to study it in much depth as undergraduates. Some talented undergraduates may master the technical and analytical skills required to develop customized software applications, but few are likely to have had the opportunity to master the array of competencies needed to excel in system design or project management. So long as the geospatial educational infrastructure remains weak at the K-12 level, and geospatial technology expertise remains diffused on college campuses, it is probably unrealistic to expect many undergraduates to progress to the upper levels of Marble's pyramid.

Formal education at the graduate level: Berdusco (2003) identifies 76 graduate degree programs in GIS or GIScience worldwide, 30 of which are U.S.-based. This is certainly an undercount, but it is the right order of magnitude. The University Consortium for Geographic Information Science (UCGIS) represents more than seventy U.S. higher education institutions that have demonstrated a "critical mass of resources to make a significant contribution to the mission of the UCGIS," which includes advancing multidisciplinary research and education in GIScience (UCGIS, 2005). Most of these institutions offer one or more M.A., M.Sc., and Ph.D. degree programs with emphases in GIS or GIScience. Not many more than ten institutions offer specialized professional master's degree programs (discussed in the following section).

Geographic information science is a research enterprise. GIScientists lead research and development efforts at GIS software firms, government agencies, and in universities. Academic GIScientists are also responsible for recruiting, training, and mentoring the next generation of researchers who will advance the capabilities of geospatial technologies in the future. Research-based, multidisciplinary graduate education in GIScience prepares students to master the technical, analytical, business, and interpersonal competencies needed to play leading roles in research and development, system analysis and design, and application development (Saalfeld, 1997). Graduate education can also promote adoption of spatial analysis and geographic modeling among the various disciplines that employ geospatial technologies.

Leading academic graduate programs with emphases in GIScience rely upon the sponsorship of government agencies and industry to provide the tuition and stipends needed to attract and retain the most promising young scholars. UCGIS's key objectives are to identify research priorities and to advocate increased and sustained support for multidisciplinary university research. This objective aligns with NSF's goal to recruit the next generation of scientists, engineers, and mathematicians that is needed to ensure U.S. industrial competitiveness through the twenty-first century. The success of programs including the Department of Geography at the University at Buffalo in attracting NSF IGERT (Integrative Graduate Education and Research Training) grants attests to the relevance and value of graduate education in GIScience. Increased support for programs like IGERT, and for sponsored university research in general, is needed to increase the capacity of research-based graduate education, which in turn is needed to "rebuild the top of the pyramid."

Formal education beyond the undergraduate and graduate levels: For many workers, formal education is no longer a prelude to a career; it is a lifelong endeavor. While their parents might have expected to work for one employer throughout their careers, a more realistic expectation for graduates entering the workforce today is a succession of careers with different employers. Workforce development experts refer to the phenomenon as "job churning." They estimate that "one-third of all [U.S.] jobs are in flux each year, meaning that they have recently been created or soon will be eliminated from the economy" (Kohl, 2000, p. 13). As the U.S. population as a whole has aged, so has its workforce. By 2006, the cohort aged 35 to 64 is expected to account for nearly two-thirds of all workers. The combination of demographic trends and job churning has led to an older clientele for higher education. Between 1970 and 2000, the proportion of college students aged eighteen to 21 years declined 24 percent, from 58.4 percent to 44.2 percent (U.S. Census Bureau, 2001). Today's "typical" graduate student "is female, in her thirties, married with dependents, and takes classes on a part-time basis while also holding a full-time job" (Kohl, 2000, p. 18).

Higher education has been criticized for its tentative responses to these changes. Kohl (2000), for example, argues that "universities' preoccupation with traditional college-age students, coupled with their typically fragmented organizational structure, often makes it difficult to focus attention on the learning demands of postbaccalaureate students" (p. 20). The same might be said of the GIS&T higher education community, which has devoted a perhaps inordinate share of attention to baccalaureate curricula. The higher education community is not oblivious to the post-graduate sector, however. Acknowledging the public's frustration with universities' perceived unresponsiveness to such changes, members of the Kellogg Commission on the Future of State and Land-Grant Universities (1999) has argued that "With a more diverse and older student population, we need a more diversified set of educational offerings. As people mature and move through successive careers, we need to be there to help them retool and retread, with special courses available at their convenience" (p. 8). The specialized academic certification programs discussed above represent one response to needs of lifelong learners in the geospatial arena. Another response is the development of distance education programs in GIS and GIScience

(Wright & DiBiase, 2005). Such programs are particularly well suited to adult learners who lack access to nighttime and weekend offerings at nearby campuses and who are highly motivated to earn credentials that will advance their careers.

- **Academic certificate programs:** Certification is the process by which organizations award credentials to individuals who demonstrate certain qualifications and/or competencies. Accredited educational institutions confer academic certificates; professional societies and businesses operate professional certification programs (these are considered later in this document). Wikle (1999) points out that academic certificate programs “differ from degree programs mostly in terms of their focus and duration. In contrast to degree programs that include general education courses, certificates are narrowly focused and require less time to complete” (p. 54). Academic certificates can be awarded as a stand-alone credential, as part of a baccalaureate degree, or as part as a graduate degree. When part of a degree program, the certificate emphasizes education and training distinct from the degree earned. For example, a degree conferred in biology earned with a GIS certificate would carry expertise in both biology and GIS.

Phoenix (personal communication, June 14, 2005) estimates that in 2005, close to 10,000 students worldwide were pursuing some sort of academic certificate of achievement that involves GIS. Certainly several thousands are pursuing such credentials in the U.S. One institution alone, the Pennsylvania State University, has conferred over 700 certificates of achievement in GIS since 1999, and now attracts new students at an annual rate of nearly 400. In 2000, Phoenix estimated that there were over 200 academic GIS certification programs in the U.S. At last count, ESRI's online database of academic GIS programs (Environmental Systems Research Institute, 2005) listed 246 two-year and four-year institutions that claim to offer GIS certificates, of which 120 were located in the United States. Twenty-four U.S. institutions claimed to deliver certificate programs by distance learning.

- **Professional masters degrees:** Every year, some 400,000 U.S. students earn master's degrees in hundreds of different specialties. Eighty-five percent of U.S. master's degree programs “are what have come to be called practice-oriented, or professional, degrees” (LaPidus, 2000, p. 6). In comparison with academic degree programs, professional programs are more “specialized in terms of focus, applied in terms of content, ... and depersonalized in that they often seek to shape students according to a predefined template of professional competencies” (LaPidus, 2000, p. 6). Such programs are tailored to adult professionals and may employ practitioners as faculty. The best professional programs “transcend professional competency and foster professional leadership” (LaPidus, 2000, p. 6).

The GIS&T education infrastructure includes relatively few professional master's degree programs. Kemp (2005) counts only 20 U.S. higher education institutions that offer master's programs in GIS and GIScience. Three are distance learning programs. Worldwide, Phoenix (2004) estimates that only about 500 students are pursuing master's degrees in GIS or GIScience.

Referring to both professional and academic programs, Phoenix (2000) has stressed that “the few graduate programs now in place cannot meet the needs of the marketplace” (p. 13). The shortage of advanced, practice-oriented master’s programs tailored to the needs of continuing adult professionals is one of the most serious weaknesses of the U.S. GIS&T education infrastructure. The *Body of Knowledge* should be a useful resource for institutions that are planning such programs.

- **Education and training by non-accredited institutions:** In terms of the numbers of learners served, GIS software companies may be the primary training providers in the GIS&T field. ESRI alone enrolls some 20,000 students annually in many offerings of over 40 instructor-led, classroom-based training courses at nearly 50 U.S. locations. Most courses span a few days. Intergraph also offers some 24 different short courses at its Huntsville, Alabama headquarters, at clients’ sites, and at six other Intergraph offices around the world.

ESRI attracts nearly 12,000 participants each year to its International Users Conference; training sessions and briefings about ESRI software product developments occupy most of the conference agenda. Intergraph’s annual GeoSpatial World conference includes “certificate programs” that consist of series of technical sessions and workshops on several different themes.

Both Intergraph and ESRI provide online instruction as well. Intergraph offers a ten-week, instructor-led “Introduction to GIS” course using WebBoard discussion forum software. Students enrolled in a M.Sc. program offered by member institutions of the UNIGIS International consortium can earn academic credit for the Intergraph course. ESRI’s “Virtual Campus” offers a variety of online education and training products, including self-paced, non-instructor-led course modules, digital video and audio recordings of software demonstrations and workshops, and instructor-led “virtual classrooms” in which students access ArcGIS software via a Citrix application server and interact with an ESRI instructor by telephone and Microsoft LiveMeeting collaboration software. Launched in 1997, the Virtual Campus is the best known online training source in the geospatial education infrastructure. By 2004 over 230,000 members in 189 countries had at least registered to view a free sample module or seminar (Johnson & Boyd, 2005). ESRI’s educational site licenses include no-cost access to many Virtual Campus modules by students and faculty. ESRI Press has become one of the leading publishers of GIS-related textbooks.

Postbaccalaureate and professional education is the most diverse and fastest-growing sector of the geospatial education infrastructure. Academic certificate programs abound. Professional master’s degree programs are relatively few, perhaps because the GIS&T enterprise has not yet consolidated as a distinct profession. Yet, since many of the few now in operation were established in the last five years, it seems reasonable to expect that more such programs will appear by the end of the decade. Commercial software companies serve many thousands of learners every year with a variety of product-oriented, non-credit offerings. Because postbaccalaureate students tend to be older, more motivated, and more experienced than their counterparts in undergraduate and graduate education, distance learn-

ing methods hold the promise of extending access to learners who are not free to participate in place-bound offerings. The capacity of accredited higher education institutions may be limited by cultural factors that value selectivity over capacity. Academic leadership—and perhaps financial incentives—will be needed to inspire faculty acceptance for innovative professional programs that involve practitioners as faculty. The capacity of commercial initiatives will continue to respond to demand and ability to pay; although software companies diligently seek to avoid competition with higher education institutions, such competition seems inevitable in the future. Efforts to increase the quantity and quality of outputs from the geospatial education infrastructure should include realizing synergies between the commercial and non-commercial components of the post-baccalaureate and professional sector. The following section outlines potential uses of the *Body of Knowledge* that will strengthen, and foster synergies among, these and other components of the education infrastructure.

Applications of the *GIS&T Body of Knowledge*

As explained above, the GIS&T education infrastructure includes a variety of actors including professional societies, commercial software and service providers, government agencies, and academic publishers, as well as accredited education institutions. A successful *GIS&T Body of Knowledge* will be useful to many of these actors, and will foster synergies among them. This section outlines several uses of the *Body of Knowledge* that have the potential to strengthen the education infrastructure.

Curriculum planning: As demand for new academic certificate and degree programs increases, program planners look for resources to guide curriculum choices. Successful curriculum planning involves a series of “critical events,” including identifying the needs of the profession, specifying job performance measures, and determining educational objectives, among others (Nadler and Nadler, 1998; see also Dacum.org, 2005). The *Body of Knowledge* specifies core and elective units made up of topics that are defined in terms of formal educational objectives. Educators charged with planning new GIS&T certificate or degree programs can use the *Body of Knowledge* to outline the minimum course content needed to ensure that students develop core competencies. They can design activities that cultivate knowledge and skills at targeted levels of competence, because most topics are defined as ranges of objectives (usually, from fundamental to advanced). They can readily convert objectives into assessment instruments that gauge students’ mastery. Most important, the granularity of units and topics in the *Body of Knowledge* is fine enough to be adaptable to the unique constraints and opportunities afforded by particular institutional settings.

Program accreditation: Accreditation is the process by which organizations attest to the qualifications and effectiveness of educational institutions and programs. Eight regional commissions accredit most of the approximately 4,000 degree-granting higher education institutions in the U.S. (Hamm, 1997; Cook, 2001). More than 60 commissions accredit a variety of professional degree programs, including computer science, engineering, landscape architecture, and planning. The traditional model of accreditation involves a periodic institutional self-study, followed by a site visit by a panel of reviewers, and finally an

evaluation report. Alternative accreditation models that emphasize internal processes over external standards are also in use, and may be applicable to GIS&T education (Wergin, 2005; DiBiase 2003).

Most GIS-related courses, certificates, and degree programs are offered by academic departments that are not subject to disciplinary accreditation (Obermeyer & Onsrud, 1997). Recently, however, the U.S. Geospatial Intelligence Foundation, an alliance of defense contractors whose major client is the National Geospatial-Intelligence Agency, announced the formation of a Geospatial Intelligence Academy that will “establish curriculum guidelines and accreditation standards and processes for geospatial intelligence academic courses and certificate programs” (U.S. Geospatial Intelligence Foundation, 2005). The *Body of Knowledge* should be a valuable resource for the panel charged with defining the academy’s guidelines and standards.

Program evaluation and assessment: Most academic programs that are not subject to disciplinary accreditation are still expected to conduct periodic self-assessments, or to invite external reviewers or advisory boards to evaluate program quality. Assessment instruments derived from the *Body of Knowledge* will help programs determine their standing relative to a comprehensive set of community-authored educational objectives. Such assessments may also help prospective students choose educational programs that align with their interests and career goals. Current students and recent graduates may use the *Body of Knowledge* to self-assess their mastery of the GIS&T domain and to plan their continuing professional development strategies.

Curriculum revision: Academic institutions that are able to respond to the demand for GIS&T education, and to the emergence of new GIS&T research priorities, must recruit new faculty members who specialize in geographic information science. As GIS&T faculties grow or turn over, GIS&T curricula need to be reviewed and revised to reflect new areas of specialization. The *Body of Knowledge* will be useful in helping faculties think strategically about how they wish to grow, writing job descriptions, conducting interviews, and identifying the topics and objectives that will make their curricula more representative of the evolving GIS&T field.

Program articulation: The GIS&T education infrastructure spans a lifetime of learning. Educational institutions accommodate the mobility of GIS&T professionals (noted above) through articulation agreements that ensure that credits earned in one institution will be count toward relevant certificate and degree programs at another institution. Articulation agreements can be difficult to execute owing to differing academic calendars, incommensurate academic credit valuations, and especially differing course titles and objectives. Institutions who agree to specify course topics and objectives consistent with the *Body of Knowledge* may find it easier to execute articulation agreements. Accommodating the mobility and advancement of current and future GIS&T workforce is one of the most important synergies to be realized in the GIS&T education infrastructure.

Professional certification: Certification is the process by which organizations award credentials to individuals who demonstrate certain qualifications and/or competencies. Two organizations—the American

Society for Photogrammetric Engineering and Remote Sensing (ASPRS) and the Geographic Information Systems Certification Institute (GISCI)—currently operate professional certification programs in the GIS&T field. Barnhart (1997) identifies three types of professional certification: portfolio-based, competence-based, and curriculum-based. ASPRS's program exemplifies competence-based certification, in which candidates must demonstrate their mastery of a common body of knowledge within their profession by examination. In contrast, GISCI's Geographic Information Systems Professional (GISP) certification program is portfolio-based, requiring individuals only to document relevant qualifications at specified levels of achievement. The *Body of Knowledge* provides a basis for adjudicating educational point claims by applicants to the GISCI program.

A spin-off of the Urban and Regional Information Systems Association (URISA), GISCI began accepting applications in 2004. Individuals are certified as GISPs by earning a requisite number of "achievement points." Point values are defined for achievements related to education, experience, and contributions to the profession. Applicants must also agree to comply with a code of ethics. No examination is required. GISCI certified 535 GISPs in its first year and claimed 1,167 through June, 2006. Portfolio-based professional certification appears to have found a niche in GIS&T.

The URISA committee that planned the GISCI certification program was mindful of the argument that GIS certification needs to attract widespread participation if it is to influence professional practice (Obermeyer, 1993). The committee adopted a portfolio-based approach as a way to lower barriers to participation in what some committee members envisioned as essentially a professional development program. While GISCI certification does little to ensure professional competence (Somers, 2004), it apparently is succeeding in building a community of practitioners who subscribe to a professional development strategy based upon ethical practice, lifelong learning, and participation in professional organizations. The *GIS&T Body of Knowledge* plays an important role in assuring the relevance of GISPs' formal educational experiences. Should GISCI choose to develop a more rigorous competency-based certification in the future, exam questions can be derived from the educational objectives associated with core units of the *Body of Knowledge*.

Employee screening: The managers and human resource personnel who are responsible for recruiting and screening applicants to GIS&T positions in government and industry are not likely to possess relevant professional experience. Several resources are available to help these professionals identify qualified candidates. URISA's Model Job Descriptions for GIS Professionals (Huxhold, 2000b) provides templates that outline typical duties and qualifications. WLPI's Geospatial Technology Competency Model identifies a variety of roles that GIS&T professionals are likely to play, as well as the kinds of competencies successful employees demonstrate. The *Body of Knowledge* complements these resources by defining, in unprecedented breadth and detail, the knowledge and skills that well-educated professionals should possess. Job descriptions and interview protocols may be derived from these objectives.



How Does the Body of Knowledge Relate to GIS&T Curriculum Planning Efforts?

Longstanding concern about GIS&T education

Critiques of the preparedness of graduates should not be taken to imply that GIS&T educators have neglected their responsibilities. In fact, “GIS instructors in higher education have shown an almost exemplary concern for teaching” (Unwin, 1997, p. 2). Since the late 1970s, GIS, cartography, and remote sensing educators have proposed frameworks to guide curriculum planning (e.g., Marble, 1979, 1981; Dahlberg and Jensen, 1986), published numerous textbooks (e.g., Burrough, 1982; DeMers, 1996; Longley et al., 2000), developed educational software products (e.g., GISTutor, OSU Map-for-the-PC, Map II), convened panel discussions, workshops, and entire international conferences devoted to teaching and learning (e.g., Goodchild, 1985; Poiker, 1985; Gilmartin & Cowen, 1991; GIS in Higher Education Conference, 1997), investigated professional job titles, salaries, qualifications, and recommended coursework (e.g., Huxhold, 1991, 2000b; Wikle, 1994), compiled lists of core topics (e.g., Macey, 1997), published local, national, and international GIS course syllabi and curricula (e.g., Tobler, 1977; Nyerges & Chrisman, 1989; Unwin, 1990; Goodchild & Kemp, 1992; Kemp & Frank, 1996; Foote, 1996), and demonstrated the propriety of including GIScience within general education curricula (DiBiase, 1996). The following section reviews national-scale efforts to develop university curricula in GIS&T (Figure 3) and leads to a discussion of the relationship of the *GIS&T Body of Knowledge* to the UCGIS Model Curricula project in the following section.

National-scale curriculum development efforts

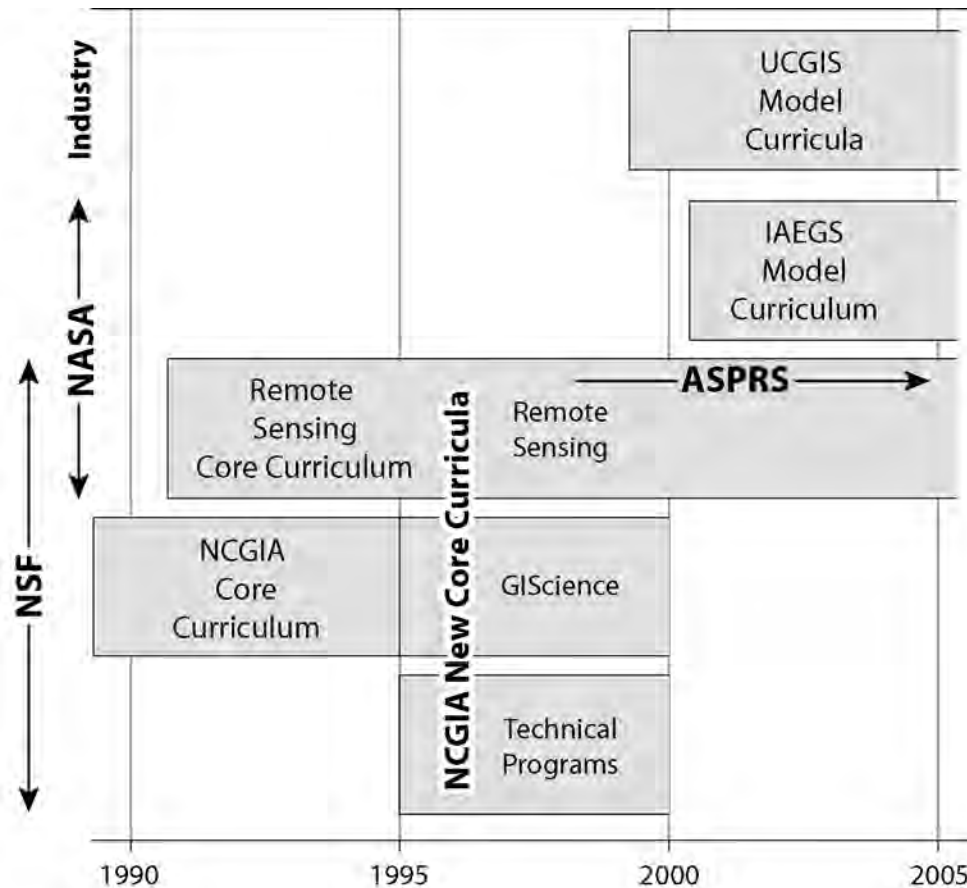


Figure 4: National-scale geospatial education curriculum initiatives in the U.S., 1988-2006.

NCGIA GIS Core Curriculum: The National Science Foundation's 1987 solicitation for a National Center for Geographic Information Analysis (NCGIA) included as one of its four goals "to augment the nation's supply of experts in GIS and geographic analysis in participating disciplines" (National Science Foundation, 1987). In 1988, shortly after winning the NSF award, the NCGIA consortium of the University of California at Santa Barbara, State University of New York at Buffalo, and the University of Maine developed and distributed for comment "a detailed outline for a three-course sequence of 75 one-hour units" (Goodchild & Kemp, 1992, p. 310). Fifty leading scholars and practitioners were recruited to prepare draft units. Over 100 institutions worldwide agreed to implement the resulting three course sequence (Introduction to GIS, Technical Issues in GIS, and Application Issues in GIS) and to share assessment data with NCGIA. Lecture notes and laboratory exercises were revised extensively in response to user comments (e.g., Coulson & Waters, 1991), and were subsequently published as the *NCGIA Core Curriculum* in July, 1990. The *Core Curriculum* has been criticized for its inconsistencies and overlap, focus on content, rigid structure, and lack of a mechanism for updating (Unwin & Dale, 1990; Jenkins, 1991). Nevertheless, the project had a significant impact. The original print version was

requested by over 1500 institutions and translated into several languages, and the Internet version is still frequently accessed (see <http://www.ncgia.ucsb.edu/pubs/core.html>).

NCGIA GIScience Core Curriculum: In 1995, NCGIA announced plans to develop a completely revised and expanded *Core Curriculum in GIScience* intended to account for developments in the field since the original 1990 *Core Curriculum*. The new curriculum was to include lecture notes corresponding to at least 176 hour-long units organized in a “tree” structure with fundamental geographic concepts as root nodes from which four branches—Fundamental Geographic Concepts for GIS, Implementing Geographic Concepts in GIS, Geographic Information Technology in Society, and Application Areas and Case Studies—were to spring. According to senior editor Karen Kemp (personal communication, May 17, 2005), “Over a period of about four years, several new units were commissioned and a few units from the original core curriculum were updated bringing the total of units available in the new curriculum up to about one-third of the units envisioned in the new tree. While it was intended that the new curriculum become a living document with revisions to the tree structure and additions to the available units continuing indefinitely, by August 2000 the momentum for a document of this type slowed.” The partial *NCGIA Core Curriculum in GIScience* (last updated in 2000) remains available for review at <http://www.ncgia.ucsb.edu/giscc/>.

Remote Sensing Core Curriculum: One of NCGIA’s research initiatives (I-12) concerned the integration of remote sensing and geographic information systems. The need for educational materials that promoted integration was recognized early on. In 1992, NCGIA empanelled a steering committee responsible for guiding development of a remote sensing core curriculum. Initially the committee focused on four courses: Introduction to Air Photo Interpretation and Photogrammetry, Overview of Remote Sensing of the Environment, Introductory Digital Image Processing, and Applications in Remote Sensing. The four original courses, along with four subsequent ones, now appear as “volumes” at the project Web site (<http://www.r-s-c-c.org/>). The materials resemble online textbooks rather than lecture notes. Course authors, who include well-known educators and researchers, contributed voluntarily and without compensation. In 1995 the project secured funding from NASA to support student assistants to format and test the volumes. In 1997, the American Society for Photogrammetric Engineering and Remote Sensing (ASPRS) agreed to support the Remote Sensing Core Curriculum project (RSCC) through 2012. The RSCC is listed on the NCGIA Core Curricula Web site (<http://www.ncgia.ucsb.edu/pubs/core.html>) as an unofficial complement to its *Core Curricula for Technical Programs and GIScience*.

UCGIS Model Curricula project: Under the auspices of the University Consortium for Geographic Information Science, and with backing from leading GIS software vendors, Marble and others organized a Task Force in 1998 to create a new undergraduate curriculum in GIS&T. In time, the plural “curricula” was adopted to emphasize the project’s goal of supporting multiple curricular pathways tailored to the requirements of the diverse occupations and application areas that rely upon geospatial technologies. Its architects envisioned a broadly-based, ongoing curriculum development process much like the joint efforts of the Association of Computing Machinery (ACM) and Institute for Electrical and Electronic

Engineers (IEEE). As in their *Computing Curricula 2001* (ACM/IEEE-CS Joint Task Force), the UCGIS Task Force set out to identify a comprehensive set of knowledge areas, and their constituent units and topics, that comprise a body of knowledge for the GIS&T domain. The Task Force also aimed to explore several pedagogy areas, including supporting topics and courses, integrative experiences, supporting infrastructure, and implementation and dissemination. As in the previous NCGIA core curricula initiatives, contributors participated as unpaid volunteers. Following the ACM/IEEE terminology, the Task Force released an initial “Strawman Report” in July, 2003. The draft included specification of twelve knowledge areas and 56 subsidiary units. The final specification of the GIS&T Model Curricula was also to define various pathways students might traverse the Body of Knowledge in preparation for a variety of career goals.

As originally conceived, the UCGIS Model Curricula project was the most ambitious undertaking of its kind in the GIS&T field. Marble and collaborators envisioned, and depended upon, a community of GIScientists, educators, practitioners, and other stakeholders who were dedicated to reforming the geospatial education infrastructure so as to better meet the workforce needs of industry, government agencies, and society. Crucial to this vision was the support of employers, academic administrators, and sponsors who make it possible for members of the community to participate. The financial and institutional support needed to fully realize the Model Curricula vision proved not to be forthcoming, despite modest cash contributions from some GIS software development firms. As the authors of the “Strawman Report” pointed out, “while there are many individuals who have expressed a strong interest in the Model Curricula work, it has proven difficult to overcome the reluctance of organizations, academic units in particular, to recognize the time spent on this activity as something of value” (Marble et al., 2003, p. 31).

In 2005, the Model Curricula project resumed as an activity of the UCGIS Education Committee. Leading the effort is a team of seven editors who consult with an Advisory Board of over fifty members. Some former Task Force members are represented on both the editorial team and the Advisory Board. Concluding that the full scope of the Model Curricula vision was not achievable in a timely fashion, the Education Committee (with the assent of the UCGIS Board) determined to focus on completion of the core component of the Model Curricula, the *GIS&T Body of Knowledge*. (A fuller exposition of the Model Curricula vision, and evolution of the Body of Knowledge since the “Strawman Report,” appears in the section IV of this document.)

IAEGS Model Curriculum: In 2001, the University of Mississippi (Ole Miss) secured a \$9 million contract from NASA to create resources that would increase the capacity of higher education institutions to prepare students for careers in the remote sensing industry. By 2005, Ole Miss’s Institute for Advanced Education in Geospatial Sciences (IAEGS) had developed its own course management system and materials comprising thirty non-instructor-led, online undergraduate courses in remote sensing and geospatial technology (<http://geoworkforce.olemiss.edu/>). With ASPRS’s help, IAEGS empanelled sixteen leading educators and researchers to outline their model curriculum. Prospective course authors were invited to submit proposals; selected authors earned \$80,000 each. Courses consist of text, graph-

ics, animations, interactive quizzes, and other content delivered through IAEGS's delivery system. The initiative is based upon a novel business model that targets institutions that wish to offer remote sensing education but lack the necessary faculty resources. Adopters pay per-student fees and are expected to provide local faculty points-of-contact. Although they were intended for licensing by higher education institutions, most early adopters of IAEGS courses have been government agencies and private firms (Luccio, 2005). The extent to which the IAEGS Model Curricula increases the productivity of the GIS&T education infrastructure remains to be seen. In any event, it is clear that the need for a *GIS&T Body of Knowledge* remains.

IV How Was the Body of Knowledge Developed?

Model Curricula vision

The UCGIS Model Curricula Task Force's "Strawman Report" of 2003 presents an ambitious vision. It suggests a rationale and justification for national-scale curricular reform in the undergraduate sector of the GIS&T education infrastructure (with implications for other sectors). It outlines guiding principles and an approach, modeled on the computer science and information science model curricula projects, for developing an adaptive, multi-path GIS&T Model Curricula. The Report also offers a draft *GIS&T Body of Knowledge*. Members of the Model Curricula Task Force anticipated that their successors would seek the community input needed to produce "a modified *Ironman* version of the *Body of Knowledge* that, hopefully, would be representative of the views of a majority of the broad GIS&T community" (Marble et al., 2003, p. 27). Additionally, the Task Force called on its successors to undertake a second "stream" of activity leading to specification of a set of "paths that individuals can take through the undergraduate portion of the GIS&T curricula." Paths were to be specified "in terms of (a) a carefully selected subset of the elements of the *GIS&T Body of Knowledge*, (b) an identified level of mastery for each of these elements, and (c) a statement of the additional supporting elements that need to be supplied from the students' own discipline and from other disciplines" (Marble et al., 2003, p. 27). The *Body of Knowledge*, the path specifications, and an accompanying "Curricula Development Support Plan" were to comprise the GIS&T Model Curricula. By completing a first edition of the *Body of Knowledge*, this document advances part of the Model Curricula vision, and sets the stage for future developments. This section describes, in further detail, the components that make up the Model Curricula vision.

Top-down design: Most curriculum planning initiatives adopt a "bottom-up" approach in which a set of lecture topics is combined into courses, and the collection of courses is said to comprise the curriculum. By contrast, top-down design "starts from a clear statement of broad educational aims, refines these into a series of explicit and testable objectives, and then devises teaching strategies, content and assess-

ment methods to meet these aims and objectives” (Unwin, 1997, p. 4). The UCGIS Model Curricula is unique among GIS&T curriculum initiatives in specifying the topics that comprise the GIS&T domain in terms of formal educational objectives. The *Body of Knowledge* is a resource for specifying course content, for designing educational activities, and for assessing courses’ effectiveness in achieving intended outcomes. This outcome-orientation reflects what Barr and Tagg (1995) characterized as a “paradigm shift” in higher education from teaching to learning.

Multiple pathways to diverse outcomes: The point of departure for the Model Curricula project was the recognition that the multidisciplinary nature of GIScience, geospatial technology, and GIS&T applications requires that the GIS&T education infrastructure support a diverse array of educational outcomes. A few possible outcomes are depicted in Figure 5 using triangular symbols. The triangles imply that each specialized outcome consists of several competency levels, as described in Marble’s pyramid model (Marble, 1998). A learner may acquire the knowledge and skills needed to achieve a particular outcome by traversing the *GIS&T Body of Knowledge*, as well as supporting topics in allied domains, and synthesized in integrative experiences like internships and capstone projects. The long-term vision of the Model Curricula includes specification of sequences of educational objectives that learners should fulfill as they follow one of several pathways leading to a diverse set of educational outcomes.

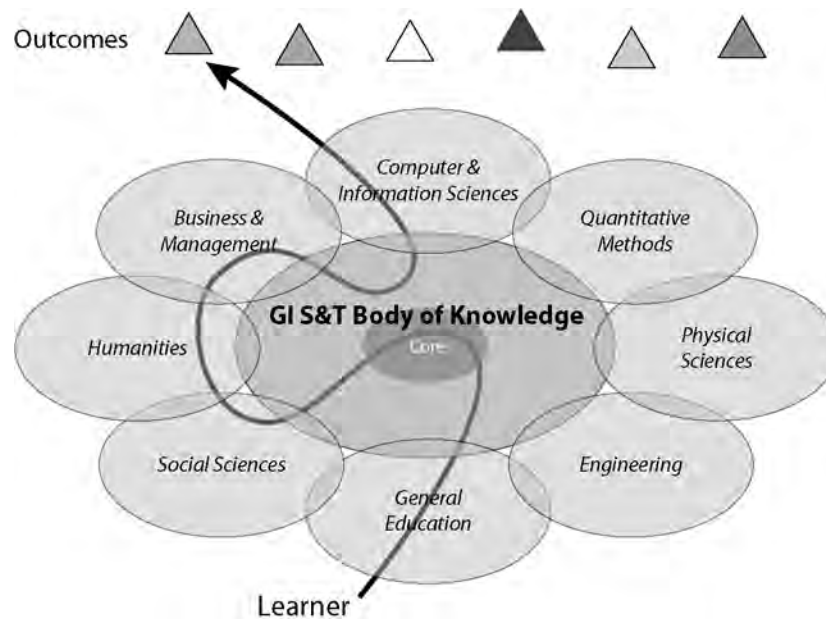


Figure 5: Schematic view of an educational pathway through the *Body of Knowledge*, and the bodies of knowledge of allied fields, leading to one of many potential educational outcomes.

Common core: To aid in the use of the *Body of Knowledge*, such as curriculum planning, the Task Force planned to highlight a subset of units as the “common core”. Other fields, including computer science and information science, also highlight core units. The GIS&T core units were to be identified by consensus of the GIS&T community. The Model Curricula Task Force envisioned that every graduate of a for-

mal undergraduate degree program in GIS&T would master “common skills and a common language” through their mastery of “a body of consistent foundation knowledge” (Marble et al., p. 13). Sample undergraduate courses that include core modules should be provided as part of the GIS&T Model Curricula, the Task Force suggested.

Problem-solving emphasis: The “Strawman Report” stressed the importance of problem-solving skills. “It is essential,” the Task Force wrote, that “academic programs ... emphasize the practical aspects of the GIS&T domain along with the theoretical ones. Today, much of the practical knowledge associated with GIS&T exists in the form of professional practices that exist in industry. To work successfully in those environments, students must be exposed to those practices as part of their education. These practices, moreover, extend beyond specific GIS&T skills to encompass a wide range of activities including project management, programming, ethics and values, written and oral communication, and the ability to work as part of a team” (Marble et al., p. 13).

Adaptability to varied institutions: From the outset the Task Force envisioned curricula that were adaptive to the special circumstances of academic institutions and departments as well as to learners and employers. The “Strawman Report” specifically mentions the need to articulate with technical programs offered by two-year institutions.

Scope includes implementation issues: The adaptability of the GIS&T Model Curricula depends on its responsiveness to the characteristics of the facilities and staff of particular institutions. The Strawman Report states that “the scope of the model curricula must extend to infrastructure questions as well as the educational content of the various paths, to explicitly address operational questions of implementation, faculty staffing, laboratory and library facilities, etc.” (p. 14).

Community participation: The “Strawman Report” observes that industry provides many of the employment opportunities available to graduates of baccalaureate and post-baccalaureate programs in GIS&T. “To ensure that graduates are properly prepared for the demands they will face in those positions,” the Task Force wrote, “we believe it is essential to actively involve practitioners in the design, development, and implementation of the model curricula” (Marble and others, 2003, p. 14).

Continual review and revision: “Given the pace of [technological and theoretical] change in our discipline,” the authors of the “Strawman Report” argue, “the notion of updating the model curricula discussed here once every decade or so is unworkable. The professional associations in the GIS&T community, together with government and industry, must establish an ongoing curricula review process that allows individual components of the curricula to be updated on a continuous basis” (Marble et al., p. 14). By comparison, the Computer Science model curriculum was revised four times between its first edition in 1969 and the latest edition in 2001; a new draft curriculum was in review in 2005 (Association of Computing Machinery, 2005).

Cross-cutting themes: The “Strawman Report” identified a preliminary set of “cross-cutting themes”—topics that occur in more than one of the knowledge areas and units that make up the *Body of*

Knowledge. The Task Force observed that cross-cutting themes sometimes have different connotations in different knowledge areas. For example, “scale in visualization refers to the relationship between the real world and its graphical representation, [whereas] scale in a data structure sense may mean how well it can scale up to handle larger amounts of data” (Marble et al., 2003, p. 19). The preliminary list of cross-cutting themes identified in the “Strawman Report” included scale, error, uncertainty, generalization, verification/QC, validation/QA, metadata, interoperability, and language.

Pedagogical and implementation issues: In addition to a *Body of Knowledge*, the GIS&T Model Curricula was intended to include specifications of:

- Supporting topics and courses offered by disciplines within allied fields that provide essential knowledge and skills. For example, Task Force member Jay Sandhu produced a white paper that suggested relevant undergraduate computer science courses (Sandhu, 2000).
- Integrative experiences, including internships and capstone experiences, that help students gain experience in problem-solving through real-world projects. Internships in particular aid in recruitment, enrich the educational experience, direct career paths, and increase retention (Leach, 1998; Wentz & Trapido-Lurie, 2001).
- Specification of the facilities, resources, and faculty training needed to implement and sustain the Model Curricula within higher education institutions
- Suggested dissemination and implementation strategies.

Mastery levels: The Model Curricula Task Force recognized that the level of mastery required for a given topic will depend on the intended outcomes of each curricular pathway. Thus, a range of educational objectives need to be specified for each topic. The Task Force identified five mastery levels: awareness, literacy, use, application development, and mastery. It was noted that mastery “...is not considered common at the undergraduate level” (Marble et al., 2003, p. 23)

Advancing the vision

The second stage of the UCGIS Model Curricula project commenced in October 2004, when UCGIS’s Board of Directors authorized the Education Committee to recruit participants and solicit the financial support needed to complete the project. The Education Committee proposed a three-year plan of work that assumed the same levels of voluntary participation and modest financial support that the Task Force had attracted. A core editorial team was recruited, including five GIS&T educators from UCGIS member institutions, one industry representative, and an instructional design specialist. Four editors had served previously as members of the Model Curricula Task Force. The remaining Task Force members, along with many other GIS&T scholars and practitioners, were invited to serve on an Advisory Board whose members would consult with editors as subject matter experts and reviewers. In all, 65 individuals have contributed to this document as editors, advisors, and/or reviewers. (Contributors are listed at the end of the document.) Additional contributions were made by many others through questions, comments, and

suggestions in personal communications, at conferences and workshops, and indirectly through the long list of references that have been consulted.

Early in 2005, in response to a request for financial support for the project, a key sponsor challenged the Education Committee to propose a more ambitious work plan that would produce results within one year. At the same time, the editorial team and Education Committee recognized that the need for a *GIS&T Body of Knowledge* had increased in urgency due to recent developments in the GIS&T education infrastructure, including massive federal government investments in two-year institutions (and resulting demand for articulation agreements among two-year and four-year institutions), the sudden popularity of GISCI professional certification, and USGIF's new initiative in academic program accreditation. Accordingly, the editors proposed to UCGIS and its sponsors a new, one-year action plan focused on completion and publication of a first edition of the *GIS&T Body of Knowledge*. Recognizing that a large and growing portion of the clientele for higher education in GIS&T participates in programs other than four-year undergraduate degrees, the editors proposed to work with content experts to develop a *Body of Knowledge* that spans the baccalaureate, graduate, and post-baccalaureate/professional sectors of the GIS&T education infrastructure. Plans to define educational pathways and supporting materials were not abandoned, but were deferred until after this document is published.

Members of the editorial team met eight times in 2005 (five times in person, three times by phone or Web conferencing) to consider comments received since the release of the "Strawman Report," to identify aspects of its draft *Body of Knowledge* that needed further development, to coordinate revisions, and to plan and execute outreach activities. Each of five team members (DeMers, DiBiase, Johnson, Kemp, and Wentz, who was relieved by Plewe during her maternity leave) accepted editorial responsibility for two of the ten knowledge areas that make up the *Body of Knowledge*. Editors solicited input from subject matter experts about the objectives, content, and structure of his or her assigned knowledge areas. The team elected to depart from the approach taken in the "Strawman Report" (and in the Computer Science and Information Science Model Curricula) by defining every topic in the *Body of Knowledge* in terms of formal educational objectives (see following section). An additional editor (Luck) reviewed and edited all ten knowledge areas for consistency of the educational objectives. Two editors (DiBiase and Wentz) contributed most of the text that comprises sections I-IV and VI. A complete draft manuscript was submitted to all Advisory Board members for review in November, 2005. A final manuscript that was revised in response to reviewer comments was completed in February, 2006.

v GIS&T Knowledge Areas

Format of the GIS&T Body of Knowledge

To ensure interoperability with corresponding documents in computer science, information science, project management, and other fields, the *Body of Knowledge* is presented as a hierarchical outline composed of three tiers, called “knowledge areas,” “units,” and “topics.” (A more ambitious possible arrangement for future editions is considered in Section VI).

Knowledge areas: The first tier consists of ten knowledge areas that span the breadth of the GIS&T domain. The *Body of Knowledge* is an inventory of the domain, not a set of academic course outlines. Neither the order of the knowledge areas, which is alphabetical, nor that of their content is prescriptive. Unlike the *Computing Curricula 2001* (ACM/IEEE-CS Joint Task Force, 2001), the GIS&T knowledge areas are not assumed to correspond with undergraduate courses. Rather, they represent more-or-less discrete clusters of knowledge, skills, and applications areas that pertain across the undergraduate, graduate, and postbaccalaureate/professional sectors of the GIS&T education infrastructure. The titles, descriptions, and composition of these clusters resulted from an iterative process of discussion and revision involving many educators, researchers, and practitioners over a period of eight years. The process is expected to continue through future editions and is hoped to attract increasing participation from the broad GIS&T community.

Units: Each knowledge area consists of several constituent units. Units are meant to be coherent sets of topics that embody representative concepts, methodologies, techniques, and applications. Units begin with brief descriptions, followed by a list of topics. Units are presented in logical order, but that order is not intended to be prescriptive. Units are designated as either “core” or “elective.” Core units are those in which all graduates of a degree or certificate program should be able to demonstrate some level of mastery. Elective units represent the breadth of the GIS&T domain, including advanced topics related to the upper levels of Marble’s competency pyramid, such as application design, system design, and

research and development. Few experienced professionals, and even fewer students, can be expected to master every unit. A sound goal for continuing professional development, however, may be to seek at least basic understanding of all the units and topics that comprise the *Body of Knowledge*. Given the dynamic nature of the field, professionals who are committed to this goal will continue to pursue knowledge throughout their careers.

An outline of the knowledge areas and units that comprise the *Body of Knowledge* follow.

Knowledge Area: Analytical Methods (AM)

- Unit AM1 Academic and analytical origins
- Unit AM2 Query operations and query languages
- Unit AM3 Geometric measures**
- Unit AM4 Basic analytical operations**
- Unit AM5 Basic analytical methods**
- Unit AM6 Analysis of surfaces
- Unit AM7 Spatial statistics
- Unit AM8 Geostatistics
- Unit AM9 Spatial regression and econometrics
- Unit AM10 Data mining
- Unit AM11 Network analysis
- Unit AM12 Optimization and location-allocation modeling

Knowledge Area: Conceptual Foundations (CF)

- Unit CF1 Philosophical foundations
- Unit CF2 Cognitive and social foundations
- Unit CF3 Domains of geographic information**
- Unit CF4 Elements of geographic information**
- Unit CF5 Relationships
- Unit CF6 Imperfections in geographic information

Knowledge Area: Cartography and Visualization (CV)

- Unit CV1 History and trends
- Unit CV2 Data considerations**
- Unit CV3 Principles of map design**
- Unit CV4 Graphic representation techniques
- Unit CV5 Map production
- Unit CV6 Map use and evaluation**

Knowledge Area: Design Aspects (DA)

- Unit DA1 The scope of GIS&T system design
- Unit DA2 Project definition
- Unit DA3 Resource planning
- Unit DA4 Database design**
- Unit DA5 Analysis design
- Unit DA6 Application design
- Unit DA7 System implementation

Knowledge Area: Data Modeling (DM)

- Unit DM1 Basic storage and retrieval structures
- Unit DM2 Database management systems**
- Unit DM3 Tessellation data models**
- Unit DM4 Vector and object data models**
- Unit DM5 Modeling 3D, temporal, and uncertain phenomena

Knowledge Area: Data Manipulation (DN)

- Unit DN1 Representation transformation**
- Unit DN2 Generalization and aggregation**
- Unit DN3 Transaction management of geospatial data

Knowledge Area: Geocomputation (GC)

- Unit GC1 Emergence of geocomputation
- Unit GC2 Computational aspects and neurocomputing
- Unit GC3 Cellular Automata (CA) models
- Unit GC4 Heuristics
- Unit GC5 Genetic algorithms (GA)
- Unit GC6 Agent-based models
- Unit GC7 Simulation modeling
- Unit GC8 Uncertainty
- Unit GC9 Fuzzy sets

Knowledge Area: Geospatial Data (GD)

- Unit GD1 Earth geometry**
- Unit GD2 Land partitioning systems
- Unit GD3 Georeferencing systems**
- Unit GD4 Datums**
- Unit GD5 Map projections**
- Unit GD6 Data quality**
- Unit GD7 Land surveying and GPS**
- Unit GD8 Digitizing
- Unit GD9 Field data collection
- Unit GD10 Aerial imaging and photogrammetry**
- Unit GD11 Satellite and shipboard remote sensing**
- Unit GD12 Metadata, standards, and infrastructures**

Knowledge Area: GIS&T and Society (GS)

- Unit GS1 Legal aspects
- Unit GS2 Economic aspects
- Unit GS3 Use of geospatial information in the public sector
- Unit GS4 Geospatial information as property
- Unit GS5 Dissemination of geospatial information
- Unit GS6 Ethical aspects of geospatial information and technology**
- Unit GS7 Critical GIS

Knowledge Area: Organizational and Institutional Aspects (OI)

- Unit OI1 Origins of GIS&T
- Unit OI2 Managing GIS operations and infrastructure
- Unit OI3 Organizational structures and procedures
- Unit OI4 GIS&T workforce themes
- Unit OI5 Institutional and inter-institutional aspects**
- Unit OI6 Coordinating organizations (national and international)**

Table 4: Knowledge areas and units comprising the *Body of Knowledge*. Core units are indicated with bold type.

Evolution of knowledge areas and units since the “Strawman Report”: In consultation with Advisory Board members, the editorial team revised the unit-level outline from the 2003 “Strawman Report” version in the following ways:

- Knowledge areas in the current version are now ordered alphabetically. Feedback from Advisory Board members revealed that readers tended to mistakenly assume that the order was prescriptive in regards to curriculum planning.
- The current *Body of Knowledge* includes ten knowledge areas instead of twelve. Early in the second stage of the Model Curricula project, the editors elected to combine two knowledge areas (“EA. Exploratory spatial data analysis” and “CA. Confirmatory spatial data analysis” became AM) and to distribute units and topics from one (“FS. Formalizing Spatial Conceptions”) into two other knowledge areas (CF and DM) for clarity and conciseness.
- Some knowledge areas were recast. “CS. Conceptualization of Space” became “CF. Conceptual Foundations” to broaden its scope, and units were added accordingly.
- Units were reordered, added, and/or elaborated in several knowledge areas. These changes follow from discussions among editors and content experts.
- One knowledge area—“PS. Professional, Social, and Legal Aspects”—was recast as “GS. GIS&T and Society.” This change followed from reviewer critiques as well as editors’ recognition that GIS and Society—which subsumes the units and topics included in the former PS knowledge area—has emerged as a vibrant and influential research focus within GIScience.
- Key readings are added at the end of each knowledge area as an aid to students and instructors, and as a way to disclose the intellectual lineage and vintage of the *Body of Knowledge*.

Topics: Units are subdivided into topics. Each topic represents a single concept, methodology, or technique. Topics are defined in terms of one or more formal educational objectives (e.g., “Define common theories on what is ‘real,’ such as realism, idealism, relativism, and experiential realism” from Knowledge Area CF: Conceptual Foundations). Explicit objectives help educators design effective instructional activities and evaluation instruments (Gronlund, 2003). Although the *Body of Knowledge* includes 1,660 objectives, these are intended to be representative rather than exhaustive.

An educational objective describes a student behavior that involves a topic. Objectives include both nouns and verbs. Nouns refer to the level of knowledge required to fulfill the objective. Verbs refer to the cognitive processes involved in fulfilling the objective. The *Taxonomy for Learning, Teaching, and Assessment*, recently expanded by Anderson and Krathwohl (2001) from the original taxonomy of Bloom (1956), is a well-known framework for categorizing educational objectives that is frequently used to guide curriculum planning and test design.

In the *Taxonomy*, knowledge levels and cognitive processes are presented as continua that can be juxtaposed to form a table (Figure 6). The “knowledge dimension” of the taxonomy table includes four cat-

egories, ranked in ascending order of sophistication: factual knowledge, conceptual knowledge, procedural knowledge, and meta-cognitive knowledge (reflective awareness of what and how one learns). The “cognitive process dimension” includes six categories, also in ascending order: remember, understand, apply, analyze, evaluate, and create. For example, the educational objective “design point, transect, and area sampling strategies for a variety of projects” involves a high-level cognitive process (design, a kind of creation) as well as both conceptual and procedural knowledge. To ensure that the *Body of Knowledge* is applicable across the undergraduate, graduate, and postbaccaluate/professional sectors of the GIS&T education infrastructure, the editors sought a range of fundamental, intermediate level, and high level objectives that span the taxonomy table. (The editors elected not to seek objectives involving metacognitive knowledge, trusting that instructors would add such objectives locally, as appropriate to particular institutions and programs.)

		Cognitive Processes					
		1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
Knowledge Type	A. Factual						
	B. Conceptual						
	C. Procedural						
	D. Metacognitive						

Figure 6: Categories of educational objectives sought for the *GIS&T Body of Knowledge* (after Anderson and Krathwohl, 2001).

Educational objectives broadly describe desired educational outcomes. They “provide the basis for planning units containing objectives that require weeks or months to learn” (Anderson & Krathwohl, 2001, p. 16-17). They differ from instructional objectives, which narrowly define activities intended to achieve objectives, or to evaluate the extent to which objectives have been achieved. For instance, an instructional objective rendered from the educational example given above (“design point, transect, and area sampling strategies for a variety of projects”) might be, “design a transect sampling strategy for a particular study area and research design.” In general, the editors sought to define topics in terms of relatively broad educational objectives. Because objectives were used to define individual topics, however, they are more specific (and much more plentiful) than the unit-level objectives in the “Strawman Report” and in the bodies of knowledge of allied fields.

Knowledge Area: Analytical Methods (AM)

This knowledge area encompasses a wide variety of operations whose objective is to derive analytical results from geospatial data. Data analysis seeks to understand both first-order (environmental) effects and second-order (interaction) effects. Approaches that are both data-driven (exploration of geospatial data) and model-driven (testing hypotheses and creating models) are included. Data driven techniques derive summary descriptions of data, evoke insights about characteristics of data, contribute to the development of research hypotheses, and lead to the derivation of analytical results. The goal of model-driven analysis is to create and test geospatial process models. In general, model-driven analysis is an advanced knowledge area where previous experience with exploratory spatial data analysis would constitute a desired prerequisite. Visual tools for data analysis are covered in Knowledge Area: Cartography and Visualization (CV) and many of the fundamental principles required to ground data analysis techniques are introduced in Knowledge Area: Conceptual Foundations (CF). Image processing techniques are considered in Knowledge Area: Geospatial Data (GD). All of the methods described in this knowledge area are more or less sensitive to data error and uncertainty as covered in Unit GC8 Uncertainty and Unit GD6 Data quality. Mastery of the educational objectives outlined in this knowledge area requires knowledge and skills in mathematics, statistics, and computer programming.

Unit AM1 Academic and analytical origins

Geospatial data analysis has foundations in many different disciplines. As a result, there are many different schools of thought or analytical approaches including spatial analysis, spatial modeling, geostatistics, spatial econometrics, spatial statistics, qualitative analysis, map algebra, and network analysis. This unit compares and contrasts these approaches.

Topic AM1-1 Academic foundations

- Differentiate between exploratory and confirmatory geospatial data analysis
- Differentiate geospatial data analysis from non-spatial data analysis
- Explain the origins of the term “Quantitative Revolution” in geography and other disciplines
- Explain how the “Quantitative Revolution” was important in the development of GIS&T
- Contrast the analytical approaches taken in various academic disciplines in which geospatial analysis has evolved

Topic AM1-2 Analytical approaches

- Compare and contrast spatial statistical analysis, spatial data analysis, and spatial modeling
- Compare and contrast spatial statistics and map algebra as two very different kinds of data analysis
- Compare and contrast the methods of analyzing aggregate data as opposed to methods of analyzing a set of individual observations
- Define the terms spatial analysis, spatial modeling, geostatistics, spatial econometrics, spatial statistics, qualitative analysis, map algebra, and network analysis
- Differentiate between geostatistics and spatial statistics

- Discuss situations when it is desirable to adopt a spatial approach to the analysis of data
- Explain what is added to spatial analysis to make it spatio-temporal analysis
- Explain what is special (i.e., difficult) about geospatial data analysis and why some traditional statistical analysis techniques are not suited to geographic problems
- Outline the sequence of tasks required to complete the analytical process for a given spatial problem

Unit AM2 Query operations and query languages

Attribute and spatial query operations are core functionalities in any GIS and they are often considered to be the most basic form of analysis.

Topic AM2-1 Set theory

- Describe set theory
- Explain how set theory relates to spatial queries
- Explain how logic theory relates to set theory
- Perform a logic (set theoretic) query using GIS software

Topic AM2-2 Structured Query Language (SQL and attribute queries)

- Define basic terms of query processing (e.g., SQL, primary and foreign keys, table join)
- Explain the basic logic of SQL syntax
- Demonstrate the basic syntactic structure of SQL
- Create an SQL query to retrieve elements from a GIS

Topic AM2-3 Spatial queries

- Demonstrate the syntactic structure of spatial and temporal operators in SQL
- Compare and contrast attribute query and spatial query
- State questions that can be solved by selecting features based on location or spatial relationships
- Construct a query statement to search for a specific spatial or temporal relationship
- Construct a spatial query to extract all point objects that fall within a polygon

Unit AM3 Geometric measures (*core unit*)

For simple data exploration, GIS offers many basic geometric operations that help in extracting meaning from sets of data or for deriving new data for further analysis. Concepts on which these operations are based are addressed in Unit CF3 Domains of geographic information and Unit CF5 Relationships.

Topic AM3-1 Distances and lengths

- Describe several different measures of distance between two points (e.g., Euclidean, Manhattan, network distance, spherical)
- Explain how different measures of distance can be used to calculate the spatial weights matrix

- Explain why estimating the fractal dimension of a sinuous line has important implications for the measurement of its length
- Explain how fractal dimension can be used in practical applications of GIS
- Explain the differences in the calculated distance between the same two places when data used are in different projections
- Outline the implications of differences in distance calculations on real world applications of GIS, such as routing and determining boundary lengths and service areas
- Estimate the fractal dimension of a sinuous line

Topic AM3-2 Direction

- Define “direction” and its measurement in different angular measures
- Compare and contrast how direction is determined and stated in raster and vector data
- Describe operations that can be performed on qualitative representations of direction
- Explain any differences in the measured direction between two places when the data are presented in a GIS in different projections
- Compute the mean of directional data

Topic AM3-3 Shape

- Identify situations in which shape affects geometric operations
- Explain what is meant by the convex hull and minimum enclosing rectangle of a set of point data
- Explain why the shape of an object might be important in analysis
- Exemplify situations in which the centroid of a polygon falls outside its boundary
- Compare and contrast different shape indices, include examples of applications to which each could be applied
- Develop a method for describing the shape of a cluster of similarly valued points by using the concept of the convex hull
- Develop an algorithm to determine the skeleton of polygons
- Find centroids of polygons under different definitions of a centroid and different polygon shapes
- Calculate several different shape indices for a polygon dataset

Topic AM3-4 Area

- List reasons why the area of a polygon calculated in a GIS might not be the same as the real world object it describes
- Explain how variations in the calculation of area may have real world implications, such as calculating density
- Demonstrate how the area of a region calculated from a raster data set will vary by resolution and orientation
- Outline an algorithm to find the area of a polygon using the coordinates of its vertices

Topic AM3-5 Proximity and distance decay

- Describe real world applications where distance decay is an appropriate representation of the strength of spatial relationships (e.g., shopping behavior, property values)
- Describe real world applications where distance decay would not be an appropriate representation of the strength of spatial relationships (e.g., distance education, commuting, telecommunications)
- Explain the rationale for using different forms of distance decay functions

- Explain how a semi-variogram describes the distance decay in dependence between data values
- Outline the geometry implicit in classical “gravity” models of distance decay
- Plot typical forms for distance decay functions
- Write typical forms for distance decay functions
- Write a program to create a matrix of pair-wise distances among a set of points

Topic AM3-6 Adjacency and connectivity

- List different ways connectivity can be determined in a raster and in a polygon dataset
- Describe real world applications where adjacency and connectivity are a critical component of analysis
- Explain the nine-intersection model for spatial relationships
- Demonstrate how adjacency and connectivity can be recorded in matrices
- Calculate various measures of adjacency in a polygon dataset
- Create a matrix describing the pattern of adjacency in a set of planar enforced polygons

Unit AM4 Basic analytical operations (core unit)

This small set of analytical operations is so commonly applied to a broad range of problems that their inclusion in software products is often used to determine if that product is a “true” GIS. Concepts on which these operations are based are addressed in Unit CF3 Domains of geographic information and Unit CF5 Relationships.

Topic AM4-1 Buffers

- Compare and contrast raster and vector definitions of buffers
- Explain why a buffer is a contour on a distance surface
- Outline circumstances in which buffering around an object is useful in analysis

Topic AM4-2 Overlay

- Explain why the process “dissolve and merge” often follows vector overlay operations
- Explain what is meant by the term “planar enforcement”
- Outline the possible sources of error in overlay operations
- Exemplify applications in which overlay is useful, such as site suitability analysis
- Compare and contrast the concept of overlay as it is implemented in raster and vector domains
- Demonstrate how the geometric operations of intersection and overlay can be implemented in GIS
- Demonstrate why the georegistration of datasets is critical to the success of any map overlay operation
- Formalize the operation called map overlay using Boolean logic

Topic AM4-3 Neighborhoods

- Discuss the role of Voronoi polygons as the dual graph of the Delaunay triangulation
- Explain how the range of map algebra operations (local, focal, zonal, and global) relate to the concept of neighborhoods
- Explain how Voronoi polygons can be used to define neighborhoods around a set of points

- Outline methods that can be used to establish non-overlapping neighborhoods of similarity in raster datasets
- Create proximity polygons (Thiessen/Voronoi polygons) in point datasets
- Write algorithms to calculate neighborhood statistics (minimum, maximum, focal flow) using a moving window in raster datasets

Topic AM4-4 Map algebra

- Describe how map algebra performs mathematical functions on raster grids
- Describe a real modeling situation in which map algebra would be used (e.g., site selection, climate classification, least-cost path)
- Explain the categories of map algebra operations (i.e., local, focal, zonal, and global functions)
- Explain why georegistration is a precondition to map algebra
- Differentiate between map algebra and matrix algebra using real examples
- Perform a map algebra calculation using command line, form-based, and flow charting user interfaces

Unit AM5 Basic analytical methods (*core unit*)

Building on the basic geometric measures and analytical operations found in most GIS products, a broad range of additional analytical methods form the fundamental GIS toolkit.

Topic AM5-1 Point pattern analysis

- List the conditions that make point pattern analysis a suitable process
- Identify the various ways point patterns may be described
- Identify various types of K-function analysis
- Describe how Independent Random Process/Chi-Squared Result (IRP/CSR) may be used to make statistical statements about point patterns
- Outline measures of pattern based on first and second order properties such as the mean center and standard distance, quadrat counts, nearest neighbor distance, and the more modern G, F, and K functions
- Outline the basis of classic critiques of spatial statistical analysis in the context of point pattern analysis
- Explain how distance-based methods of point pattern measurement can be derived from a distance matrix
- Explain how proximity polygons (e.g., Thiessen polygons) may be used to describe point patterns
- Explain how the K function provides a scale-dependent measure of dispersion
- Compute measures of overall dispersion and clustering of point datasets using nearest neighbor distance statistics

Topic AM5-2 Kernels and density estimation

- Describe the relationships between kernels and classical spatial interaction approaches, such as surfaces of potential
- Differentiate between kernel density estimation and spatial interpolation
- Outline the likely effects on analysis results of variations in the kernel function used and the bandwidth adopted

- Explain why and how density estimation transforms point data into a field representation
- Explain why, in some cases, an adaptive bandwidth might be employed
- Create density maps from point datasets using kernels and density estimation techniques using standard software

Topic AM5-3 Spatial cluster analysis

- Identify several cluster detection techniques and discuss their limitations
- Discuss the characteristics of the various cluster detection techniques
- Demonstrate the extension of spatial clustering to deal with clustering in space-time using the Know and Mantel tests
- Perform a cluster detection analysis to detect “hot spots” in a point pattern

Topic AM5-4 Spatial interaction

- State the classic formalization of the interaction model
- Differentiate between the gravity model and spatial interaction models
- Describe the formulation of the classic gravity model, the unconstrained spatial interaction model, the production constrained spatial interaction model, the attraction constrained spatial interaction model, and the doubly constrained spatial interaction model
- Explain how dynamic, chaotic, complex, or unpredictable aspects in some phenomena make spatial interaction models more appropriate than gravity models
- Explain the concept of competing destinations, describing how traditional spatial interaction model forms are modified to account for it
- Create a matrix that shows spatial interaction

Topic AM5-5 Analyzing multidimensional attributes

- Relate plots of multidimensional attribute data to geography by equating similarity in data space with proximity in geographical space
- Assemble a data matrix of attributes
- Produce plots in several data dimensions using a data matrix of attributes
- Conduct a simple hierarchical cluster analysis to classify area objects into statistically similar regions
- Perform multidimensional scaling (MDS) and principal components analysis (PCA) to reduce the number of coordinates, or dimensionality, of a problem

Topic AM5-6 Cartographic modeling

- Describe the difference between prescriptive and descriptive cartographic models
- Discuss the origins of cartographic modeling with reference to the work of Ian McHarg
- Develop a flowchart of a cartographic model for a site suitability problem

Topic AM5-7 Multi-criteria evaluation

- Describe the implementation of an ordered weighting scheme in a multiple-criteria aggregation
- Compare and contrast the terms multi-criteria evaluation, weighted linear combination, and site suitability analysis
- Differentiate between contributing factors and constraints in a multi-criteria application
- Explain the legacy of multi-criteria evaluation in relation to cartographic modeling
- Determine which method to use to combine criteria (e.g., linear, multiplication)

- Create initial weights using the analytical hierarchy process (AHP)
- Calibrate a linear combination model by adjusting weights using a test data set

Topic AM5-8 Spatial process models

- Discuss the relationship between spatial processes and spatial patterns
- Differentiate between deterministic and stochastic spatial process models
- Describe a simple process model that would generate a given set of spatial patterns

Unit AM6 Analysis of surfaces

There is a wide range of phenomena that can be studied using a set of techniques and tools that are designed to help understand the characteristics of continuous surface data. Applications of these techniques using terrain data include overland transport, flow, and siting tasks, but similar analyses can be conducted using non-tangible surfaces such as those of temperature, pressure, and population density.

Topic AM6-1 Calculating surface derivatives

- List the likely sources of error in slope and aspect maps derived from digital elevation models (DEMs) and state the circumstances under which these can be very severe
- Outline a number of different methods for calculating slope from a DEM
- Outline how higher order derivatives of height can be interpreted
- Explain how slope and aspect can be represented as the vector field given by the first derivative of height
- Explain why the properties of spatial continuity are characteristic of spatial surfaces
- Explain why zero slopes are indicative of surface specific points such as peaks, pits, and passes, and list the conditions necessary for each
- Design an algorithm that calculates slope and aspect from a triangulated irregular network (TIN) model

Topic AM6-2 Interpolation of surfaces

- Identify the spatial concepts that are assumed in different interpolation algorithms
- Describe how surfaces can be interpolated using splines
- Compare and contrast interpolation by inverse distance weighting, bi-cubic spline fitting, and kriging
- Differentiate between trend surface analysis and deterministic spatial interpolation
- Explain why different interpolation algorithms produce different results and suggest ways by which these can be evaluated in the context of a specific problem
- Design an algorithm that interpolates irregular point elevation data onto a regular grid
- Outline algorithms to produce repeatable contour-type lines from point datasets using proximity polygons, spatial averages, or inverse distance weighting
- Implement a trend surface analysis using either the supplied function in a GIS or a regression function from any standard statistical package

Topic AM6-3 Surface features

- Describe how a network of stream channels and ridges can be estimated from a DEM
- Explain how ridgelines and streamlines can be used to improve the result of an interpolation process

Topic AM6-4 Intervisibility

- Define “intervisibility”
- Explain the sources and impact of errors that affect intervisibility analyses
- Outline an algorithm to determine the viewshed (area visible) from specific locations on surfaces specified by DEMs
- Perform siting analyses using specified visibility, slope, and other surface related constraints

Topic AM6-5 Friction surfaces

- Define “friction surface”
- Explain how friction surfaces are enhanced by the use of impedance and barriers
- Apply the principles of friction surfaces in the calculation of least-cost paths

Unit AM7 Spatial statistics

Traditional statistical methods are used to describe the central tendency, dispersion, and other characteristics of data but are not always suited to use with spatial data for which specialized techniques are often required. The field of spatial statistical analysis forms the backbone for the testing of hypotheses about the nature of spatial pattern, dependency, and heterogeneity. The techniques are widely used in both exploratory and confirmatory spatial analysis in many different fields.

Topic AM7-1 Graphical methods

- Describe the statistical characteristics of a set of spatial data using a variety of graphs and plots (including scatterplots, histograms, boxplots, q–q plots)
- Select the appropriate statistical methods for the analysis of given spatial datasets by first exploring them using graphic methods

Topic AM7-2 Stochastic processes

- List the two basic assumptions of the purely random process
- Justify the stochastic process approach to spatial statistical analysis
- Exemplify deterministic and spatial stochastic processes
- Exemplify non-stationarity involving first and second order effects
- Differentiate between isotropic and anisotropic processes
- Discuss the theory leading to the assumption of intrinsic stationarity
- Outline the logic behind the derivation of long run expected outcomes of the independent random process using quadrat counts

Topic AM7-3 The spatial weights matrix

- Explain how different types of spatial weights matrices are defined and calculated
- Explain the rationale used for each type of spatial weights matrix
- Discuss the appropriateness of different types of spatial weights matrices for various problems
- Construct a spatial weights matrix for lattice, point, and area patterns

Topic AM7-4 Global measures of spatial association

- Describe the effect of the assumption of stationarity on global measures of spatial association
- Explain how a statistic that is based on combining all the spatial data and returning a single summary value or two can be useful in understanding broad spatial trends
- Explain how the K function provides a scale-dependent measure of dispersion
- Compute Moran's I and Geary's c for patterns of attribute data measured on interval/ratio scales
- Compute measures of overall dispersion and clustering of point datasets using nearest neighbor distance statistics
- Compute the K function
- Justify, compute, and test the significance of the join count statistic for a pattern of objects

Topic AM7-5 Local measures of spatial association

- Describe the effect of non-stationarity on local indices of spatial association
- Compare and contrast global and local statistics and their uses
- Explain how a weights matrix can be used to convert any classical statistic into a local measure of spatial association
- Explain how geographically weighted regression provides a local measure of spatial association
- Decompose Moran's I and Geary's c into local measures of spatial association
- Compute the G_i and G_i^* statistics

Topic AM7-6 Outliers

- Explain how outliers affect the results of analyses
- Explain how the following techniques can be used to examine outliers: tabulation, histograms, box plots, correlation analysis, scatter plots, local statistics

Topic AM7-7 Bayesian methods

- Define "prior and posterior distributions" and "Markov-Chain Monte Carlo"
- Explain how the Bayesian perspective is a unified framework from which to view uncertainty
- Compare and contrast Bayesian methods and classical "frequentist" statistical methods

Unit AM8 Geostatistics

Geostatistics are a variety of techniques used to analyze continuous data (e.g., rainfall, elevation, air pollution). The fundamental structure of geostatistics is based on the concept of semi-variograms and their use for spatial prediction (kriging). Sampling methods are also discussed in Unit GD9 Field data collection.

Topic AM8-1 Spatial sampling for statistical analysis

- List and describe several spatial sampling schemes and evaluate each one for specific applications
- Describe sampling schemes for accurately estimating the mean of a spatial data set
- Differentiate between model-based and design-based sampling schemes
- Design a sampling scheme that will help detect when space-time clusters of events occur
- Create spatial samples under a variety of requirements, such as coverage, randomness, and transects

Topic AM8-2 Principles of semi-variogram construction

- Identify and define the parameters of a semi-variogram (range, sill, nugget)
- Describe the relationships between semi-variograms and correlograms, and Moran's indices of spatial association
- Demonstrate how semi-variograms react to spatial nonstationarity
- Construct a semi-variogram and illustrate with a semi-variogram cloud

Topic AM8-3 Semi-variogram modeling

- List the possible sources of error in a selected and fitted model of an experimental semi-variogram
- Describe some commonly used semi-variogram models
- Describe the conditions under which each of the commonly used semi-variograms models would be most appropriate
- Explain the necessity of defining a semi-variogram model for geographic data
- Apply the method of weighted least squares and maximum likelihood to fit semi-variogram models to datasets

Topic AM8-4 Principles of kriging

- Describe the relationship between the semi-variogram and kriging
- Explain why kriging is more suitable as an interpolation method in some applications than others
- Explain why it is important to have a good model of the semi-variogram in kriging
- Explain the concept of the kriging variance, and describe some of its shortcomings
- Explain how block-kriging and its variants can be used to combine data sets with different spatial resolution (support)
- Compare and contrast block-kriging with areal interpolation using proportional area weighting and dasymetric mapping
- Outline the basic kriging equations in their matrix formulation
- Conduct a spatial interpolation process using kriging from data description to final error map

Topic AM8-5 Kriging variants

- Compare and contrast co-kriging, log-normal kriging, disjunctive kriging, indicator kriging, factorial kriging, and universal kriging
- Apply universal kriging to appropriate data sets
- Interpret the results of universal kriging

Unit AM9 Spatial regression and econometrics

Many problems of the social sciences can be expressed in terms of spatial regression analysis. The development of spatial autoregressive models and the estimation of their parameters is the focus for the field of spatial econometrics.

Topic AM9-1 Principles of spatial econometrics

- Describe the general types of spatial econometric models
- Explain how spatial dependence and spatial heterogeneity violate the Gauss-Markov assumptions of regression used in traditional econometrics

- Demonstrate how spatially lagged, trend surface, or dummy spatial variables can be used to create the spatial component variables missing in a standard regression analysis
- Demonstrate how the spatial weights matrix is fundamental in spatial econometrics models
- Demonstrate why spatial autocorrelation among regression residuals can be an indication that spatial variables have been omitted from the models

Topic AM9-2 Spatial autoregressive models

- Explain Anselin's typology of spatial autoregressive models
- Conduct a spatial econometric analysis to test for spatial dependence in the residuals from least-squares models and spatial autoregressive models
- Demonstrate how the parameters of spatial auto-regressive models can be estimated using univariate and bivariate optimization algorithms for maximizing the likelihood function
- Justify the choice of a particular spatial autoregressive model for a given application
- Implement a maximum likelihood estimation procedure for determining key spatial econometric parameters
- Apply spatial statistic software (e.g., GEODA) to create and estimate an autoregressive model

Topic AM9-3 Spatial filtering

- Identify modeling situations where spatial filtering might not be appropriate
- Describe the relationship between factorial kriging and spatial filtering
- Explain how spatial correlation can result as a side effect of the spatial aggregation in a given dataset
- Explain how dissolving clusters of blocks with similar values may resolve the spatial correlation problem
- Explain how the Getis and Tiefelsdorf-Griffith spatial filtering techniques incorporate spatial component variables into OLS regression analysis in order to remedy misspecification and the problem of spatially auto-correlated residuals
- Demonstrate how spatial autocorrelation can be "removed" by resampling

Topic AM9-4 Spatial expansion and geographically weighted regression (GWR)

- Describe the characteristics of the spatial expansion method
- Discuss the appropriateness of GWR under various conditions
- Explain how allowing the parameters of the model to vary with the spatial location of the sample data can be used to accommodate spatial heterogeneity
- Explain the principles of geographically weighted regression
- Compare and contrast GWR with universal kriging using moving neighborhoods
- Perform an analysis using the geographically weighted regression technique
- Analyze the number of degrees of freedom in GWR analyses and discuss any possible difficulties with the method based on your results

Unit AM10 Data mining

Algorithms have been developed to scan and search through extremely large data sets to find patterns within the data. These data mining and knowledge discovery techniques have been expanded to the spatial case. Legal and ethical concerns associated with such practices are considered in Knowledge Areas GIS&T and Society (GS) and Organizational and Institutional Aspects (OI).

Topic AM10-1 Problems of large spatial databases

- Describe emerging geographical analysis techniques in geocomputation derived from artificial intelligence (e.g., expert systems, artificial neural networks, genetic algorithms, and software agents)
- Describe difficulties in dealing with large spatial databases, especially those arising from spatial heterogeneity
- Explain what is meant by the term “contaminated data,” suggesting how it can arise
- Explain how to recognize contaminated data in large datasets
- Outline the implications of complexity for the application of statistical ideas in geography

Topic AM10-2 Data mining approaches

- Describe how data mining can be used for geospatial intelligence
- Differentiate between data mining approaches used for spatial and non-spatial applications
- Compare and contrast the primary types of data mining: summarization/characterization, clustering/categorization, feature extraction, and rule/relationships extraction
- Explain how spatial statistics techniques are used in spatial data mining
- Explain how the analytical reasoning techniques, visual representations, and interaction techniques that make up the domain of visual analytics have a strong spatial component
- Demonstrate how cluster analysis can be used as a data mining tool
- Interpret patterns in space and time using Dorling and Openshaw’s geographical analysis machine (GAM) demonstration of disease incidence diffusion

Topic AM10-3 Knowledge discovery

- Explain how spatial data mining techniques can be used for knowledge discovery
- Explain how visual data exploration can be combined with data mining techniques as a means of discovering research hypotheses in large spatial datasets
- Explain how a Bayesian framework can incorporate expert knowledge in order to retrieve all relevant datasets given an initial user query

Topic AM10-4 Pattern recognition and matching

- Differentiate among machine learning, data mining, and pattern recognition
- Explain the outcome of an artificial intelligence analysis (e.g., edge recognition), including a discussion of what the human did not see that the computer identified and vice versa
- Explain the principles of pattern recognition
- Apply a simple spatial mean filter to an image as a means of recognizing patterns
- Construct an edge-recognition filter
- Design a simple spatial mean filter

Unit AM11 Network analysis

Network analysis encompasses a wide range of procedures, techniques, and methods that allow for the examination of phenomena that can be modeled in the form of connected sets of edges and vertices. Such sets are termed a network, or a graph, and the mathematical basis for network analysis is known as graph theory. Graph theory contains descriptive measures and indices of networks (such as connectivity, adjacency, capacity, and flow) as well as methods for proving the properties of networks. Networks

have long been recognized as an efficient way to model many types of geographic data, including transportation networks, river networks, and utility networks (electric, cable, sewer and water, etc.) to name just a few. The data structures to support network analysis are covered in Unit DM4 Vector and object data models.

Topic AM11-1 Networks defined

- Define the following terms pertaining to a network: Loops, multiple edges, the degree of a vertex, walk, trail, path, cycle, fundamental cycle
- Define different interpretations of “cost” in various routing applications
- Describe networks that apply to specific applications or industries
- Create a data set with network attributes and topology

Topic AM11-2 Graph theoretic (descriptive) measures of networks

- Demonstrate how networks can be measured using the number of elements in a network, the distances along network edges, and the level of connectivity of the network
- Explain the concept of the diameter of a network
- Compute the estimated number of fundamental cycles in a graph
- Compute the alpha, beta, and gamma indices of network connectivity
- Compute the detour index and the measure of network density for a given network

Topic AM11-3 Least-cost (shortest) path

- Describe some variants of Dijkstra’s algorithm that are even more efficient
- Explain how a leading World Wide Web-based routing system works (e.g., MapQuest, Yahoo Maps, Google)
- Discuss the difference of implementing Dijkstra’s algorithm in raster and vector modes
- Demonstrate how K-shortest path algorithms can be implemented to find many efficient alternate paths across the network
- Compute the optimum path between two points through a network with Dijkstra’s algorithm

Topic AM11-4 Flow modeling

- Describe practical situations in which flow is conserved while splitting or joining at nodes of the network
- Explain how the concept of capacity represents an upper limit on the amount of flow through the network
- Demonstrate how capacity is assigned to edges in a network using the appropriate data structure
- Apply a maximum flow algorithm to calculate the largest flow from a source to a sink, using the edges of the network, subject to capacity constraints on the arcs and the conservation of flow

Topic AM11-5 The classic transportation problem

- Describe the classic transportation problem
- Explain why, if supply equals demand, there will always be a feasible solution to the classic transportation problem
- Demonstrate how the classic transportation problem can be structured as a linear program
- Implement the transportation simplex method to determine the optimal solution

Topic AM11-6 Other classic network problems

- Describe several classic problems to which network analysis is applied (e.g., the traveling salesman problem, the Chinese postman problem)
- Explain why heuristic solutions are generally used to address the combinatorially complex nature of these problems and the difficulty of solving them optimally

Topic AM11-7 Accessibility modeling

- Describe alternate definitions of accessibility on a network
- Describe methods for measuring different kinds of accessibility on a network
- Contrast accessibility modeling at the individual level versus at an aggregated level
- Compare current accessibility models with early models of market potential

Unit AM12 Optimization and location-allocation modeling

A wide variety of optimization techniques are now solvable within the GIS&T domain. Operations research is a branch of mathematics practiced in the allied fields of business and engineering. New models and software tools allow for the solution of transportation routing, facility location, and a host of other location-allocation modeling problems.

Topic AM12-1 Operations research modeling and location modeling principles

- Explain how optimization models can be used to generate models of alternate options for presentation to decision makers
- Explain the concept of solution space
- Explain the principles of operations research modeling and location modeling
- Explain, using the concept of combinatorial complexity, why some location problems are very hard to solve
- Compare and contrast the concepts of discrete location problems and continuous location problems

Topic AM12-2 Linear programming

- Describe the structure of linear programs
- Explain the role of objective functions in linear programming
- Explain the role of constraint functions using the graphical method
- Explain the role of constraint functions using the simplex method
- Implement linear programs for spatial allocation problems

Topic AM12-3 Integer programming

- Differentiate between a linear program and an integer program
- Explain why integer programs are harder to solve than linear programs

Topic AM12-4 Location-allocation modeling and p-median problems

- Describe the structure of origin-destination matrices
- Explain the concepts of demand and service
- Explain Weber's locational triangle

- Assess the outcome of location-allocation models using other spatial analysis techniques
- Compare and contrast covering, dispersion, and p-median models
- Locate, using location-allocation software, service facilities that meet given sets of constraints

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Knowledge Area: Conceptual Foundations (CF)

The GIScience perspective is grounded in spatial thinking. The aim of this knowledge area is to recognize, identify, and appreciate the explicit spatial, spatio-temporal and semantic components of the geographic environment at an ontological and epistemological level in preparation for modeling the environment with geographic data and analysis. To do this, one must understand the nature of space and time as a context for geographic phenomena. This knowledge area covers the ways in which views of the geographic environment depend on philosophical viewpoints, physics, human cognition, society, and the task at hand. This knowledge area also requires an understanding of the fundamental principles in the discipline of geography, the “language” of spatial tasks. On a more advanced level, this area incorporates mathematical and graphical models that formalize these concepts, such as set theory, algebra, and semantic nets.

Because of its wide range of foundational principles, this knowledge area forms a basis for the other knowledge areas. Wise design and use of geospatial technologies requires an understanding of the nature of geographic information, the social and philosophical context of geographic information, and the principles of geography. This knowledge area is especially closely tied to Knowledge Areas Data Modeling (DM) and Design Aspects (DA), as generic data models (such as raster and vector) and application designs need to be grounded in sound conceptual models.

The foundations of geographic information have developed over several decades. Philosophical and scientific views on the nature of space and time have evolved since the ancient Greeks. Early papers during the Quantitative Revolution, such as Berry (1964), began to formalize the structure of information used in geographic inquiry. The fundamental data structures and algorithms comprising the GIS software developed in the 1960's and 1970's were based on implicit “common-sense” conceptual models of geographic information. During the 1980's, several researchers questioned these underlying assumptions. Some were refuted, other confirmed, and many extended. However, the most rapid pace of development in this area was during the 1990's with the rise of GIScience as a distinct discipline, and the many cooperative initiatives it comprised. The new millennium has seen some of these foundational principles incorporated into commercial software, thus making theoretical knowledge even more important for practitioners.

It is expected that the concepts in this knowledge area will be learned gradually. An introductory course may cover only a few topics in a cursory manner, an intermediate course on data modeling or data analysis may consider several theoretical topics of practical application, and a number of graduate courses could cover each topic in a research-oriented environment.

Discussion of this knowledge area includes several terms that can have multiple meanings. For the purposes of this document, two in particular require definition:

1. Geographic: Almost any subject or discourse involving earthly phenomena, studied from a spatial perspective at a medium scale (sub-astronomical and super-architectural).

2. Phenomenon: Any subject of geographic discourse that is perceived to be external to the individual, including entities, events, processes, social constructs, and the like.

Unit CF1 Philosophical foundations

Many branches of philosophy are relevant to an understanding of geographic information, especially metaphysics and epistemology. Researchers and practitioners of GIS&T have followed (explicitly or unknowingly) several different philosophical approaches to understanding the nature of our work, which influences our structuring, analysis, and interpretation of geographic information. It is, therefore, crucial for professionals to understand these principles in order to bridge (rather than eliminate) the differences and work together. Philosophical perspectives on GIS practice are covered in Unit GS7 Critical GIS.

Topic CF1-1 Metaphysics and ontology

- Define common theories on what is “real,” such as realism, idealism, relativism, and experiential realism
- Evaluate the influences of particular worldviews (including one’s own) on GIS practices
- Identify the ontological assumptions underlying the work of colleagues
- Justify the metaphysical theories with which you agree
- Compare and contrast the ability of different theories to explain various situations
- Recognize the commonalities of philosophical viewpoints and appreciate differences to enable work with diverse colleagues

Topic CF1-2 Epistemology

- Define common theories on what constitutes knowledge, including positivism, reflectance-correspondence, pragmatism, social constructivism, and memetics
- Explain the notions of model and representation in science
- Recognize the influences of epistemology on GIS practices
- Justify the epistemological frameworks with which you agree
- Compare and contrast the ability of various theories to explain different situations
- Identify the epistemological assumptions underlying the work of colleagues
- Bridge the differences in epistemological viewpoints to enable work with diverse colleagues

Topic CF1-3 Philosophical perspectives

- Define common philosophical theories that have influenced geography and science, such as logical positivism, Marxism, phenomenology, feminism, and critical theory
- Defend or refute the statement, “All data are theory-laden”
- Describe a brief history of major philosophical movements relating to the nature of space, time, geographic phenomena and human interaction with it
- Compare and contrast the kinds of questions various philosophies ask, the methodologies they use, the answers they offer, and their applicability to different phenomena
- Evaluate the influences of one’s own philosophical views and assumptions on GIS&T practices
- Identify the philosophical views and assumptions underlying the work of colleagues

Unit CF2 Cognitive and social foundations

Geographic information is observed, comprehended, organized, and used in human processes, with both personal and social influences. Therefore, models of geographic information should be grounded on a sound understanding of human perception, cognition, memory, and behavior, as well as human institutions.

Topic CF2-1 Perception and cognition of geographic phenomena

- Describe the differences between real phenomena, conceptual models, and GIS data representations thereof
- Compare and contrast the symbolic and connectionist theories of human cognition and memory and their ability to model various cases
- Compare and contrast theories of spatial knowledge acquisition (e.g., Marr on vision, Piaget on childhood, Golledge on wayfinding)
- Explain the role of metaphors and image schema in our understanding of geographic phenomena and geographic tasks
- Explore the contribution of linguistics to the study of spatial cognition and the role of natural language in the conceptualization of geographic phenomena

Topic CF2-2 From concepts to data

- Define the following terms: data, information, knowledge, and wisdom
- Transform a conceptual model of information for a particular task into a data model
- Describe the limitations of various information stores for representing geographic information, including the mind, computers, graphics, and text

Topic CF2-3 Geography as a foundation for GIS

- Define the properties that make a phenomenon geographic
- Describe some insights that a spatial perspective can contribute to a given topic
- Justify or refute whether geography (as a discipline) should have a central role in GIS&T
- Explore the history of geography including (but not limited to) Greek and Roman contributions to geography (Eratosthenes, Strabo, Ptolemy), geography and cartography in the age of discovery, military geography, and geography since the Quantitative Revolution
- Justify a chosen position on which disciplines should have as important a role in GIS&T as geography
- Discuss the differing denotations and connotations of the terms spatial, geographic, and geospatial

Topic CF2-4 Place and landscape

- Explain how the concept of place encompasses more than just location
- Define the notions of cultural landscape and physical landscape
- Select a place or landscape with personal meaning and discuss its importance
- Evaluate the differences in how various parties think or feel differently about a place being modeled
- Describe the elements of a sense of place or landscape that are difficult or impossible to adequately represent in GIS

- Differentiate between space and place
- Differentiate among elements of the meaning of a place that can or cannot be easily represented using geospatial technologies

Topic CF2-5 Common-sense geographies

- Identify common-sense views of geographic phenomena that sharply contrast with established theories and technologies of geographic information
- Evaluate the impact of geospatial technologies (e.g., Google Earth) that allow non-geospatial professionals to create, distribute, and map geographic information
- Effectively communicate the design, procedures, and results of GIS projects to non-GIS audiences (clients, managers, general public)
- Collaborate with non-GIS experts who use GIS to design applications that match common-sense understanding to an appropriate degree
- Differentiate applications that can make use of common-sense principles of geography from those that should not

Topic CF2-6 Cultural influences

- Describe the ways in which the elements of culture (e.g., language, religion, education, traditions) may influence the understanding and use of geographic information
- Recognize the impact of one's social background on one's own geographic worldview and perceptions and how it influences one's use of GIS
- Collaborate effectively with colleagues of differing social backgrounds in developing balanced GIS applications

Topic CF2-7 Political influences

- Evaluate the influences of political ideologies (e.g., Marxism, Capitalism, conservative/liberal) on the understanding of geographic information
- Evaluate the influences of political actions, especially the allocation of territory, on human perceptions of space and place
- Recognize the constraints that political forces place on geospatial applications in public and private sectors

Unit CF3 Domains of geographic information (*core unit*)

Geographic phenomena, geographic information, and geographic tasks are described in terms of space, time, and properties. Different theories exist as to the nature and formal representation of these aspects, including space-like dimensions, sets, and phenomenology. Information in each of these three “aspects” is measured and reported with respect to one of several frames of reference or domains, including both absolute and relative approaches. Early frameworks such as those of Berry (1964) and Sinton (1978) were influential in setting forth the importance of space, time, and theme in GIS. This unit is closely tied to the creation of data models in Knowledge Area: Data Modeling (DM).

Topic CF3-1 Space

- Define the four basic dimensions or shapes used to describe spatial objects (i.e., points, lines, regions, volumes)
- Differentiate between absolute and relative descriptions of location
- Differentiate between common-sense, Cartesian/metric, relational, relativistic, phenomenological, social constructivist, and other theories of the nature of space
- Discuss the contributions that different perspectives on the nature of space bring to an understanding of geographic phenomenon
- Justify the discrepancies between the nature of locations in the real world and representations thereof (e.g., towns as points)
- Select appropriate spatial metaphors and models of phenomena to be represented in GIS
- Develop methods for representing non-cartesian models of space in GIS
- Discuss the advantages and disadvantages of the use of cartesian/metric space as a basis for GIS and related technologies

Topic CF3-2 Time

- Differentiate between mathematical and phenomenological theories of the nature of time
- Exemplify different temporal frames of reference: linear and cyclical, absolute and relative
- Recognize the role that time plays in “static” GISystems
- Compare and contrast models of a given spatial process using continuous and discrete perspectives of time
- Select the temporal elements of geographic phenomena that need to be represented in particular GIS applications

Topic CF3-3 Relationships between space and time

- Discuss common prepositions and adjectives (in any particular language) that signify either spatial or temporal relations but are used for both kinds, such as “after” or “longer”
- Compare and contrast the characteristics of spatial and temporal dimensions
- Identify various types of geographic interactions in space and time
- Describe different types of movement and change
- Understand the physical notions of velocity and acceleration which are fundamentally about movement across space through time

Topic CF3-4 Properties

- Define Stevens’ four levels of measurement (i.e., nominal, ordinal, interval, ratio)
- Recognize attribute domains that do not fit well into Stevens’ four levels of measurement such as cycles, indexes, and hierarchies
- Describe particular geographic phenomena in terms of attributes
- Characterize the domains of attributes in a GIS, including continuous and discrete, qualitative and quantitative, absolute and relative
- Determine the proper uses of attributes based on their domains
- Recognize situations and phenomena in the landscape which cannot be adequately represented by formal attributes, such as aesthetics
- Formalize attribute values and domains in terms of set theory
- Compare and contrast the theory that properties are fundamental (and objects are human simplifications of patterns thereof) with the theory that objects are fundamental (and properties are attributes thereof)

- Develop alternative forms of representations for situations in which attributes do not adequately capture meaning

Unit CF4 Elements of geographic information *(core unit)*

The concepts below form the basic elements of common human conceptions of geographic phenomena. Concepts from many units in this knowledge area have been synthesized to create general conceptual models of geographic information. Attempts to resolve the “object-field debate” have led to attempts to create comprehensive models that bridge these views. Consideration of this unit should also include formal models of these elements in mathematics and other fields. Knowledge Area DM: Data Modeling discusses the representation of these elements in digital models.

Topic CF4-1 Discrete entities

- Discuss the human predilection to conceptualize geographic phenomena in terms of discrete entities
- Describe particular entities in terms of space, time, and properties
- Describe the perceptual processes (e.g., edge detection) that aid cognitive objectification
- Compare and contrast differing epistemological and metaphysical viewpoints on the “reality” of geographic entities
- Identify the types of features that need to be modeled in a particular GIS application or procedure
- Identify phenomena that are difficult or impossible to conceptualize in terms of entities
- Describe the difficulties in modeling entities with ill-defined edges
- Describe the difficulties inherent in extending the “tabletop” metaphor of objects to the geographic environment
- Evaluate the effectiveness of GIS data models for representing the identity, existence, and lifespan of entities
- Justify or refute the conception of fields (e.g., temperature, density) as spatially-intensive attributes of (sometimes amorphous and anonymous) entities
- Model “gray area” phenomena, such as categorical coverages (a.k.a. discrete fields), in terms of objects
- Evaluate the influence of scale on the conceptualization of entities

Topic CF4-2 Events and processes

- Compare and contrast the concepts of continuants (entities) and occurrents (events)
- Compare and contrast the concepts of event and process
- Describe particular events or processes in terms of identity, categories, attributes, and locations
- Evaluate the assertion that “events and processes are the same thing, but viewed at different temporal scales”
- Apply or develop formal systems for describing continuous spatio-temporal processes
- Describe the “actor” role that entities and fields play in events and processes
- Discuss the difficulty of integrating process models into GIS software based on the entity and field views, and methods used to do so

Topic CF4-3 Fields in space and time

- Define a field in terms of properties, space, and time
- Identify applications and phenomena that are not adequately modeled by the field view
- Identify examples of discrete and continuous change found in spatial, temporal, and spatio-temporal fields
- Differentiate various sources of fields, such as substance properties (e.g., temperature), artificial constructs (e.g., population density), and fields of potential or influence (e.g., gravity)
- Formalize the notion of field using mathematical functions and calculus
- Relate the notion of field in GIS to the mathematical notions of scalar and vector fields
- Recognize the influences of scale on the perception and meaning of fields
- Evaluate the representation of movement as a field of location over time [e.g., $\langle x,y,z \rangle = f(t)$]
- Evaluate the field view's description of "objects" as conceptual discretizations of continuous patterns

Topic CF4-4 Integrated models

- Discuss the contributions of early attempts to integrate the concepts of space, time, and attribute in geographic information, such as Berry (1964) and Sinton (1978)
- Illustrate major integrated models of geographic information, such as Peuquet's triad, Mennis' pyramid, and Yuan's three-domain
- Determine whether phenomena or applications exist that are not adequately represented in an existing comprehensive model
- Discuss the degree to which these models can be implemented using current technologies
- Design data models for specific applications based on these comprehensive general models

Unit CF5 Relationships

Like geography, geographic information not only models phenomena but the relationships between them. This can include relationships between entities, between attributes, and between locations. In addition, one of the strengths of geography (and GIS) is its ability to use a spatial perspective to relate disparate subjects, such as climate and economy. Methods for analyzing relationships are discussed in Unit AM4 Modeling relationships and patterns.

Topic CF5-1 Categories

- Explain the human tendency to simplify the world using categories
- Identify specific examples of categories of entities (i.e., common nouns), properties (i.e., adjectives), space (i.e., regions), and time (i.e., eras)
- Explain the role of categories in common-sense conceptual models, everyday language, and analytical procedures
- Recognize and manage the potential problems associated with the use of categories (e.g., the ecological fallacy)
- Construct taxonomies and dictionaries (also known as formal ontologies) to communicate systems of categories
- Describe the contributions of category theory to understanding the internal structure of categories
- Document the personal, social, and/or institutional meaning of categories used in GIS applications

- Create or use GIS data structures to represent categories, including attribute columns, layers/themes, shapes, and legends
- Use categorical information in analysis, cartography, and other GIS processes, avoiding common interpretation mistakes
- Reconcile differing common-sense and official definitions of common geospatial categories of entities, attributes, space, and time

Topic CF5-2 Mereology: structural relationships

- Describe particular geographic phenomena in terms of their place in mereonomic hierarchies (parts and composites)
- Identify phenomena that are best understood as networks
- Explain the modeling of structural relationships in standard GIS data models, such as stored topology
- Represent structural relationships in GIS data
- Explain the effects of spatial or temporal scale on the perception of structure
- Explain the contributions of formal mathematical methods such as graph theory to the study and application of geographic structures

Topic CF5-3 Genealogical relationships: lineage, inheritance

- Describe ways in which a geographic entity can be created from one or more others
- Describe the genealogy (as identity-based change or temporal relationships) of particular geographic phenomena
- Determine whether it is important to represent the genealogy of entities for a particular application
- Discuss the effects of temporal scale on the modeling of genealogical structures

Topic CF5-4 Topological relationships

- Define various terms used to describe topological relationships, such as disjoint, overlap, within, and intersect
- Describe geographic phenomena in terms of their topological relationships in space and time to other phenomena
- List the possible topological relationships between entities in space (e.g., 9-intersection) and time
- Use methods that analyze topological relationships
- Recognize the contributions of topology (the branch of mathematics) to the study of geographic relationships

Topic CF5-5 Metrical relationships: distance and direction

- Describe geographic phenomena in terms of their distances and directions (in space and time)
- Define spatial autocorrelation in the context of geographic proximity
- Use methods that analyze metrical relationships
- Identify situations in which Tobler's first law of geography is valuable
- Identify situations in which Tobler's first law of geography does not apply
- Explain why Tobler's first law of geography is fundamental to many operations in GIS and whether it should be
- Define the principle of friction of distance and geographic models that are based on it (e.g., gravity models, spatial interaction models)

Topic CF5-6 Spatial distribution

- Find spatial patterns in the distribution of geographic phenomena using geographic visualization and other techniques
- Discuss the causal relationship between spatial processes and spatial patterns, including the possible problems in determining causality
- Hypothesize the causes of a pattern in the spatial distribution of a phenomenon
- Differentiate among distributions in space, time, and attribute
- Identify influences of scale on the appearance of distributions
- Employ techniques for visualizing, describing, and analyzing distributions in space, time, and attribute

Topic CF5-7 Region

- Delineate regions using properties, spatial relationships, and geospatial technologies
- Exemplify regions found at different scales
- Explain the relationship between regions and categories
- Differentiate among different types of regions, including functional, cultural, physical, administrative, and others
- Identify the kinds of phenomena commonly found at the boundaries of regions
- Explain why general-purpose regions rarely exist
- Compare and contrast the opportunities and pitfalls of using regions to aggregate geographic information (e.g., census data)
- Use established analysis methods that are based on the concept of region (e.g., landscape ecology)
- Explain the nature of the Modifiable Areal Unit Problem (MAUP)

Topic CF5-8 Spatial integration

- Describe the ways in which a spatial perspective enables the synthesis of different subjects (e.g., climate and economy)
- Describe the common constraints on spatial integration
- Use established analysis methods that are based on the concept of spatial integration (e.g., overlay)

Unit CF6 Imperfections in geographic information

Human models (mental, digital, visual, etc.) of the geographic environment are necessarily imperfect. While the mathematical principle of homomorphism (often operationalized as “fitness for use”) allows for imperfect data to be useful as long as they yield results adequate for the use for which they are intended, imperfections are frequently problematic. Although terminology still varies, two types of imperfection are generally accepted: vagueness (a.k.a. fuzziness, imprecision, and indeterminacy), which is generally caused by human simplification of a complex, dynamic, ambiguous, subjective world; and uncertainty (or ambiguity), generally the result of imperfect measurement processes (as discussed in Knowledge Area GD: Geospatial Data). Both of these can be manifested in all forms of geographic information, including space, time, attribute, categories, and even existence. Imperfection is also dealt with in Units GD6 Data quality (in the context of measurement), GC8 Uncertainty and GC9 Fuzzy sets (for the han-

dling and propagation of imperfections), and CV4 Graphic representation techniques (in the context of visualization).

Topic CF6-1 Vagueness

- Compare and contrast the meanings of related terms such as vague, fuzzy, imprecise, indefinite, indiscrete, unclear, and ambiguous
- Evaluate the role that system complexity, dynamic processes, and subjectivity play in the creation of vague phenomena and concepts
- Identify the hedges used in language to convey vagueness
- Describe the cognitive processes that tend to create vagueness
- Differentiate applications in which vagueness is an acceptable trait from those in which it is unacceptable
- Recognize the degree to which vagueness depends on scale
- Evaluate vagueness in the locations, time, attributes, and other aspects of geographic phenomena
- Differentiate between the following concepts: vagueness and ambiguity, well defined and poorly defined objects and fields, and discord and non-specificity

Topic CF6-2 Mathematical models of vagueness: Fuzzy sets and rough sets

- Compare and contrast the relative merits of fuzzy sets, rough sets, and other models
- Explain the problems inherent in fuzzy sets
- Create appropriate membership functions to model vague phenomena
- Differentiate between fuzzy set membership and probabilistic set membership

Topic CF6-3 Error-based uncertainty

- Define uncertainty-related terms, such as error, accuracy, uncertainty, precision, stochastic, probabilistic, deterministic, and random
- Differentiate uncertainty in geospatial situations from vagueness
- Recognize the degree to which the importance of uncertainty depends on scale and application
- Recognize expressions of uncertainty in language
- Evaluate the causes of uncertainty in geospatial data
- Describe a stochastic error model for a natural phenomenon
- Explain how the familiar concepts of geographic objects and fields affect the conceptualization of uncertainty

Topic CF6-4 Mathematical models of uncertainty: Probability and statistics

- Describe the basic principles of randomness and probability
- Devise simple ways to represent probability information in GIS
- Recognize the assumptions underlying probability and geostatistics and the situations in which they are useful analytical tools
- Compute descriptive statistics and geostatistics of geographic data
- Interpret descriptive statistics and geostatistics of geographic data

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- Plewe, B. (2002). The nature of uncertainty in historical geographic information. *Transactions in GIS*, 6, 431-456. (Unit CF6)
- Sinton, D. (1978). The inherent structure of information as a constraint to analysis: Mapped thematic data as a case study. In Dutton, G. (Ed.), *Harvard Papers in GIS #7*. Cambridge, MA: Harvard University. (Unit CF3, CF4)
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Knowledge Area: Cartography and Visualization (CV)

Cartography and visualization primarily relate to the visual display of geographic information. This knowledge area addresses the complex issues involved in effective visual thinking and communication of geospatial data and of the results of geospatial analysis. This knowledge area reflects much of the domain of cartography and visualization, although some concepts and skills in these areas can be found in other knowledge areas. For example, the process of visualization encompasses aspects of analysis as well as cartography. Specifically, visualization is currently being reformulated as visual analytics in the context of homeland security.

Unit CV1 History and trends

The history of cartography can be described as an interplay of change in the motives for mapping, the history of exploration, printing technologies, data collection technologies, design technologies, scientific understanding of map use, visual analysis of graphic displays, application domains, and creative design innovations.

Topic CV1-1 History of cartography

- Describe how compilation, production, and distribution methods used in map-making have evolved
- Describe how symbolization methods used in map-making have evolved
- Describe the contributions by Robinson, Jenks, Raisz, and others to U.S. academic cartography
- Discuss the influence of some cartographers of the 16th and 17th centuries (Mercator, Ortelius, Jansson, Homann and others)
- Discuss the perspectives of Brian Harley and others on the political motivation for the development of certain kinds of maps
- Discuss the relationship between the history of exploration and the development of a more accurate map of the world
- Discuss the Swiss influence on map design and production, highlighting Imhof's contributions
- Outline the development of some of the major map projections (e.g., Mercator, Gnomonic, Robinson)
- Explain how Bertin has influenced trends in cartographic symbolization
- Explain how technological changes have affected cartographic design and production
- Explain the impact of advances in visualization methods on the evolution of cartography
- Compare and contrast cartographic developments in various countries and world regions such as Switzerland, France, China, the Middle East, and Greece

Topic CV1-2 Technological transformations

- Discuss the impact that mapping on the Web via applications such as Google Earth have had on the practice of cartography
- Explain how emerging technologies in related fields (e.g., the stereoplotted, aerial and satellite imagery, GPS and LiDAR, the World Wide Web, immersive and virtual environments) have advanced cartography and visualization methods

- Explain how MacEachren's Cartography-cubed (C³) concept can be used to understand the evolving role of cartography and visualization
- Explain how software innovations such as Synagraphic Mapping System (SYMAP), Surfer, and automated contouring methods have affected the design of maps
- Evaluate the advantages and limitations of various technological approaches to mapping
- Select new technologies in related fields that have the most potential for use in cartography and visualization

Unit CV2 Data considerations (*core unit*)

This unit relates to data compilation and management for cartography and visualization. Certain data manipulations can and should be made prior to symbolization and labeling, although they are not made without consideration of the symbolization and labeling that will be applied. Symbolization and labeling requirements will shape the way the data used in the displays are selected, generalized, classified, projected, and otherwise manipulated. In this unit, the considerations for data selection, subsequent abstraction for cartographic and visualization purposes, and manipulations for display are considered. Related fundamental topics such as projections and datums are introduced in Knowledge Area GD: Geospatial Data rather than here. The procedures for implementing the tasks described in this unit are primarily covered in Unit DN2 Generalization and aggregation.

Topic CV2-1 Source materials for mapping

- List the data required to compile a map that conveys a specified message
- List the data required to explore a specified problem
- Discuss the extent, classification, and currency of government data sources and their influence on mapping
- Discuss the issue of conflation of data from different sources or for different uses as it relates to mapping
- Describe a situation in which it would be acceptable to use smaller-scale data sources for compilation to compile a larger scale map
- Describe the copyright issues involved in various cartographic source materials
- Explain how data acquired from primary sources, such as satellite imagery and GPS, differ from data compiled from maps, such as DLGs
- Explain how digital data compiled from map sources influences how subsidiary maps are compiled and used
- Explain how geographic names databases (i.e., gazetteer) are used for mapping
- Explain how the inherent properties of digital data, such as Digital Elevation Models, influence how maps can be compiled from them
- Identify the types of attributes that will be required to map a particular distribution for selected geographic features
- Determine the standard scale of compilation of government data sources
- Assess the data quality of a source dataset for appropriateness for a given mapping task, including an evaluation of the data resolution, extent, currency or date of compilation, and level of generalization in the attribute classification
- Compile a map using at least three data sources

Topic CV2-2 Data abstraction: classification, selection, and generalization

- Discuss advantages and disadvantages of various data classification methods for choropleth mapping, including equal interval, quantiles, mean-standard deviation, natural breaks, and “optimal” methods
- Discuss the limitations of current technological approaches to generalization for mapping purposes
- Explain how generalization of one data theme can and must be reflected across multiple themes (e.g., if the river moves, the boundary, roads and towns also need to move)
- Explain how the decisions for selection and generalization are made with regard to symbolization in mapping
- Explain why the reduction of map scale sometimes results in the need for mapped features to be reduced in size and moved
- Identify mapping tasks that require each of the following: smoothing, aggregation, simplification, and displacement
- Illustrate specific examples of feature elimination and simplification suited to mapping at smaller scales
- Demonstrate how different classification schemes produce very different maps from a single set of interval- or ratio-level data
- Apply appropriate selection criteria to change the display of map data to a smaller scale
- Write algorithms to perform equal interval, quantiles, mean-standard deviation, natural breaks, and “optimal” classification for choropleth mapping

Topic CV2-3 Projections as a map design issue

- Identify the map projections commonly used for certain types of maps
- Identify the most salient projection property of various generic mapping goals (e.g., choropleth map, navigation chart, flow map)
- Explain why certain map projection properties have been associated with specific map types
- Select appropriate projections for world or regional scales that are suited to specific map purposes and phenomena with specific directional orientations or thematic areal aggregations
- Determine the parameters needed to optimize the pattern of scale distortion that is associated with a given map projection for a particular mapping goal and area of interest
- Diagnose an inappropriate projection choice for a given map and suggest an alternative
- Construct a map projection suited to a given purpose and geographic location

Unit CV3 Principles of map design (core unit)

This topic covers basic design principles that are used in mapping and visualization, as well as cartographic design principles specific to the display of geographic data. Both page layout design and data display are addressed.

Topic CV3-1 Map design fundamentals

- List the major factors that should be considered in preparing a map
- Describe the design needs of special purpose maps, such as subdivision plans, cadastral mapping, drainage plans, nautical charts, aeronautical charts, geological maps, military maps, wire-mesh volume maps, and 3-D plans of urban change

- Describe differences in design needed for a map that is to be viewed on the Internet versus as a 5-by 7-foot poster, including a discussion of the effect of viewing distance, lighting, and media type
- Discuss how to create an intellectual and visual hierarchy on maps
- Discuss the differences between maps that use the same data but are for different purposes and intended audiences
- Discuss Tufte's influence (or lack thereof) on cartographic design
- Critique the graphic design of several maps in terms of balance, legibility, clarity, visual contrast, figure-ground organization, and hierarchal organization
- Critique the layout of several maps, taking into account the map audience and purpose and the graphic design (visual balance, hierarchy, figure-ground), as well as the map components (north arrow, scale bar, and legend)
- Design maps that are appropriate for users with vision limitations
- Apply one or more Gestalt principles to achieve appropriate figure-ground for map elements
- Prepare different map layouts using the same map components (main map area, inset maps, titles, legends, scale bars, north arrows, grids, and graticule) to produce maps with very distinctive purposes
- Prepare different maps using the same data for different purposes and intended audiences (e.g., expert and novice hikers)

Topic CV3-2 Basic concepts of symbolization

- List the variables used in the symbolization of map data for visual, tactile, haptic, auditory, and dynamic displays
- Identify the visual variables (e.g., size, lightness, shape, hue) and graphic primitives (points, lines, areas) commonly used in maps to represent various geographic features at all attribute measurement levels (nominal, ordinal, interval, ratio)
- Illustrate how a single geographic feature can be represented by various graphic primitives (e.g., land surface as a set of elevation points, as contour lines, as hypsometric layers or tints, and as a hillshaded surface)
- Select effective symbols for map features based on the dimensionality and attributes of the geographic phenomena being mapped
- Design map symbols with sufficient contrast to be distinguishable by typical users

Topic CV3-3 Color for cartography and visualization

- List the range of factors that should be considered in selecting colors
- Describe color decisions made for various production workflows
- Describe how cultural differences with respect to color associations impact map design
- Describe the common color models used in mapping
- Determine the CMYK (cyan, magenta, yellow, and black) primary amounts in a selection of colors
- Discuss the role of "gamut" in choosing colors that can be reproduced on various devices and media
- Explain how real-world connotations (e.g., blue=water, white=snow) can be used to determine color selections on maps
- Exemplify colors for different forms of harmony, concordance, and balance
- Estimate RGB (red, green, blue) primary amounts in a selection of colors
- Plan color proofing suited for checking a map publication job
- Select a color scheme (e.g., qualitative, sequential, diverging, spectral) that is appropriate for a given map purpose and variable

- Select colors appropriate for map readers with color limitations
- Specify a set of colors in device-independent Commission Internationale de L'Eclairage (CIE) specifications

Topic CV3-4 Typography for cartography and visualization

- Name the authorities used to confirm the spelling of geographic names for a specific mapping project
- Describe the role of labels in assisting readers in understanding feature locations (e.g., label to the right of point, label follows line indicating its position, area label assists understanding extent of feature and feature type)
- Compare and contrast the strengths and limitations of methods for automatic label placement
- Compare and contrast the relative merits of having map labels placed dynamically versus having them saved as annotation data
- Explain how text properties can be used as visual variables to graphically represent the type and attributes of geographic features
- Explain how to label features having indeterminate boundaries (e.g., canyons, oceans)
- Position labels on a map to name point, line, and area features
- Apply the appropriate technology to place name labels on a map using a geographic names database
- Set type font, size, style, and color for labels on a map by applying basic typography design principles
- Create a set of mapping problems that can be used to illustrate point, line, and area label conventions for placing text on maps
- Solve a labeling problem for a dense collection of features on a map using minimal leader lines

Unit CV4 Graphic representation techniques

This unit addresses mapping methods and the variations of those methods for specialized mapping and visualization instances, such as thematic mapping, dynamic and interactive mapping, Web mapping, mapping and visualization in virtual and immersive environments, using the map metaphor to display other forms of data (spatialization), and visualizing uncertainty. Analytical techniques used to derive the data employed in these graphic representations are discussed in Knowledge Area: Analytical Methods (AM) and Unit DN2 Generalization and aggregation.

Topic CV4-1 Basic thematic mapping methods

- Describe the design considerations for each of the following methods: choropleth, dasymetric, proportioned symbol, graduated symbol, isoline, dot, cartogram, and flow map
- Evaluate the strengths and limitations of each of the following methods: choropleth, dasymetric, proportioned symbol, graduated symbol, isoline, dot, cartogram, and flow map
- Explain why choropleth maps should (almost) never be used for mapping count data and suggest alternative methods for mapping count data
- Choose suitable mapping methods for each attribute of a given type of feature in a GIS (e.g., roads with various attributes such as surface type, traffic flow, number of lanes, direction such as one-way)
- Select base information suited to providing a frame of reference for thematic map symbols (e.g., network of major roads and state boundaries underlying national population map)

- Create maps using each of the following methods: choropleth, dasymetric, proportioned symbol, graduated symbol, isoline, dot, cartogram, and flow
- Create well-designed legends using the appropriate conventions for the following methods: choropleth, dasymetric, proportioned symbol, graduated symbol, isoline, dot, cartogram, and flow

Topic CV4-2 Multivariate displays

- Differentiate the interpretation of a series of three maps and a single multivariate map, each representing the same three related variables
- Explain the relationship among several variables in a parallel coordinate plot
- Detect a multivariate outlier using a combination of maps and graphs
- Design a map series to show the change in a geographic pattern over time
- Design a single map symbol that can be used to symbolize a set of related variables
- Create a map that displays related variables using different mapping methods (e.g., choropleth and proportional symbol, choropleth and cartogram)
- Create a map that displays related variables using the same mapping method (e.g., bivariate choropleth map, bivariate dot map)

Topic CV4-3 Dynamic and interactive displays

- Explain how interactivity influences map use in animated displays
- Describe a mapping goal in which the use of each of the following would be appropriate: brushing, linking, multiple displays
- Describe the uses of the map as a user interface element in interactive presentations of geographic information
- Critique the interactive elements of an online map
- Develop a useful interactive interface and legend for an animated map
- Create an animated map for a specified purpose
- Create an interactive map suitable for a given audience

Topic CV4-4 Representing terrain

- Describe situations in which methods of terrain representation (e.g., shaded relief, contours, hypsometric tints, block diagrams, profiles) are well suited
- Describe situations in which methods of terrain representation are poorly suited
- Differentiate 3-D representations from 2^{1/2}-D representations
- Explain how maps that show the landscape in profile can be used to represent terrain
- Create a map that represents both slope and aspect on the same map using the Moellering-Kimerling coloring method

Topic CV4-5 Web mapping and visualizations

- Describe considerations for using maps on the Web as a method for downloading data
- Discuss the influence of the user interface on maps and visualizations on the Web
- Critique the user interface for existing Internet mapping services
- Construct a Web page that includes an interactive map
- Edit the symbology, labeling, and page layout for a map originally designed for hard copy printing so that it can be seen and used on the Web

Topic CV4-6 Virtual and immersive environments

- Discuss the nature and use of virtual environments, such as Google Earth
- Explain how the virtual and immersive environments become increasingly more complex as we move from the relatively non-immersive VRML desktop environment to a stereoscopic display (e.g., a GeoWall) to a more fully immersive CAVE
- Explain how various data formats and software and hardware environments support immersive visualization
- Compare and contrast the relative advantages of different immersive display systems used for cartographic visualization (e.g., CAVEs, GeoWalls)
- Evaluate the extent to which a GeoWall or CAVE does or does not enhance understanding of spatial data

Topic CV4-7 Spatialization

- Explain how spatial metaphors can be used to illustrate the relationship among ideas
- Explain how spatialization is a core component of visual analytics
- Evaluate graphic techniques used to portray spatializations
- Create a pseudo-topographic surface to portray the relationships in a collection of documents
- Create a concept map that represents the contents and topology of a physical or social process

Topic CV4-8 Visualization of temporal geographic data

- Describe how the adding time-series data reveals or does not reveal patterns not evident in a cross-sectional data
- Describe how an animated map reveals patterns not evident without animation
- Demonstrate how Bertin's "graphic variables" can be extended to include animation effects
- Create a temporal sequence representing a dynamic geospatial process

Topic CV4-9 Visualization of uncertainty

- Describe a technique that can be used to represent the value of each of the components of data quality (positional and attribute accuracy, logical consistency, and completeness)
- Apply multivariate and dynamic visualization methods to display uncertainty in data
- Sketch a map with a reliability overlay using symbols suited to reliability representations
- Develop graphic techniques that clearly show different forms of inexactness (e.g., existence uncertainty, boundary location uncertainty, attribute ambiguity, transitional boundary) of a given feature (e.g., a culture region)

Unit CV5 Map production

This unit addresses map production and reproduction, as well as computation issues that relate to those workflows.

Topic CV5-1 Computational issues in cartography and visualization

- Identify areas in cartography and visualization that have, and those that have not, advanced because of computational approaches
- Describe the structure and function of geographic names databases (i.e., gazetteer) for use in mapping

- Differentiate between GIS and graphics software tools for mapping and those for visualization purposes
- Explain how optimization techniques are improving the automated design of maps
- Explain how the concept “digital cartographic models” unifies a number of principles for computer cartography
- Explain how the rise of interoperability and open standards has affected the production of cartographic representations and visualizations

Topic CV5-2 Map production

- Differentiate among the various raster map outputs (JPEG, GIF, TIFF) and various vector formats (PDF, Adobe Illustrator Postscript)
- Discuss the purpose of advanced production methods (e.g., stochastic screening, hexachrome color, color management and device profiles, trapping, overprinting)
- Explain how color fastness and color consistency are ensured in map production
- Compare and contrast the file formats suited to presentation of maps on the Web to those suited to publication in high resolution contexts
- Compare and contrast the issues that arise for map production using black-and-white and four-color process specifications
- Outline the process for the digital production of offset press printed maps, including reference to feature and color separates, feature and map composites, and resolution
- Compare outputs of the same map at various low and high resolutions
- Critique typographic integrity in export formats (e.g., some file export processes break type into letters degrading searchability, font processing, and reliability of Raster Image Processing)
- Prepare a map file for CMYK publication in a book
- Prepare a map file for RGB presentation on a Web site

Topic CV5-3 Map reproduction

- Describe print quality characteristics and price differences for limited-run color map distribution
- Describe production concerns that might be discussed with a publisher who will print a map product
- Compare and contrast the quality of product evaluation that can be made from process proofs and color laser prints
- Outline the stages in lithographic offset printing
- Prepare a color map for black-and-white photocopy distribution
- Specify a print job for publication, including paper, ink, lpi, proof needs, press check, and other contract decisions

Unit CV6 Map use and evaluation (*core unit*)

This unit addresses how people use maps or visualizations for map reading, analysis, discovery, and interpretation. Map reading is the translation of the graphic or other representation of features into a mental image of the environment. It involves the identification of map symbols and the interpretation of the symbology to understand the geographic phenomena. Map analysis allows the reader to analyze and understand the spatial structure of and relationships among features on a map. Visualizations often allow discovery of unexpected patterns and associations in data sets. Interpretation allows the reader to seek explanations for unusual or interesting patterns on maps. The reader can either look at one map and

seek explanations for the patterns observed or look at several maps and seek understanding of the variations (perhaps through time) between the maps. Evaluation leads to better understanding of the user experience with the map or visualization. This unit also examines the impact of uncertainty in the data on the map use and evaluation of the use of the displayed data by the map reader. Technical aspects of uncertainty are covered in more depth in Unit GC8 Uncertainty and Unit GD6 Data quality. Issues of maps and power are also considered in Knowledge Area GS: GIS&T and Society.

Topic CV6-1 The power of maps

- Describe how maps such as topographic maps are produced within certain relations of power and knowledge
- Discuss how the choices used in the design of a road map will influence the experience visitors may have of the area
- Explain how legal issues impact the design and content of such special purpose maps as subdivision plans, nautical charts, and cadastral maps
- Exemplify maps that illustrate the provocative, propagandistic, political, and persuasive nature of maps and geospatial data
- Demonstrate how different methods of data classification for a single dataset can produce maps that will be interpreted very differently by the user
- Deconstruct the silences (feature omissions) on a map of a personally well known area
- Construct two maps about a conflict or war producing one supportive of each side's viewpoint

Topic CV6-2 Map reading

- Discuss the advantages and disadvantages of using conventional symbols (e.g., blue=water, green=vegetation, Swiss cross=a hospital) on a map
- Explain how the anatomy of the eye and its visual sensor cells affect how one sees maps in terms of attention, acuity, focus, and color
- Explain how memory limitations effect map reading tasks
- Find specified features on a topographic map (e.g., gravel pit, mine entrance, well, land grant)
- Match map labels to the corresponding features
- Match the symbols on a map to the corresponding explanations in the legend
- Execute a well designed legend that facilitates map reading

Topic CV6-3 Map interpretation

- Compare and contrast the interpretation of landscape, geomorphic features, and human settlement types shown on a series of topographic maps from several different countries
- Match features on a map to corresponding features in the world
- Identify the landforms represented by specific patterns in contours on a topographic map
- Hypothesize about geographic processes by synthesizing the patterns found on one or more thematic maps or data visualizations

Topic CV6-4 Map analysis

- Describe maps that can be used to find direction, distance, or position, plan routes, calculate area or volume, or describe shape
- Describe the differences between azimuths, bearings, and other systems for indicating directions

- Explain how maps can be used in determining an optimal route or facility selection
- Explain how maps can be used in terrain analysis (e.g., elevation determination, surface profiles, slope, viewsheds, and gradient)
- Explain how the types of distortion indicated by projection metadata on a map will affect map measurements
- Explain the differences between true north, magnetic north, and grid north directional references
- Compare and contrast the manual measurement of the areas of polygons on a map printed from a GIS with those calculated by the computer and discuss the implications these variations in measurement might have on map use
- Determine feature counts of point, line, and area features on maps
- Analyze spatial patterns of selected point, line, and area feature arrangements on maps
- Calculate slope using a topographic map and a DEM
- Calculate the planimetric and actual road distances between two locations on a topographic map
- Create a profile of a cross section through a terrain using a topographic map and a digital elevation model (DEM)
- Measure point-feature movement and point-feature diffusion on maps
- Plan an orienteering tour of a specific length that traverses slopes of an appropriate steepness and crosses streams in places that can be forded based on a topographic map

Topic CV6-5 Evaluation and testing

- Describe the baseline expectations that a particular map makes of its audience
- Discuss the use limitations of the USGS map accuracy standards for a range of projects demanding different levels of precision (e.g., driving directions vs. excavation planning)
- Compare and contrast the interpretive dangers (e.g., ecological fallacy, Modifiable Areal Unit Problem) that are inherent to different types of maps or visualizations and their underlying geographic data
- Identify several uses for which a particular map is or is not effective
- Identify the particular design choices that make a map more or less effective
- Evaluate the effectiveness of a map for its audience and purpose
- Design a testing protocol to evaluate the usability of a simple graphical user interface
- Perform a rigorous sampled field check of the accuracy of a map

Topic CV6-6 Impact of uncertainty

- Describe a scenario in which possible errors in a map may impact subsequent decision making, such as a land use decision based on a soils map
- Compare the decisions made using a map with a reliability overlay from those made using a map pair separating data and reliability, both drawn from the same dataset
- Critique the assumption that maps can or should be “accurate”
- Evaluate the uncertainty inherent in a map

Key readings in Cartography and Visualization

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Knowledge Area: Design Aspects (DA)

Proper design of geospatial applications, models, and databases and the validation and verification of design activities are critical components of work in all areas related to GIS&T. Design failures can negate well-intentioned efforts to apply concepts and technology to solve real-world problems. While sharing a number of concerns with general systems analysis, the unique and complex spatial elements of geospatial information provide significant additional challenges. The focus of this knowledge area is on the design of applications and databases for a particular need. The design of general-purpose models and tools (e.g., raster and vector) is covered in Knowledge Area: Data Modeling (DM). In the context of specific implementations, design activities fall into three general classes:

1. Application Design addresses the development of workflows, procedures, and customized software tools for using geospatial technologies and methods to accomplish both routine and unique tasks that are inherently geographic.
2. Analytic Model Design incorporates methods for developing effective mathematical and other models of spatial situations and processes. The design of the analytic model is often influenced by decisions that are made about data models and structures.
3. Database Design concerns the optimal organization of the necessary spatial data in a computer environment in order to efficiently sustain a particular application or enterprise.

Several units in Knowledge Area GD: Geospatial Data follow from Knowledge Area DA: Design Aspects, especially those that discuss the collection of data in conformance with the designs discussed herein. This knowledge area is also closely related to Knowledge Area OI: Organizational and Institutional Aspects, which discusses several issues relating to the management of systems in organizations after they are designed and implemented. Beyond GIS&T, this knowledge area has strong ties to information science and technology (e.g., Gorgone, G. B. & Gray, P., 2000, and Gorgone, G. B. & others, 2002), and to business management in the area of resource planning. Some of the methods of geospatial system design are identical to established methods in information system design, while others are unique.

Unit DA1 The scope of GIS&T system design

Geospatial applications, such as GIS, consist of data and procedures (automated or manual) that attempt to represent real world phenomena and processes. While necessarily imperfect, these applications should be homomorphic (in a mathematical sense) to the world, meaning that they are close enough to achieve acceptable results. These applications are built in different situations, ranging from systems put together to solve a single problem to permanent enterprise databases.

Topic DA1-1 Using models to represent information and processes

- Define a homomorphism as a mathematical property

- Describe the ways in which an existing model faithfully represents reality and the ways in which it does not
- Evaluate existing systems to determine whether they are adequate representations
- Assess the data quality needed for a new application to be successful
- Recognize the advantages and disadvantages of using models to study and manage the world as opposed to experimenting in the world directly

Topic DA1-2 Components of models: data, structures, procedures

- Differentiate the three major parts of a model
- Identify the composition of existing models
- Explain the importance of context in effectively using models
- Describe the mapping from components of the world (and conceptualizations of them) to the components of a model

Topic DA1-3 The scope of GIS&T applications

- Differentiate between project-specific applications and enterprise systems
- Identify tasks that are structured, semi-structured, and unstructured
- Differentiate between applications for scientific research and resource management decision support

Topic DA1-4 The scope of GIS&T design

- Differentiate between general data models and application-specific data models
- Differentiate among application design, database design, and analytic model design

Topic DA1-5 The process of GIS&T design

- Describe the major approaches to the design of geospatial systems
- Compare and contrast the relative merits of the use-case driven and architecture-centric design processes
- Analyze past cases to identify best practices of design and implementation

Unit DA2 Project definition

The first part of the process of designing geospatial systems is recognizing and verifying the need for geospatial technology in carrying out geographic tasks. Adequate planning requires the support and involvement of potential users and decision makers. A thoughtful analysis of users, their tasks, and their needs will yield a plan that is easier to implement with better results. A more thorough treatment of related social and institutional issues is found in Knowledge Area GS: GIS&T and Society and Knowledge Area OI: Organizational and Institutional Aspects.

Topic DA2-1 Problem definition

- Create a charter or hypothesis that defines and justifies the mission of a GIS to solve existing problems

- Identify geographic tasks for which particular geospatial technologies are not adequate or sufficient
- Identify what is typically needed to garner support among managers for designing and/or creating a GIS
- Define an enterprise GIS in terms of institutional missions and goals
- Recognize the challenges of implementing and using geospatial technologies

Topic DA2-2 Planning for design

- Define Gantt and PERT charts
- Identify the people necessary to effectively design a GIS
- Collaborate effectively with a variety of people in a design team
- Create a schedule for the design and implementation of a GIS
- Justify the funding necessary for the design process of a GIS
- Use project management tools and techniques to manage the design process

Topic DA2-3 Application/user assessment

- Identify current and potential users of geospatial technology in an enterprise
- Differentiate the concepts of efficiency and effectiveness in application requirements
- Recognize geographic tasks and geographic information that already exist in an enterprise
- Classify potential users as casual or professional, early adopters or reluctant users
- Educate potential users on the value of geospatial technology
- Evaluate the potential for using geospatial technology to improve the efficiency and/or effectiveness of existing activities
- Identify new geographic tasks or information that align with institutional missions and goals

Topic DA2-4 Requirements analysis

- Describe the need for user-centered requirements analysis
- Develop use cases for potential applications using established techniques with potential users, such as questionnaires, interviews, focus groups, the Delphi method, and/or joint application development (JAD)
- Document existing and potential tasks in terms of workflow and information flow
- Create requirements reports for individual potential applications in terms of the data, procedures, and output needed
- Assess the relative importance and immediacy of potential applications
- Synthesize the needs of individual users and tasks into enterprise-wide needs
- Differentiate between the responsibilities of the proposed system and those that remain with the user
- Illustrate how a business process analysis can be used to identify requirements during a GIS implementation
- Describe how spatial data and GIS&T can be integrated into a workflow process
- Evaluate how external spatial data sources can be incorporated into the business process

Topic DA2-5 Social, political, and cultural issues

- Recognize the unique constraints or opportunities of the social or cultural context of a potential application
- Compare and contrast the needs, constraints, and opportunities of different types of institutions, such as corporations, non-profit organizations, government agencies, and educational institutions

Unit DA3 Resource planning

In order to design, build, and maintain a GIS, sufficient resources (e.g., labor, capital, and time) must be secured. These resources are needed for a variety of elements of the system, including design, software purchase, labor, hardware, and facilities. The most crucial task is to determine whether the project is worthy of the required resources. The focus here is on the initial startup costs: budgeting for ongoing management and the design of management infrastructure is discussed in Unit OI2 Managing the GIS, which should also be mastered to complete this process successfully. Further consideration of economic issues is found in Knowledge Area GS: GIS&T and Society, Unit GS2 Economic aspects. Data sources and characteristics are covered in Knowledge Area GD: Geospatial Data.

Topic DA3-1 Feasibility analysis

- List the costs and benefits (financial and intangible) of implementing geospatial technology for a particular application or an entire institution
- Compare and contrast the relative merits of outsourcing the feasibility analysis and system design processes or doing them in-house
- Identify major obstacles to the success of a GIS proposal
- Evaluate possible solutions to the major obstacles that stand in the way of a successful GIS proposal
- List some of the topics that should be addressed in such a justification of geospatial technology (e.g., ROI, workflow, knowledge sharing)
- Decide whether geospatial technology should be used for a particular task
- Perform a pilot study to evaluate the feasibility of an application
- Justify feasibility recommendations to decision makers

Topic DA3-2 Software systems

- Describe the major geospatial software architectures available currently, including desktop GIS, server-based, Internet, and component-based custom applications
- Describe non-spatial software that can be used in geospatial applications, such as databases, Web services, and programming environments
- Compare and contrast the primary sources of geospatial software, including major and minor commercial vendors and open-source options
- List the major functionality needed from off-the-shelf software based on a requirements report
- Identify software options that meet functionality needs for a given task or enterprise
- Evaluate software options that meet functionality needs for a given task or enterprise

Topic DA3-3 Data costs

- Identify potential sources of data (free or commercial) needed for a particular application or enterprise
- Estimate the cost to collect needed data from primary sources (e.g., remote sensing, GPS)
- Judge the relative merits of obtaining free data, purchasing data, outsourcing data creation, or producing and managing data in-house for a particular application or enterprise

Topic DA3-4 Labor and management

- Identify the positions necessary to design and implement a GIS
- Discuss the advantages and disadvantages of outsourcing elements of the implementation of a geospatial system, such as data entry
- Evaluate the labor needed in past cases to build a new geospatial enterprise
- Create a budget of expected labor costs, including salaries, benefits, training, and other expenses

Topic DA3-5 Capital: facilities and equipment

- Identify the hardware and space that will be needed for a GIS implementation
- Hypothesize the ways in which capital needs for GIS may change in the future
- Compare and contrast the relative merits of housing GISs within IT (information technology) and MIS (management information system) facilities versus keeping them separate
- Collaborate effectively with various units in an institution to develop efficient hardware and space solutions

Topic DA3-6 Funding

- Identify potential sources of funding (internal and external) for a project or enterprise GIS
- Analyze previous attempts at funding to identify successful and unsuccessful techniques
- Create proposals and presentations to secure funding

Unit DA4 Database design (*core unit*)

The effective design of geospatial databases should follow the established methods and principles of database modeling and design developed in computer science. The basic method is a three-step process—generally called the conceptual, logical, and physical models—transforming the application from very human-oriented to machine-oriented. Several standards and software tools exist to aid the process of database design. This unit relies heavily on the concepts developed in Knowledge Area CF: Conceptual Foundations and the general-purpose data models developed in Knowledge Area DM: Data Modeling.

Topic DA4-1 Modeling tools

- Compare and contrast the relative merits of various textual and graphical tools for data modeling, including E-R diagrams, UML, and XML
- Create conceptual, logical, and physical data models using automated software tools
- Create E-R and UML diagrams of database designs

Topic DA4-2 Conceptual model

- Define entities and relationships as used in conceptual data models
- Describe the degree to which attributes need to be modeled in the conceptual modeling phase
- Explain the objectives of the conceptual modeling phase of design
- Deconstruct an application use case into conceptual components

- Create a conceptual model diagram of data needed in a geospatial application or enterprise database
- Design application-specific conceptual models

Topic DA4-3 Logical models

- Differentiate between conceptual and logical models, in terms of the level of detail, constraints, and range of information included
- Define the cardinality of relationships
- Explain the various types of cardinality found in databases
- Distinguish between the incidental and structural relationships found in a conceptual model
- Determine which relationships need to be stored explicitly in the database
- Evaluate the various general data models common in GIS&T for a given project, and select the most appropriate solutions
- Create logical models based on conceptual models and general data models using UML or other tools

Topic DA4-4 Physical models

- Differentiate between logical and physical models, in terms of the level of detail, constraints, and range of information included
- Recognize the constraints and opportunities of a particular choice of software for implementing a logical model
- Create physical model diagrams, using UML or other tools, based on logical model diagrams and software requirements
- Create a complete design document ready for implementation

Unit DA5 Analysis design

This unit addresses the design of GIS procedures and data to implement mathematical, geographical, statistical, and other analytical models. This process requires critical thinking and problem-solving skills for resolving unstructured tasks into analysis procedures. Successful analysis design also requires a working knowledge of many of the tools and techniques in Knowledge Area AM: Analytical Methods and Knowledge Area GC: Geocomputation.

Topic DA5-1 Recognizing analytical components

- Identify components in the conceptual model of a particular application that will require analytical modeling rather than data modeling
- Identify relationships (e.g., topology) within a conceptual model that can be derived by analysis rather than being stored explicitly
- Discuss the relevance of the scientific method to a particular system design problem
- Deconstruct a scientific hypothesis to identify possible strategies for testing

Topic DA5-2 Identifying and designing analytical procedures

- Identify the sequence of operations and statistical/mathematical methods (a procedure) appropriate for a particular application (e.g., multi-criteria evaluation for site suitability)

- Critique the necessity of the operations used in a pre-defined procedure for a particular application (e.g., suitability analysis)
- Develop a planned analytical procedure to solve a new unstructured problem (e.g., long-term business strategy)
- Implement a pre-defined procedure for a sample dataset

Topic DA5-3 Coupling scientific models with GIS

- Discuss the current state-of-the-art of the coupling of scientific models and simulations with GIS
- Design a modeling procedure to integrate a spatial arrangement constraint for a mathematical optimization model

Topic DA5-4 Formalizing a procedure design

- Compare and contrast the relative merits of various tools and methods for procedure design, including flowcharting and pseudocode
- Compare and contrast the relative merits of object-oriented and procedural designs for modeling tasks
- Select the appropriate environment (e.g., GIS software, software development environment) for implementing an analytical procedure

Unit DA6 Application design

This unit addresses the development of customized software for using geospatial technologies in geographic tasks. It also considers types of procedures: structured vs. unstructured, routine vs. unique; various approaches to implementing applications, including standard workflows and customized software; and making the design appropriate to the expected user. It includes procedural and object-oriented approaches to software development, as well. Successful mastery of this unit will require mastery of core portions of the computer science Body of Knowledge (ACM/IEEE-CS Joint Task Force, 2001) especially high-level programming.

Topic DA6-1 Workflow analysis and design

- Compare and contrast various methods for modeling workflows, including narratives, flowcharts, and UML
- Differentiate between structured and unstructured tasks
- Discuss the degree to which structured and unstructured tasks can be automated
- Compare and contrast the relative merits of various software design methods, including traditional procedural designs, object-oriented design, the Rational Unified Process, Extreme Programming, and the Unified Software Development Process
- Transform traditional workflows into computer-assisted workflows leveraging geospatial technologies to an appropriate degree

Topic DA6-2 User interfaces

- Design an application-level software/user interface based on user requirements
- Create user interface components in available development environments

Topic DA6-3 Development environments for geospatial applications

- Compare and contrast the relative merits of available environments for geospatial applications, including desktop software scripting (e.g., VBA), graphical modeling tools, geospatial components in standard environments, and “from-scratch” development in standard environments
- Develop a geospatial application using the most appropriate environment

Topic DA6-4 Computer-Aided Software Engineering (CASE) tools

- Use CASE tools to design geospatial software
- Evaluate available CASE tools for their appropriateness for a given development task

Unit DA7 System implementation

Once a design is created, it is time to actually create the system. This phase generally requires the majority of the resources of the entire project, so it is crucial that it be done well. This unit leads directly into Unit OI2 Managing GIS operations and infrastructure, which covers the permanent maintenance of a system. Workforce development is also an important part of system implementation, but is discussed in Unit OI4 GIS&T workforce themes.

Topic DA7-1 Implementation planning

- Discuss the importance of planning for implementation as opposed to “winging it”
- Create a schedule for the implementation of a geospatial system based on a complete design
- Create a budget for the resources needed to implement the system
- Discuss pros and cons of different implementation strategies (e.g., spiral development versus waterfall development) given the needs of a particular system

Topic DA7-2 Implementation tasks

- Explain the rationale for piloting and prototyping new systems
- Plan a formal quality assurance procedure
- Construct an effective database structure in a selected GIS or database software based on the physical model
- Acquire data from primary and secondary sources
- Transfer data from primary and secondary sources into the database
- Create customized programs and scripts based on an application design

Topic DA7-3 System testing

- Describe the goals of alpha and beta testing
- Implement established testing procedures on prototype systems
- Use testing results to prepare a system for deployment
- Conduct a quality assurance review

Topic DA7-4 System deployment

- Develop a phasing schedule for deployment of an enterprise-wide system
- Integrate geospatial applications with other enterprise information systems

Key readings in Design Aspects

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Knowledge Area: Data Modeling (DM)

This knowledge area deals with representation of formalized spatial and spatio-temporal reality through data models and the translation of these data models into data structures that are capable of being implemented within a computational environment (i.e., within a GIS). Data models provide the means for formalizing the spatio-temporal conceptualizations that will be translated into computational data structures. Examples of spatial data model types are discrete (object-based), continuous (location-based), dynamic, and probabilistic. Database management systems and their application to geospatial data are included within this knowledge area. Data structures represent the operational implementation of data models within a computational environment. Mastery of the objectives presented in this knowledge area require knowledge and skills presented in the bodies of knowledge of allied fields, including computer science (ACM/IEEE-CS Joint Task Force, 2001) and information systems (Gorgone & Gray, 2000; Gorgone & others, 2002). The topics presented here are based on concepts covered in Knowledge Area CF: Conceptual Foundations.

Unit DM1 Basic storage and retrieval structures

This unit deals with mechanisms built into data structures to facilitate search and retrieval of geospatial data. These are generic principles and would often be a review, in a spatial context, of material learned in a basic computer science course.

Topic DM1-1 Basic data structures

- Define basic data structure terminology (e.g., records, field, parent/child, nodes, pointers)
- Differentiate among data models, data structures, and file structures
- Discuss the advantages and disadvantages of different data structures (e.g., arrays, linked lists, binary trees) for storing geospatial data
- Analyze the relative storage efficiency of each of the basic data structures
- Implement algorithms that store geospatial data to a range of data structures

Topic DM1-2 Data retrieval strategies

- Compare and contrast direct and indirect access search and retrieval methods
- Discuss the advantages and disadvantages of different data structures (e.g., arrays, linked lists, binary trees, hash tables, indexes) for retrieving geospatial data
- Analyze the relative performance of data retrieval strategies
- Implement algorithms that retrieve geospatial data from a range of data structures
- Describe the particular advantages of Morton addressing relative to geographic data representation

Unit DM2 Database management systems (*core unit*)

This unit considers the use of database management systems (DBMS) in geographic contexts and the evolution of modern database design technologies to better handle geographic data in its various forms.

The form of structured query language (SQL) and its use in querying databases is covered in Unit AM2 Query operations and query languages. The design of databases specific to a particular application is discussed in Unit DA4 Database design. These concepts are also considered in the Body of Knowledge of the allied field of Computer Science (ACM/IEEE 2001).

Topic DM2-1 Coevolution of DBMS and GIS

- Demonstrate how DBMS are currently used in conjunction with GIS
- Explain why some of the older DBMS are now of limited use within GIS
- Diagram hierarchical DBMS architecture
- Diagram network DBMS architecture
- Differentiate among network, hierarchical and relational database structures, and their uses and limitations for geographic data storage and processing
- Describe the geo-relational model (or dual architecture) approach to GIS DBMS

Topic DM2-2 Relational DBMS

- Explain the advantage of the relational model over earlier database structures including spreadsheets
- Demonstrate how search and relational join operations provide results for a typical GIS query and other simple operations using the relational DBMS within a GIS software application
- Define the basic terms used in relational database management systems (e.g., tuple, relation, foreign key, SQL, relational join)
- Discuss the efficiency and costs of normalization
- Describe the entity-relationship diagram approach to data modeling
- Explain how entity-relationship diagrams are translated into relational tables
- Describe the problems associated with failure to follow the first and second normal forms (including data confusion, redundancy, and retrieval difficulties)
- Create an SQL query that extracts data from related tables

Topic DM2-3 Object-oriented DBMS

- Describe the basic elements of the object-oriented paradigm, such as inheritance, encapsulation, methods, and composition
- Differentiate between object-oriented programming and object-oriented databases
- Evaluate the degree to which the object-oriented paradigm does or does not approximate cognitive structures
- Explain how the principle of inheritance can be implemented using an object-oriented programming approach
- Defend or refute the notion that the Extensible Markup Language (XML) is a form of object-oriented database
- Explain how the properties of object orientation allows for combining and generalizing objects
- Evaluate the advantages and disadvantages of object-oriented databases compared to relational databases, focusing on representational power, data entry, storage efficiency, and query performance
- Implement a GIS database design in an off-the-shelf, object-oriented database

Topic DM2-4 Extensions of the relational model

- Explain why early attempts to store geographic data in standard relational tables failed
- Describe extensions of the relational model designed to represent geospatial and other semi-structured data, such as stored procedures, Binary Large Objects (BLOBs), nested tables, abstract data types, and spatial data types
- Describe standards efforts relating to relational extensions, such as SQL:1999 and SQL-MM
- Evaluate the degree to which an available object-relational database management system approximates a true object-oriented paradigm
- Evaluate the adequacy of contemporary proprietary database schemes to manage geospatial data

Unit DM3 Tessellation data models (*core unit*)

“Tessellation” partitions a continuous surface into a set of non-overlapping polygons that cover the surface without gaps. Tessellation data models represent continuous surfaces with sets of data values that correspond to partitions. The theoretical foundations for a field-centered view of geographic information are covered in Knowledge Area CF: Conceptual Foundations. Tessellated georeferencing systems are considered in Knowledge Area GD: Geospatial Data, Unit GD3. Analytical methods for surfaces and other tessellations are considered in Knowledge Area AM: Analytical Methods.

Topic DM3-1 Grid representations

- Explain how grid representations embody the field-based view
- Differentiate among a lattice, a tessellation, and a grid
- Explain how terrain elevation can be represented by a regular tessellation and by an irregular tessellation
- Identify the national framework datasets based on a grid model

Topic DM3-2 The raster model

- Define basic terms used in the raster data model (e.g., cell, row, column, value)
- Explain how the raster data model instantiates a grid representation
- Interpret the header of a standard raster data file
- Compare and contrast the raster with other types of regular tessellations for geographic data storage
- Compare and contrast the raster with other types of regular tessellations for geographic data analysis
- Write a program to read and write a raster data file

Topic DM3-3 Grid compression methods

- Illustrate the existing methods for compressing gridded data (e.g., run length encoding, Lempel-Ziv, wavelets)
- Differentiate between lossy and lossless compression methods
- Evaluate the relative merits of grid compression methods for storage
- Explain the advantage of wavelet compression

Topic DM3-4 The hexagonal model

- Illustrate the hexagonal model
- Exemplify the uses (past and potential) of the hexagonal model
- Explain the limitations of the grid model compared to the hexagonal model

Topic DM3-5 The Triangulated Irregular Network (TIN) model

- Describe the architecture of the TIN model
- Demonstrate the use of the TIN model for different statistical surfaces (e.g., terrain elevation, population density, disease incidence) in a GIS software application
- Describe how to generate a unique TIN solution using Delaunay triangulation
- Construct a TIN manually from a set of spot elevations
- Delineate a set of break lines that improve the accuracy of a TIN
- Describe the conditions under which a TIN might be more practical than GRID

Topic DM3-6 Resolution

- Relate the concept of grid cell resolution to the more general concept of “support” and granularity
- Illustrate the impact of grid cell resolution on the information that can be portrayed
- Evaluate the implications of changing grid cell resolution on the results of analytical applications by using GIS software
- Evaluate the ease of measuring resolution in different types of tessellations

Topic DM3-7 Hierarchical data models

- Illustrate the quadtree model
- Describe the advantages and disadvantages of the quadtree model for geographic database representation and modeling
- Describe alternatives to quadtrees for representing hierarchical tessellations (e.g., hextrees, r-trees, pyramids)
- Explain how quadtrees and other hierarchical tessellations can be used to index large volumes of raster or vector data
- Implement a format for encoding quadtrees in a data file

Unit DM4 Vector and object data models (*core unit*)

Vector data models represent discrete entities by delineating points, lines, boundaries, and nodes as sets of coordinate values with associated attributes. This unit also examines recent methods and strategies for representing information in a more human-centered and natural way that goes beyond traditional vector models for representing an object-based view. Linear referencing systems are considered in Unit GD3 Georeferencing systems, and analytical methods for vector data are considered in Knowledge Area AM: Analytical Methods. The theoretical foundations for an object-centered view of geographic information are covered in Knowledge Area CF: Conceptual Foundations. Topics in this unit are also considered in the Body of Knowledge of the allied field of Computer Science (ACM/IEEE-CS Joint Task Force, 2001).

Topic DM4-1 Geometric primitives

- Identify the three fundamental dimensionalities used to represent points, lines, and areas
- Describe the data models used to encode coordinates as points, lines, or polygons
- Critique the assumptions that are made in representing the world as points, lines, and polygons
- Evaluate the correspondence between geographic phenomena and the shapes used to represent them

Topic DM4-2 The spaghetti model

- Identify a widely-used example of the spaghetti model (e.g., AutoCAD DWF, ESRI shapefile)
- Describe how geometric primitives are implemented in the spaghetti model as independent objects without topology
- Explain how the spaghetti data model embodies an object-based view of the world
- Explain the conditions under which the spaghetti model is useful
- Write a program to read and write a vector data file using a common published format

Topic DM4-3 The topological model

- Define terms related to topology (e.g., adjacency, connectivity, overlap, intersect, logical consistency)
- Illustrate a topological relation
- Explain the advantages and disadvantages of topological data models
- Demonstrate how a topological structure can be represented in a relational database structure
- Exemplify the concept of planar enforcement (e.g., TIN triangles)
- Discuss the role of graph theory in topological structures
- Describe the integrity constraints of integrated topological models (e.g., POLYVRT)
- Discuss the historical roots of the Census Bureau's creation of GBF/DIME as the foundation for the development of topological data structures
- Explain why integrated topological models have lost favor in commercial GIS software
- Evaluate the positive and negative impacts of the shift from integrated topological models

Topic DM4-4 Classic vector data models

- Illustrate the GBF/DIME data model
- Explain what makes POLYVRT a hierarchical vector data model
- Discuss the advantages and disadvantages of POLYVRT
- Describe the relationship between the GBF/DIME and TIGER structures, the rationale for their design, and their intended primary uses, paying particular attention to the role of graph theory in establishing the difference between GBF/DIME and TIGER files
- Describe a Freeman-Huffman chain code
- Describe the relationship of Freeman-Huffman chain codes to the raster model
- Discuss the impact of early prototype data models (e.g., POLYVRT and GBF/DIME) on contemporary vector formats

Topic DM4-5 The network model

- Define the following terms pertaining to a network: Loops, multiple edges, the degree of a vertex, walk, trail, path, cycle, fundamental cycle
- Demonstrate how a network is a connected set of edges and vertices
- List definitions of networks that apply to specific applications or industries
- Create an adjacency table from a sample network

- Explain how a graph can be written as an adjacency matrix and how this can be used to calculate topological shortest paths in the graph
- Create an incidence matrix from a sample network
- Explain how a graph (network) may be directed or undirected
- Demonstrate how attributes of networks can be used to represent cost, time, distance, or many other measures
- Demonstrate how the star (or forward star) data structure, which is often employed when digitally storing network information, violates relational normal form, but allows for much faster search and retrieval in network databases
- Discuss some of the difficulties of applying the standard process-pattern concept to lines and networks

Topic DM4-6 Linear referencing

- Construct a data structure to contain point or linear geometry for database record events that are referenced by their position along a linear feature
- Demonstrate how linear referenced locations are often much more intuitive and easy to find in the real world than geographic coordinates
- Explain how linear referencing allows attributes to be displayed and analyzed that do not correspond precisely with the underlying segmentation of the network features
- Discuss dynamic segmentation as a process for transforming between linear and planar coordinate systems
- Describe how linear referencing can eliminate unnecessary segmentation of the underlying network features due to attribute value changes over time

Topic DM 4-7 Object-based spatial databases

- Discuss the merits of storing geometric data in the same location as attribute data
- Evaluate the advantages and disadvantages of the object-based data model compared to the layer-based vector data model (topological or spaghetti)
- Describe the architectures of various object-relational spatial data models, including spatial extensions of DBMS, proprietary object-based data models from GIS vendors, and open-source and standards-based efforts
- Discuss the degree to which various object-relational spatial data models approximate a true object-oriented paradigm, and whether they should
- Differentiate between the topological vector data model and spaghetti object data with topological rulebases
- Write a script (in a GIS, database, or Web environment) to read and write data in an object-based spatial database
- Transfer geospatial data from an XML schema to a database

Unit DM5 Modeling 3-D, temporal, and uncertain phenomena

Traditional raster and vector data models cannot easily represent the more complex aspects of geographic information, such as temporal change, uncertainty, three-dimensional phenomena, and integrated multimedia. A variety of models have been proposed to represent these complexities, including both extensions to existing models and software, and entirely new models and software. During the 1990s, work in this area was largely experimental, but many solutions are now available to practitioners in com-

mercial and open source software. The data models in this unit are based on concepts discussed in Knowledge Area CF: Conceptual Foundations.

Topic DM5-1 Spatio-temporal GIS

- Describe extensions to relational DBMS to represent temporal change in attributes
- Describe SQL extensions for querying temporal change
- Differentiate the two types of temporal information to be modeled in databases: database (or transaction) time and valid (or world) time
- Identify whether it is important to represent temporal change in a particular GIS application
- Describe the architecture of data models (both field and object based) to represent spatio-temporal phenomena
- Evaluate the advantages and disadvantages of existing space-time models based on storage efficiency, query performance, ease of data entry, and ability to implement in existing software
- Create a GIS database that models temporal information
- Utilize two different space-time models to characterize a given scenario, such as a daily commute

Topic DM5-2 Modeling uncertainty

- Describe extensions to relational DBMS to represent different types of uncertainty in attributes, including both vagueness/fuzziness and error-based uncertainty
- Describe SQL extensions for querying uncertainty information in databases
- Differentiate among modeling uncertainty for entire datasets, for features, and for individual data values
- Identify whether it is important to represent uncertainty in a particular GIS application
- Discuss the role of metadata in representing and communicating dataset-level uncertainty
- Describe the architecture of data models (both field- and object-based) to represent feature-level and datum-level uncertainty
- Evaluate the advantages and disadvantages of existing uncertainty models based on storage efficiency, query performance, ease of data entry, and ability to implement in existing software
- Create a GIS database that models uncertain information

Topic DM5-3 Modeling three-dimensional (3-D) entities

- Identify GIS application domains in which true 3-D models of natural phenomena are necessary
- Differentiate between $2\frac{1}{2}$ -D representations and true 3-D models
- Explain how voxels and stack-unit maps that show the topography of a series of geologic layers might be considered 3-D extensions of field and vector representations respectively
- Explain the difficulties in creating true 3-D objects in a vector or raster format
- Explain the use of multi-patching to represent 3-D objects
- Explain how 3-D models can be extended to additional dimensions
- Illustrate the use of Virtual Reality Modeling Language (VRML) to model landscapes in 3-D
- Explain how octatrees are the 3-D extension of quadtrees

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Knowledge Area: Data Manipulation (DN)

GIS is a cyclical rather than a linear system, unlike computer aided drafting (CAD) and computer assisted cartographic systems. Changes in projection, grid systems, data forms, and formats take place during the modeling process for which GIS was designed. Many non-analytical manipulations are necessary to accommodate the analytical power of the GIS. The manipulations of spatial and spatio-temporal data involve three general classes of operation:

1. Their transformation into formats that facilitate subsequent analysis,
2. Generalization and aggregation that affect the accuracy and integrity of the data used for analysis, and
3. Transaction management that allows for the tracking of changes, versioning, and updating without loss of the original data.

Practitioners frequently need to make decisions on when and how to engage in data manipulation. The ability to switch between raster and vector systems without substantial information loss is necessary for effective spatial analysis. Furthermore, knowledge of how particular data types respond to changes in format, organization, scale, resolution, and quality is often paramount to the ability to perform modeling and spatial analysis. During data manipulation operations, it is extremely important to know how to handle error propagation, as discussed in Unit GC8 Uncertainty.

Unit DN1 Representation transformation (*core unit*)

Other knowledge areas have identified different forms of data structures, data models, projections, and other forms of geospatial data representation. These differences present both opportunities and challenges for analysis and modeling. The ability to transform one representation to another, in a manner that maintains the integrity of the information as much as possible, can enhance the analysis and visualization of geospatial data. The raster and vector data models are described in Units DM3 Tessellation data models and DM4 Vector and object data models. The principles of coordinate systems, datums, and projections are also considered in Knowledge Area GD: Geospatial Data.

Topic DN1-1 Impacts of transformations

- Compare and contrast the impacts of different conversion approaches, including the effect on spatial components
- Prioritize a set of algorithms designed to perform transformations based on the need to maintain data integrity (e.g., converting a digital elevation model into a TIN)
- Create a flowchart showing the sequence of transformations on a data set (e.g., geometric and radiometric correction and mosaicking of remotely sensed data)

Topic DN1-2 Data model and format conversion

- Identify the conceptual and practical difficulties associated with data model and format conversion
- Describe a workflow for converting and implementing a data model in a GIS involving an Entity-Relationship (E-R) diagram and the Universal Modeling Language (UML)
- Discuss the role of metadata in facilitating conversation of data models and data structures between systems
- Convert a data set from the native format of one GIS product to another

Topic DN1-3 Interpolation

- Differentiate among common interpolation techniques (e.g., nearest neighbor, bilinear, bicubic)
- Explain how the elevation values in a digital elevation model (DEM) are derived by interpolation from irregular arrays of spot elevations
- Discuss the pitfalls of using secondary data that has been generated using interpolations (e.g., Level 1 USGS DEMs)
- Estimate a value between two known values using linear interpolation (e.g., spot elevations, population between census years)

Topic DN1-4 Vector-to-raster and raster-to-vector conversions

- Explain how the vector/raster/vector conversion process of graphic images and algorithms takes place and how the results are achieved
- Convert vector data to raster format and back using GIS software
- Illustrate the impact of vector/raster/vector conversions on the quality of a dataset
- Create estimated tessellated data sets from point samples or isolines using interpolation operations that are appropriate to the specific situation

Topic DN1-5 Raster resampling

- Discuss the consequences of increasing and decreasing resolution
- Evaluate methods used by contemporary GIS software to resample raster data on-the-fly during display
- Select appropriate interpolation techniques to resample particular types of values in raster data (e.g., nominal using nearest neighbor)
- Resample multiple raster data sets to a single resolution to enable overlay
- Resample raster data sets (e.g., terrain, satellite imagery) to a resolution appropriate for a map of a particular scale

Topic DN1-6 Coordinate transformations

- Cite appropriate applications of several coordinate transformation techniques (e.g., affine, similarity, Molodenski, Helmert)
- Differentiate between polynomial coordinate transformations (including linear) and rubbersheeting
- Describe the impact of map projection transformation on raster and vector data

Unit DN2 Generalization and aggregation (*core unit*)

All geospatial data are generalized. Even the most detailed data represent only subsets of reality. Furthermore, data are further generalized for purposes of mapping, visualization, and efficient storage. A variety of generalization techniques have been developed to facilitate this process. All are scale dependent. Aggregation is one form of generalization that transforms large numbers of individual objects into summarized groups. This unit is concerned with the nature of these procedures and their implications for professional practice. Generalization is an important part of cartography (and is therefore discussed conceptually in Unit CV2 Data considerations), but is also a transformation common to many GIS procedures.

Topic DN2-1 Scale and generalization

- Differentiate among the concepts of scale (as in map scale), support, scope, and resolution
- Determine the mathematical relationships among scale, scope, and resolution, including Töpfer's radical law
- Defend or refute the statement "GIS data are scaleless"
- Discuss the implications of tradeoff between data detail and data volume
- Select a level of data detail and accuracy appropriate for a particular application (e.g., viewshed analysis, continental land cover change)

Topic DN2-2 Approaches to point, line, and area generalization

- Describe the basic forms of generalization used in applications in addition to cartography (e.g., selection, simplification)
- Discuss the possible effects on topological integrity of generalizing data sets
- Explain why areal generalization is more difficult than line simplification
- Explain the logic of the Douglas-Poiker line simplification algorithm
- Explain the pitfalls of using data generalized for small scale display in a large scale application
- Design an experiment that allows one to evaluate the effect of traditional approaches of cartographic generalization on the quality of digital data sets created from analog originals
- Evaluate various line simplification algorithms by their usefulness in different applications

Topic DN2-3 Classification and transformation of attribute measurement levels

- Identify a variety of likely measurement level transformations (e.g., the classification of ratio data yields ordinal data)
- Discuss the relationship of attribute measurement levels to database query operations
- Describe the pitfalls, in terms of information loss and analytical options, of transforming attribute measurement levels
- Reclassify (group) a nominal attribute domain to fewer, broader classes

Topic DN2-4 Aggregation of spatial entities

- Discuss the conditions that require individual spatial entities to be aggregated (e.g., privacy, security, proprietary interests, data simplification)
- Demonstrate the relationship between district size (resolution/support) and patterns in aggregate data

- Summarize the attributes of individuals within regions using spatial joins
- Demonstrate how changing the geometry of regions changes the data values (e.g., voting patterns before and after redistricting)
- Discuss the potential pitfalls of using regions to aggregate geographic information (e.g., census data)
- Explain the nature and causes of the Modifiable Areal Unit Problem (MAUP)
- Attempt to design aggregation regions that overcome MAUP

Unit DN3 Transaction management of geospatial data

In many circumstances, such as with data pertaining to land records, both spatial entities and their attribute data undergo frequent and often profound changes. Complete cataloging of these changes requires that the initial conditions, the new conditions, and any intermediate changes and methods of change be explicitly cataloged. In short, the geospatial database needs to contain an archival history of change. The updating of geospatial databases is discussed in Unit OI Managing GIS operations and infrastructure, in the context of overall GIS management.

Topic DN3-1 Database change

- Demonstrate the importance of a clean, relatively error-free database (together with an appropriate geodetic framework) with the use of GIS software
- Modify spatial and attribute data while ensuring consistency within the database
- Discuss the implication of “long transactions” on database integrity
- Exemplify scenarios in which one would need to perform a number of periodic changes in a real GIS database
- Explain how one would establish the criteria for monitoring the periodic changes in a real GIS database

Topic DN3-2 Modeling database change

- Define a set of rules for modeling changes in spatial databases
- Describe techniques for handling version control in spatial databases
- Describe techniques for managing long transactions in a multi-user environment
- Explain why logging and rollback techniques are adequate for managing “short transactions”

Topic DN3-3 Reconciling database change

- Design a test of reliability of change information (e.g., the logical consistency of updates to the TIGER database)
- Implement a test of reliability of change information

Topic DN3-4 Managing versioned geospatial databases

- Describe an application in which it is crucial to maintain previous versions of the database
- Produce viable queries for change scenarios using GIS or database management tools
- Describe existing algorithms designed for performing dynamic queries
- Demonstrate how both the time criticality and the data security might determine whether one performs change detection on-line or off-line in a given scenario

- Explain why the lack of a data librarian to manage data can have disastrous consequences on the resulting dataset

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Knowledge Area: Geocomputation (GC)

The knowledge area emphasizes the research, development, and application of computationally intensive approaches to the study of complex spatial-temporal problems. It is motivated by the fact that some geographical systems can be difficult to model or analyze well when relying on more traditional statistical approaches due to a combination of data complexity, invalid assumptions and computational demands. Geocomputational methods are often drawn from machine learning and simulation research, and include a variety of methods designed to simulate, model, analyze, and visualize a range of highly complex, often non-deterministic, non-linear problems. Methods include, but are not limited to, cellular automata, neural networks, agent-based models, genetic algorithms, and fuzzy sets. The boundary between Knowledge Areas AM: Analytical Methods and GC: Geocomputation is blurred as a consequence of their shared goals. As methods evolve within geocomputation, computer science, and GIS&T, units and topics included in Knowledge Area GC: Geocomputation today may be more aptly included in Knowledge Area AM: Analytical Methods in the future. Curriculum planners should not consider the order in which units are presented to be prescriptive. Furthermore, although much of the content may best be studied within graduate-level programs, fostering awareness of these topics may be appropriate at other levels as well. Mastery of the objectives presented in this knowledge area require knowledge and skills presented in the computer science body of knowledge (ACM/IEEE-CS Joint Task Force, 2001).

Unit GC1 Emergence of geocomputation

Techniques that comprise this knowledge area tend to be computationally intensive. They have become feasible with the advent of modern computing capabilities and sophisticated machine learning methods. Continuing developments in this area may continue to expand the GIS&T domain.

Topic GC1-1 Origins

- Discuss Openshaw's contributions in the development of this sub-discipline
- Summarize the development of geocomputation techniques and algorithms and the related advances in computer technology/architecture that have aided in the ability to carry out more complex processes in GIS&T
- Summarize the role of the GeoComputation conference series in shaping this sub-discipline (<http://www.geocomputation.org/>)

Topic GC1-2 Trends

- Describe GIS&T topics that may be addressed by new geocomputation techniques
- Identify topics and techniques that may be addressed as computer capabilities increase

Unit GC2 Computational aspects and neurocomputing

Taking advantage of parallel processing, supercomputers, and other high performance devices, geospatial analysis can be brought to a new level of insight, detail, and diversity. Neural network techniques and analysis takes advantage of intensive computation and is especially well suited for complex geospatial classification problems (e.g., those associated with highly multivariate remote sensing imagery, for prediction problems, or downscaling of climate models or evacuation plans for cities, running as agent-based simulations of individuals). Many of the basic analytic tools used in these models are also considered in Knowledge Area AM: Analytical Methods.

Topic GC2-1 High performance computing

- Describe how the power increase in desktop computing has expanded the analytic methods that can be used for GIS&T
- Exemplify how the power increase in desktop computing has expanded the analytic methods that can be used for GIS&T

Topic GC2-2 Computational intelligence

- Describe computational intelligence methods that may apply to GIS&T
- Describe a hypothesis space that includes searches for optimality of solutions within that space
- Exemplify the potential for machine learning to expand performance of specialized geospatial analysis functions
- Identify artificial intelligence tools that may be useful for GIS&T

Topic GC2-3 Non-linearity relationships and non-Gaussian distributions

- Define non-linear and non-Gaussian distributions in a geospatial data environment
- Exemplify non-linear and non-Gaussian distributions in a geospatial data environment
- Understand how some machine learning methods might be more adept at modeling or representing such distributions

Topic GC2-4 Pattern recognition

- Describe the use of based on temporal relationships of objects and space (crime or disease analyses are examples)

Topic GC2-5 Geospatial data classification

- Compare and contrast the assumptions and performance of parametric and non-parametric approaches to multivariate data classification
- Compare and contrast the results of the neural approach to those obtained using more traditional Gaussian maximum likelihood classification (available in most remote sensing systems)
- Describe three algorithms that are commonly used to conduct geospatial data classification
- Explain the effect of including geospatial contiguity as an explicit neighborhood classification criterion

Topic GC2-6 Multi-layer feed-forward neural networks

- Analyze the stability of the network using multiple runs with the same training data and architecture
- Describe the architecture and components of a feed-forward neural network
- Differentiate between feed-forward and recurrent architectures
- Compare and contrast classification results when the architecture of the network and initial parameters are changed

Topic GC2-7 Space-scale algorithms

- Describe how space-scale algorithms can, or should, be used

Topic GC2-8 Rule learning

- Describe how a neural network may use training rules to learn from input data

Topic GC2-9 Neural network schemes

- Appraise the relative value of neural networks or alternative inductive machine learning methods, such as decision trees or genetic classifiers, in a hypothetical or real case
- Evaluate the success of neural network schemes
- Implement a neural network classification scheme for a complex data set

Unit GC3 Cellular automata (CA) models

Cellular automata are computational models in a cell-based space that employ simple context-sensitive state-transition rules applied to cells across the domain, resulting in potentially complex patterns and behaviors of cell states.

Topic GC3-1 CA model structure

- Analyze the advantages and limitations of CA geospatial representations
- Describe how CA might represent a geographical region
- Explain how the use of CA to represent a geographical region relates to how places in a region are interconnected

Topic GC3-2 CA transition rule

- Describe classic CA transition rules
- Describe how local and global transitional rules are handled in CA
- Describe how the rules of the Game of Life typically result in a continuously evolving pattern
- Explain two geographical processes that could be effectively represented using CA
- Explain two geographical processes that could not be effectively represented using CA

Topic GC3-3 CA simulation and calibration

- Describe the challenges of calibrating CA models
- Describe error sources of CA models
- Explain how temporal concepts are implemented in CA models

Topic GC3-4 Integration of CA and other geocomputation methods

- Appraise the possible improvement of integrating GeoAlgebra, Graph-Based Cellular Automata, or agent-based models to overcome the fixed-grid limitations of CA models
- Compare and contrast the analysis of a process using a CA with the analysis of the same process in a GIS using map algebra and similar raster operations
- Explain the potential contribution of integrating data mining into CA models

Topic GC3-5 Typical CA applications

- Exemplify CA simulations of urban growth
- Exemplify CA simulations of wild fire
- Exemplify CA simulations of real estate development

Unit GC4 Heuristics

Among the recent artificial intelligence techniques are those pertaining to heuristics. The five topics introduced in this unit, and the genetic algorithms unit which follows, are especially important and powerful heuristic methods. Evolution of natural life is very much a trial and error process. Adaptation and “survival of the fittest” are central to this area of concern. The algorithms that mimic evolution have now been applied to geospatial phenomena such as the location of optimal habitat sites. Skills in computer programming are needed to effectively carry out the process.

Topic GC4-1 Greedy heuristics

- Demonstrate how to implement a greedy heuristic process
- Identify problems for which the greedy heuristic also produces the optimal solution (e.g., Kruskal’s algorithm for minimum spanning tree, the fractional Knapsack problem)

Topic GC4-2 Interchange heuristics

- Define alternatives to the Tietz and Bart heuristic
- Describe the process whereby an element within a random solution is exchanged, and if it improves the solution, it is accepted, and if not, it is rejected and another element is tried until no improvement occurs in the objective function value
- Outline the Tietz and Bart interchange heuristic

Topic GC4-3 Interchange with probability

- Explain how the process to break out local optima can be based on a probability function
- Outline the TABU heuristic

Topic GC4-4 Simulated annealing

- Outline the rationale for and usefulness of simulated annealing

Topic GC4-5 Lagrangian relaxation

- Describe how Lagrangian relaxation can provide approximate solutions to complex problems

Unit GC5 Genetic algorithms (GA)

Evolution of natural life is very much a trial and error process. Adaptation and ‘survival of the fittest’ are central to this area of concern. Genetic algorithms (GA) mimic evolution and have been applied to diverse geospatial problems such as the location of facilities on networks or the selection of optimal habitat sites on raster domains. A genetic algorithm harnesses evolutionary power by representing an optimization problem as a population of strings of parameters; initializing the first generation of strings with valid but otherwise random values; evaluating the fitness of each string according to an objective function; creating child strings by selecting parent strings according to their relative fitness; applying crossover and (rare) mutations to parent strings to create child string(s); and repeating the process for subsequent generations. Included in this unit are global search methods, cross breeding, mutations, competition and selection. Also included are ways to create rules for representing evolutionary processes and encoding agent based models.

Topic GC5-1 GA and global solutions

- Describe the difficulty of finding globally optimal solutions for problems with many local optima
- Compare and contrast the effectiveness of multiple search criteria for finding the optimal solution with a simple greedy hill climbing approach
- Explain the important advantage that GA methods may offer to find diverse near-optimal solutions
- Explain how a GA searches for solutions by using selection proportional to fitness, crossover, and (very low levels of) mutation to fitness criteria and crossover mutation to search for a globally optimal solution to a problem
- Explain how evolutionary algorithms may be used to search for solutions

Topic GC5-2 Genetic algorithms and artificial genomes

- Create an artificial genome that can be used in a genetic algorithm to solve a specific problem
- Describe a potential solution for a problem in a way that could be represented in a chromosome and evaluated according to some measure of fitness (such as the total distance everyone travels to the facility or the diversity of plants and animals that would be protected) genome
- Describe a cluster in a way that could be represented in a genome
- Explain how and why the representation of a GA’s chromosome strings can enhance or hinder the effectiveness of the GA
- Use one of the many freely available GA packages to apply a GA to implement a simple genetic algorithm to a simple problem, such as optimizing the location of one or more facilities or optimizing the selection of habitat for a nature preserve geospatial pattern optimization (such as for finding clusters of disease points)

Unit GC6 Agent-based models

Many geographic patterns and dynamics are formed by systems of interacting actors that have heterogeneous characteristics and/or behaviors and interact with a heterogeneous environment. Agent-based models are constructed with object-oriented programming to represent these actors, their environments,

and their interactions with one another and with their environments. These models can be used as laboratories for exploring social and geospatial patterns and processes.

Topic GC6-1 Structure of agent-based models

- Compare and contrast agent-based models and cellular automata as approaches for modeling spatial processes
- Describe how agent-based models use object-oriented programming constructs of inheritance and encapsulation to represent the behavior of heterogeneous and interactive and adaptive actors

Topic GC6-2 Specification of agent-based models

- Describe how multiple, different types of agents in a given system behave and interact with each other and their environment
- Describe how multiple parameters (e.g., number of agents, variability of agents, random number seeds for different series of random events or choices during each simulation) can be set within an agent-based model to change the model behavior
- Explain how agent behaviors can be used to represent the effects actors have on each other and on their environment
- Generate multiple, different types of agents in a given system

Topic GC6-3 Adaptive agents

- Describe different approaches to represent the effects of agent adaptation in the context of a specific agent-based model
- Explain the effects of agent adaptation in the context of a specific agent-based model

Topic GC6-4 Microsimulation and calibration of agent activities

- Describe a “bottom-up” simulation from an activity-perspective with changes in the locations and/or activities the individual person (and/or vehicle) in space and time, in the activity patterns and space-time trajectories created by these activity patterns, and in the consequent emergent phenomena, such as traffic jams and land-use patterns
- Describe how measurements on the output of a model can be used to describe model behavior
- Describe how various parameters in an agent-based model can be modified to evaluate the range of behaviors possible with a model specification

Topic GC6-5 Encoding agent-based models

- Conduct simple experiments with an agent-based model, analyze results, and evaluate their statistical significance with respect to degrees of freedom, sensitivity analyses, and uncertainty in the model
- Determine if an agent-based model has been run enough times with enough different random number seeds for rigorous inference of its results
- Describe how measurements on various inputs and outputs of a model can be used to describe model behavior and to relate model outcomes to various initial conditions
- Describe how various parameters in an agent-based model can be modified to evaluate the range of behaviors possible with a model specification; this should include special emphasis on the rigorous use of scientific “long-series” random number generators such as the Mersenne

Twister, and on rigorous use of separable random number seeds and series to separate random effects

- Design simple experiments with an agent-based model
- Design and implement a simple agent-based model using appropriate commercial or open source development tools

Unit GC7 Simulation modeling

This unit introduces tools for creating new models, visualizing model simulations and outcomes, and analyzing key characteristics of initial conditions. It also addresses how results can be optimized based on systematic targeted searches through the parameter and random seed spaces via supervisory search and optimization methods, such as genetic algorithms.

Topic GC7-1 Simulation modeling

- Conduct an experiment using simulation techniques from an activity perspective
- Describe how supervisory search and optimization methods can be used to analyze key characteristics of initial conditions and results and to optimize results based on systematic targeted search through the parameter and random seed spaces
- Discuss effective scientific use of supervisory genetic algorithms with agent-based simulation models
- Discuss whether, when prior information is absent, repeatedly generating random synthetic datasets can be used to provide statistical significance
- Discuss Monte Carlo simulation use in GIS&T
- Discuss important computational laboratory tools for creating new models and visualizing model simulations and model outcomes
- Explain how a simulation from an activity perspective can be used in transportation

Unit GC8 Uncertainty

Computers allow for the specification of increasingly more and more complex geospatial models and simulations. The work associated with them is subject to a certain degree of uncertainty, both because of the nature of input data and the nature of the estimation techniques for model output. Parameters can vary widely. It is the mark of a good scientist to understand the nature of uncertainty in problem specification and results. Unit CF6 Imperfections in geographic information focuses on the theoretical roots of uncertainty, while this unit focuses on the role of uncertainty in the use of geographic information.

Topic GC8-1 Definitions within a conceptual model of uncertainty

- Describe a stochastic error model for a natural phenomenon
- Differentiate between the following concepts: vagueness and ambiguity, well defined and poorly defined objects, and fields or discord and non-specificity
- Explain how the familiar concepts of geographic objects and fields affect the conceptualization of uncertainty

Topic GC8-2 Error

- Compare and contrast how systematic errors and random errors affect measurement of distance
- Describe the causes of at least five different types of errors (e.g., positional, attribute, temporal, logical inconsistency, and incompleteness)

Topic GC8-3 Problems of scale and zoning

- Describe the modifiable areal unit problem (MAUP) associated with aggregation of data collected at different scales and its affect on spatial autocorrelation
- Describe the MAUP and its affects on correlation, regression, and classification
- Describe the concept of ecological fallacy, and comment on its relationship with the MAUP

Topic GC8-4 Propagation of error in geospatial modeling

- Compare and contrast error propagation techniques (e.g., Taylor, Monte Carlo)
- Explain how some operations can exacerbate error while others dampen it (e.g., mean filter)

Topic GC8-5 Theory of error propagation

- Describe stochastic error models
- Exemplify stochastic error models used in GIScience

Topic GC8-6 Problems of currency, source, and scale

- Describe the problem of conflation associated with aggregation of data collected at different times, from different sources, and to different scales and accuracy requirements
- Explain how geostatistical techniques might be used to address such problems

Unit GC9 Fuzzy sets

The field of fuzzy sets casts a new light on the way the world and data about the world are viewed. Not all classification schemes need be considered crisp, in the sense of definitive. Fuzzy logic and fuzzy set techniques allow for the geospatial analysis of a more nuanced approach to data analysis. The concept of vagueness, and the associated fuzzy set theory, is discussed theoretically in Unit CF6 Imperfections in geographic information. The focus here is on the application of those concepts to modeling and analysis.

Topic GC9-1 Fuzzy logic

- Describe how linear functions are used to fuzzify input data (i.e., mapping domain values to linguistic variables)
- Explain why fuzzy logic, rather than Boolean algebra models, can be useful for representing real world boundaries between different tree species
- Support or refute the statement by Lotfi Zadeh, that “As complexity rises, precise statements lose meaning and meaningful statements lose precision,” as it relates to GIS&T

Topic GC9-2 Fuzzy measures

- Define fuzzy measures and give an example of a fuzzy measure
- Explain how numerical values can be mapped onto linguistic variables (e.g., “big,” “distant”)
- Explain how and why fuzzy measures can be used in geocomputation

Topic GC9-3 Fuzzy aggregation operators

- Compare and contrast Boolean and fuzzy logical operations
- Describe fuzzy aggregation operators
- Describe how an approach to map overlay analysis might be different if region boundaries were fuzzy rather than crisp
- Exemplify one use of fuzzy aggregation operators
- Compare and contrast several operators for fuzzy aggregation, including those for intersect and union

Topic GC9-4 Standardization

- Develop a standardization criterion that recasts values into a statement of fuzzy set membership

Topic GC9-5 Weighting schemes

- Evaluate a fuzzy weighting scheme in terms of uncertainty and error propagation

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Knowledge Area: Geospatial Data (GD)

Geospatial data represent measurements of the locations and attributes of phenomena at or near Earth's surface. Information is data made meaningful in the context of a question or problem. Information is rendered from data by analytical methods. Information quality and value depends to a large extent on the quality and currency of data (though historical data are valuable for many applications). Geospatial data may have spatial, temporal, and attribute (descriptive) components, as well as associated metadata. Data may be acquired from primary or secondary data sources. Examples of primary data sources include surveying, remote sensing (including aerial and satellite imaging), the global positioning system (GPS), work logs (e.g., police traffic crash reports), environmental monitoring stations, and field surveys. Secondary geospatial or geospatial-temporal data can be acquired by digitizing and scanning analog maps, as well as from other sources, such as governmental agencies.

The legitimacy of geographic information science as a discrete field has been claimed in terms of the unique properties of geospatial data. In a paper in which he coined the term GIScience, Goodchild (1992) identified several such properties, including:

1. Geospatial data represent spatial locations and non-spatial attributes measured at certain times.
2. The Earth's surface is highly complex in shape and continuous in extent.
3. Geospatial data tend to be spatially autocorrelated.

It has long been said that data account for the largest portion of geospatial project costs. While this maxim remains true for many projects, practitioners and their clients now can reasonably expect certain kinds of data to be freely or cheaply available via the World Wide Web. Federal, state, regional, and local government agencies, as well as commercial geospatial data producers, operate clearinghouses that provide access to geospatial data. The U.S. Geological Survey envisions a "National Map" that is nationwide in coverage and updated continuously. Although geospatial data are much more abundant now than they were ten years ago, data quality issues persist. Good data are expensive to produce and to maintain. Proprietary interests simultaneously increase the supply of geospatial data and impede data accessibility.

Standards for geospatial data and metadata are useful in facilitating effective search, retrieval, evaluation, integration with existing data, and appropriate uses. National and international organizations, such as the Federal Geographic Data Committee (FGDC) and International Organization for Standardization (ISO), develop and promulgate such standards.

Unit GD1 Earth geometry (*core unit*)

Accurate geospatial data are based upon an accurate model of the shape of the Earth's surface. The Earth's shape is complex and difficult to measure. Approximations of the Earth's shape are used to minimize both positioning error and complexity.

Topic GD1-1 History of understanding Earth's shape

- Describe how scientists' understanding of the Earth's shape has evolved throughout history
- Describe and critique early efforts to measure the Earth's size and shape
- Explain how technological and mathematical advances have led to more sophisticated knowledge about the Earth's shape
- Describe the contributions of key individuals (e.g., Eratosthenes, Newton, Picard, Bouguer, LaPlace, La Candamine) to scientists' understanding of the Earth's shape

Topic GD1-2 Approximating the Earth's shape with geoids

- Explain why gravity varies over the Earth's surface
- Explain the concept of an equipotential gravity surface (i.e., a geoid)
- Explain how geoids are modeled
- Explain the role that the U.S. National Geodetic Survey plays in maintaining and developing geoid models

Topic GD1-3 Approximating the geoid with spheres and ellipsoids

- Distinguish between a geoid, an ellipsoid, a sphere, and the terrain surface
- Explain why spheres and ellipsoids are used to approximate geoids
- Describe an application for which it is acceptable to use a sphere rather than an ellipsoid
- Identify the parameters used to define an ellipsoid
- Differentiate the Clarke 1866 and WGS 84 ellipsoids in terms of ellipsoid parameters
- Differentiate between a bi-axial and tri-axial ellipsoid and their applications

Unit GD2 Land partitioning systems

Parcel-based geospatial reference systems used at the time of settlement left a lasting imprint on the pattern of development in many areas of the U.S.

Topic GD2-1 Unsystematic methods

- Compare and contrast the typical spatial arrangements of land parcels characteristic of early English, Spanish, and French settlements in the U.S.
- Discuss advantages and disadvantages of unsystematic land partitioning methods in the context of GIS
- State a metes and bounds land description of a property parcel delineated in a land survey drawing

Topic GD2-2 Systematic methods

- Compare and contrast the United States Public Land Survey System (USPLS) and the Spanish land grant and French long lot systems
- Describe the historical context of the USPLS
- Describe the New England Town partitioning system
- Differentiate the USPLS from the geographic coordinate system
- Discuss advantages and disadvantages of systematic land partitioning methods in the context of GIS
- Discuss the consequences of the USPLS with regard to public administration (i.e., zoning)

- Explain how townships, ranges, and their sections are delineated in terms of baselines and principal meridians
- Illustrate how to quarter-off portions of a township and range section

Unit GD3 Georeferencing systems (*core unit*)

Geospatial referencing systems provide unique codes for every location on the surface of the Earth (or other celestial bodies). These codes are used to measure distances, areas, and volumes; to navigate; and to predict how and where phenomena on the Earth's surface may move, spread, or contract. Point-based, vector coordinate systems specify locations in relation to the origins of planar or spherical grids. Tessellated referencing systems specify locations hierarchically, as sequences of numbers that represent smaller and smaller subdivisions of two- or three-dimensional surfaces that approximate the Earth's shape. Linear referencing systems (also considered in topic DM4-6) specify locations in relation to distances along a path from a starting point. Tessellation data models are considered in Unit DM3 Tessellation data models, and linear referencing models are considered in Unit DM4 Vector data models.

Topic GD3-1 Geographic coordinate system

- Distinguish between various latitude definitions (e.g., geocentric, geodetic, astronomic latitudes)
- Explain the angular measurements represented by latitude and longitude coordinates
- Locate on a globe the positions represented by latitude and longitude coordinates
- Write an algorithm that converts geographic coordinates from decimal degrees (DD) to degrees, minutes, seconds (DMS) format
- Calculate the latitude and longitude coordinates of a given location on the map using the coordinate grid ticks in the collar of a topographic map and the appropriate interpolation formula
- Mathematically express the relationship between Cartesian coordinates and polar coordinates
- Calculate the uncertainty of a ground position defined by latitude and longitude coordinates specified in decimal degrees to a given number of decimal places
- Use GIS software and base data encoded as geographic coordinates to geocode a list of address-referenced locations

Topic GD3-2 Plane coordinate systems

- Explain why plane coordinates are sometimes preferable to geographic coordinates
- Explain what Universal Transverse Mercator (UTM) eastings and northings represent
- Associate UTM coordinates and zone specifications with corresponding position on a world map or globe
- Identify the map projection(s) upon which UTM coordinate systems are based, and explain the relationship between the projection(s) and the coordinate system grid
- Discuss the magnitude and cause of error associated with UTM coordinates
- Differentiate the characteristics and uses of the UTM coordinate system from the Military Grid Reference System (MGRS) and the World Geographic Reference System (GEOREF)
- Explain what State Plane Coordinates system (SPC) eastings and northings represent

- Associate SPC coordinates and zone specifications with corresponding positions on a U.S. map or globe
- Identify the map projection(s) upon which SPC coordinate systems are based, and explain the relationship between the projection(s) and the coordinate system grids
- Discuss the magnitude and cause of error associated with SPC coordinates
- Recommend the most appropriate plane coordinate system for applications at different spatial extents and justify the recommendation
- Critique the U.S. Geological Survey's choice of UTM as the standard coordinate system for the U.S. National Map
- Describe the characteristics of the "national grids" of countries other than the U.S.

Topic GD3-3 Tessellated referencing systems

- Explain the concept "quadtree"
- Describe the octahedral quarternary triangulated mesh georeferencing system proposed by Dutton
- Discuss the advantages of hierarchical coordinates relative to geographic and plane coordinate systems

Topic GD3-4 Linear referencing systems

- Describe an application in which a linear referencing system is particularly useful
- Discuss the magnitude and cause of error generated in the transformation from linear to planar coordinate systems
- Explain how a network can be used as the basis for reference as opposed to the more common rectangular coordinate systems
- Explain how the datum associated with a linear referencing system differs from a horizontal or vertical datum
- Identify several different linear referencing methods (e.g., mileposts, reference posts, link and node) and compare them to planar grid systems
- Identify the characteristics that all linear referencing systems have in common

Unit GD4 Datums (*core unit*)

"Horizontal" datums define the geometric relationship between a coordinate system grid and the Earth's surface, where the Earth's surface is approximated by an ellipsoid or other figure. "Vertical" datums are elevation reference surfaces, such as mean sea level.

Topic GD4-1 Horizontal datums

- Define "horizontal datum" in terms of the relationship between a coordinate system and an approximation of the Earth's surface
- Describe the limitations of a Molodenski transformation and in what circumstances a higher parameter transformation such as Helmert may be appropriate
- Discuss appropriate applications of the various datum transformation options
- Explain the difference between NAD 27 and NAD 83 in terms of ellipsoid parameters
- Explain the difference in coordinate specifications for the same position when referenced to NAD 27 and NAD 83

- Explain the methodology employed by the U.S. National Geodetic Survey to transform control points from NAD 27 to NAD 83
- Explain the rationale for updating NAD 27 to NAD 83
- Explain why all GPS data are originally referenced to the WGS 84 datum
- Identify which datum transformation options are available and unavailable in a GIS software package
- Outline the historical development of horizontal datums
- Perform a Molodenski transformation manually
- Determine the impact of a datum transformation from NAD 27 to NAD 83 for a given location using a conversion routine maintained by the U.S. National Geodetic Survey
- Use GIS software to perform a datum transformation

Topic GD4-2 Vertical datums

- Outline the historical development of vertical datums
- Explain how a vertical datum is established
- Differentiate between NAVD 29 and NAVD 88
- Illustrate the difference between a vertical datum and a geoid
- Illustrate the relationship among the concepts ellipsoidal (or geodetic) height, geoidal height, and orthometric elevation

Unit GD5 Map projections (*core unit*)

Map projections are plane coordinate grids that have been transformed from spherical coordinate grids using mathematical formulae. Inverse projections transform plane coordinates to geographic coordinates. Plane coordinate systems are thus based upon map projections. Because transformation from a spherical grid to a flat grid inevitably distorts the geometry of the grid, and because different projection formulae produce different distortion patterns, knowledgeable selection of appropriate map projections for particular uses is critical. Selection criteria for small-scale thematic mapping are considered in Knowledge Area: Cartography and Visualization (CV), especially Unit CV2 Data considerations, while procedures for transforming data between projections are considered in Unit DN1 Representation transformation.

Topic GD5-1 Map projection properties

- Describe the visual appearance of the Earth's graticule
- Define the four geometric properties of the globe that may be preserved or lost in projected coordinates
- Explain the concept of a "compromise" projection and for which purposes it is useful
- Discuss what a Tissot indicatrix represents and how it can be used to assess projection-induced error
- Interpret a given a projected graticule, continent outlines, and indicatrices at each graticule intersection in terms of geometric properties preserved and distorted
- Illustrate distortion patterns associated with a given projection class
- Recognize distortion patterns on a map based upon the graticule arrangement
- Explain the kind of distortion that occurs when raster data are projected

- Explain the rationale for the selection of the geometric property that is preserved in map projections used as the basis of the UTM and SPC systems
- Recommend the map projection property that would be useful for various mapping applications, including parcel mapping, route mapping, etc., and justify your recommendations

Topic GD5-2 Map projection classes

- Explain the concepts “developable surface” and “reference globe” as ways of projecting the Earth’s surface
- Classify various map projection types by the three main classes of map projections based on developable surfaces
- Classify various map projection types according to the geometric properties preserved
- Illustrate the graticule configurations for “other” projection classes, such as polyconic, pseudo-cylindrical, etc.
- Explain the mathematical basis by which latitude and longitude locations are projected into x and y coordinate space

Topic GD5-3 Map projection parameters

- Define key terms such as “standard line,” “projection case,” and “latitude and longitude of origin”
- Explain how the concepts of the tangent and secant cases relate to the idea of a standard line
- Identify the possible “aspects” of a projection and describe the graticule’s appearance in each aspect
- Identify the parameters that allow one to focus a projection on an area of interest
- Use GIS software to produce a graticule that matches a target graticule
- Implement a given map projection formula in a software program that reads geographic coordinates as input and produces projected (x, y) coordinates as output

Topic GD5-4 Georegistration

- Differentiate rectification and orthorectification
- Explain the role and selection criteria for “ground control points” (GCPs) in the georegistration of aerial imagery
- Identify and explain an equation used to perform image-to-map registration
- Identify and explain an equation used to perform image-to-image registration
- Use GIS software to transform a given dataset to a specified coordinate system, projection, and datum

Unit GD6 Data quality (*core unit*)

The ultimate standard of quality is the degree to which a geospatial data set is fit for use in a particular application. That standard varies from one application to another. In general, however, the key criteria are how much uncertainty is present in a data set and how much is acceptable. Judgments about fitness for use may be more difficult when data are acquired from secondary rather than primary sources. Aspects of data quality include accuracy, resolution, and precision. Concepts data quality, error, and uncertainty are also covered in Knowledge Areas CF: Conceptual Foundations (in a theoretical context) and GC: Geocomputation (in the context of analysis); the focus here is on the measurement and assessment of data quality.

Topic GD6-1 Geometric accuracy

- State the geometric accuracies associated with the various orders of the U.S. horizontal geodetic control network
- Explain how geometric accuracies associated with the various orders of the U.S. horizontal geodetic control network are assured
- State the approximate number and spacing of control points in each order of the horizontal geodetic control network
- Explain the factors that influence the geometric accuracy of data produced with Global Positioning System (GPS) receivers
- Explain the concept of dilution of precision
- Describe the impact of the concept of dilution of precision on the uncertainty of GPS positioning
- Explain the principle of differential correction in relation to the Global Positioning System
- Apply the National Map Accuracy Standard to calculate the accuracy associated with the various USGS topographic map scales
- Compare the National Map Accuracy Standard with the ASPRS Coordinate Standard
- In contrast to the National Map Accuracy Standard, explain how the spatial accuracy of a digital road centerlines data set may be evaluated and documented
- Explain the formula for calculating root mean square error
- Compare the concepts of geometric accuracy and topological fidelity
- Describe how geometric accuracy should be documented in terms of the FGDC metadata standard

Topic GD6-2 Thematic accuracy

- Explain the distinction between thematic accuracy, geometric accuracy, and topological fidelity
- Describe the different measurement levels on which thematic accuracy is based
- Describe the component measures and the utility of a misclassification matrix
- Discuss how measures of spatial autocorrelation may be used to evaluate thematic accuracy
- Outline the SDTS and ISO TC211 standards for thematic accuracy

Topic GD6-3 Resolution

- Illustrate and explain the distinction between resolution, precision, and accuracy
- Illustrate and explain the distinctions between spatial resolution, thematic resolution, and temporal resolution
- Discuss the implications of the sampling theorem ($\lambda = 0.5 \delta$) to the concept of resolution
- Differentiate among the spatial, spectral, radiometric, and temporal resolution of a remote sensing instrument
- Explain how resampling affects the resolution of image data
- Discuss the advantages and potential problems associated with the use of minimum mapping unit (MMU) as a measure of the level of detail in land use, land cover, and soils maps

Topic GD6-4 Precision

- Calculate, in terms of ground area, the uncertainty associated with decimal coordinates specified to three, four, and five decimal places
- Explain the concept of error propagation
- Explain, in general terms, the difference between single and double precision and impacts on error propagation

Topic GD6-5 Primary and secondary sources

- Explain the distinction between primary and secondary data sources in terms of census data, cartographic data, and remotely sensed data
- Describe a scenario in which data from a secondary source may pose obstacles to effective and efficient use

Unit GD7 Land surveying and GPS (*core unit*)

In the U.S., land surveyors are licensed by state governments to produce geospatial data that conforms to legal accuracy standards. Such standards pertain to property demarcation, construction engineering, and other applications. Land surveyors and geodesists also create and maintain the control networks upon which highly accurate positioning depends. GPS is supplanting electro-optical methods for point positioning in surveying, mapping, and navigation. The topics included in this unit do not comprise an exhaustive treatment of land surveying and GPS, but they are aspects of the field about which all geospatial professionals should be knowledgeable.

Topic GD7-1 Survey theory and electro-optical methods

- Apply coordinate geometry to calculate positions in a coordinate system grid based on control point locations and measured angles and distances
- Explain how electronic distance measurement instruments work
- Define the concepts ellipsoidal (or geodetic) height, geoidal height, and orthometric elevation
- Illustrate the relationship between the concepts of ellipsoidal (or geodetic) height, geoidal height, and orthometric elevation
- Given the elevation of one control point, calculate the elevation of a second point by differential (spirit or direct) leveling
- Given the elevation of one control point, calculate the elevation of a second point by trigonometric (indirect) leveling
- Describe the differences between differential and trigonometric leveling

Topic GD7-2 Land records

- Distinguish between GIS, LIS, and CAD/CAM in the context of land records management
- Distinguish between topological fidelity and geometric accuracy in the context of a plat map
- Exemplify and compare deed descriptions in terms of how accurately they convey the geometry of a parcel
- Evaluate the difference in accuracy requirements for deeds systems versus registration systems

Topic GD7-3 Global Positioning System

- Explain how GPS receivers calculate coordinate data
- Distinguish between horizontal and vertical accuracies when using coarse acquisition codes/standard positioning service (C-codes) and precision acquisition codes/precise positioning service (P-codes)
- Perform differential correction of GPS data using reference data from a CORS station
- List, define, and rank the sources of error associated with GPS positioning

- Explain the relevance of the concept of trilateration to both GPS positioning and control surveying
- Specify the features of a GPS receiver that is able to achieve geometric accuracies on the order of centimeters without post-processing
- Discuss the relationship of GPS to the Global Satellite Navigation System
- Explain “selective availability,” why it was discontinued in 2000, and what alternatives are available to the U.S. Department of Defense
- Explain the relationship of the U.S. Global Positioning System with comparable systems sponsored by Russia and the European Union and the Global Navigation Satellite System
- Discuss the role of GPS in location-based services (LBS)

Unit GD8 Digitizing

Encoding vector points, lines, and polygons by tracing map sheets on digitizing tablets has diminished in importance since the early years of GIS&T, but remains a useful technique for incorporating historical geographies and local knowledge. “Heads-up” digitizing using digital imagery as a backdrop on-screen is a standard technique for editing and updating GIS databases.

Topic GD8-1 Tablet digitizing

- Digitize and georegister a specified vector feature set to a given geometric accuracy and topological fidelity threshold using a given map sheet, digitizing tablet, and data entry software

Topic GD8-2 On-screen digitizing

- Outline a workflow that can be used to train a new employee to update a county road center-lines database using digital aerial imagery and standard GIS editing tools

Topic GD8-3 Scanning and automated vectorization techniques

- Outline the process of scanning and vectorizing features depicted on a printed map sheet using a given GIS software product, emphasizing issues that require manual intervention

Unit GD9 Field data collection

Field data collection involves the in situ measurement of physical and demographic phenomena occurring at or near the Earth’s surface at particular locations and times.

Topic GD9-1 Sample size selection

- Determine the minimum number and distribution of point samples for a given study area and a given statistical test of thematic accuracy
- Assess the practicality of statistically reliable sampling in a given situation
- Determine minimum homogeneous ground area for a particular application
- Describe how spatial autocorrelation influences selection of sample size and sample statistics

Topic GD9-2 Spatial sample types

- Design point, transect, and area sampling strategies for given applications
- Differentiate among random, systematic, stratified random, and stratified systematic unaligned sampling strategies
- Differentiate between situations in which one would use stratified random sampling and systematic sampling

Topic GD9-3 Sample intervals

- Identify the fundamental principle of the sampling theorem for specifying a sampling rate or interval
- Discuss what sampling intervals should be used to investigate some of the temporal patterns encountered in oceanography
- Propose a sampling strategy considering a variable range in autocorrelation distances for a variable

Topic GD9-4 Field data technologies

- Identify the measurement framework that applies to moving object tracking
- Considering the measurement framework applied to moving object tracking, identify which of the dimensions of location, attribute, and time is fixed, which is controlled, and which is measured
- Describe a real or hypothetical application of a sensor network in field data collection
- Outline a combination of positioning techniques that can be used to support location-based services in a given environment
- Explain the advantage of real-time kinematic GPS in field data collection
- Describe an application of hand-held computing or personal digital assistants (PDAs) for field data collection

Unit GD10 Aerial imaging and photogrammetry (*core unit*)

Since the 1940s aerial imagery has been the primary source of detailed geospatial data for extensive study areas. Photogrammetry is the profession concerned with producing precise measurements from aerial imagery. Aerial imaging and photogrammetry comprise a major component of the geospatial industry. The topics included in this unit do not comprise an exhaustive treatment of photogrammetry, but they are aspects of the field about which all geospatial professionals should be knowledgeable.

Topic GD10-1 Nature of aerial image data

- Explain the phenomenon that is recorded in an aerial image
- Compare and contrast digital and photographic imaging
- Explain the significance of “bit depth” in aerial imaging
- Differentiate oblique and vertical aerial imagery
- Describe the location and geometric characteristics of the “principal point” of an aerial image
- Recognize the distortions and implications of relief displacement and radial distortion in an aerial image

Topic GD10-2 Platforms and sensors

- Compare common sensors—including LiDAR, and airborne panchromatic and multispectral cameras and scanners—in terms of spatial resolution, spectral sensitivity, ground coverage, and temporal resolution

Topic GD10-3 Aerial image interpretation

- Describe the elements of image interpretation
- Use photo interpretation keys to interpret features on aerial photographs
- Produce a map of land use/land cover classes using a vertical aerial image
- Calculate the nominal scale of a vertical aerial image
- Calculate heights and areas of objects and distances between objects shown in a vertical aerial image

Topic GD10-4 Stereoscopy and orthoimagery

- Explain the relevance of the concept “parallax” in stereoscopic aerial imagery
- Outline the sequence of tasks involved in generating an orthoimage from a vertical aerial photograph
- Evaluate the advantages and disadvantages of photogrammetric methods and LiDAR for production of terrain elevation data
- Specify the technical components of an aerotriangulation system

Topic GD10-5 Vector data extraction

- Describe the source data, instrumentation, and workflow involved in extracting vector data (features and elevations) from analog and digital stereoimagery
- Discuss the extent to which vector data extraction from aerial stereoimagery has been automated
- Discuss future prospects for automated feature extraction from aerial imagery

Topic GD10-6 Mission planning

- Plan an aerial imagery mission in response to a given request for proposals and map of a study area, taking into consideration vertical and horizontal control, atmospheric conditions, time of year, and time of day

Unit GD11 Satellite and shipboard remote sensing (*core unit*)

Satellite-based sensors enable frequent mapping and analysis of very large areas. Many sensing instruments are able to measure electromagnetic energy at multiple wavelengths, including those beyond the visible band. Satellite remote sensing is a key source for regional- and global-scale land use and land cover mapping, environmental resource management, mineral exploration, and global change research. Shipboard sensors employ acoustic energy to determine seafloor depth or to create imagery of the seafloor or water column. The topics included in this unit do not comprise an exhaustive treatment of remote sensing, but they are aspects of the field about which all geospatial professionals should be knowledgeable.

Topic GD11-1 Nature of multispectral image data

- Explain the concepts of spatial resolution, radiometric resolution, and spectral sensitivity
- Draw and explain a diagram that depicts the key bands of the electromagnetic spectrum in relation to the magnitude of electromagnetic energy emitted and/or reflected by the Sun and Earth across the spectrum
- Draw and explain a diagram that depicts the bands in the electromagnetic spectrum at which Earth's atmosphere is sufficiently transparent to allow high-altitude remote sensing
- Illustrate the spectral response curves for basic environmental features (e.g., vegetation, concrete, bare soil)
- Describe an application that requires integration of remotely sensed data with GIS and/or GPS data
- Explain the concept of "data fusion" in relation to remote sensing applications in GIS&T

Topic GD11-2 Platforms and sensors

- Compare and contrast common sensors by spatial resolution, spectral sensitivity, ground coverage, and temporal resolution (e.g., AVHRR, MODIS [intermediate resolution ~500 m, high temporal] Landsat, commercial high resolution [Ikonos and Quickbird]; LIDAR and microwave [Radarsat; SIR-A & -B]; hyperspectral [AVRIS, Hyperion])
- Differentiate between "active" and "passive" sensors, citing examples of each
- Differentiate between "push-broom" and "cross-track" scanning technologies
- Explain the principle of multibeam bathymetric mapping
- Evaluate the advantages and disadvantages of airborne remote sensing versus satellite remote sensing
- Evaluate the advantages and disadvantages of acoustic remote sensing versus airborne or satellite remote sensing for seafloor mapping
- Select the most appropriate remotely sensed data source for a given analytical task, study area, budget, and availability

Topic GD11-3 Algorithms and processing

- Differentiate supervised classification from unsupervised classification
- Produce pseudocode for common unsupervised classification algorithms, including chain method, ISODATA method, and clustering
- Perform a manual unsupervised classification given a two-dimensional array of reflectance values and ranges of reflectance values associated with a given number of land cover categories
- Calculate a set of filtered reflectance values for a given array of reflectance values and a digital image filtering algorithm
- Describe a situation in which filtered data are more useful than the original unfiltered data
- Describe the sequence of tasks involved in the geometric correction of the Advanced Very High Resolution Radiometer (AVHRR) Global Land Dataset
- Compare pixel-based image classification methods with segmentation techniques
- Explain how to enhance contrast of reflectance values clustered within a narrow band of wavelengths
- Describe an application of hyperspectral image data

Topic GD11-4 Ground verification and accuracy assessment

- Explain how U.S. Geological Survey scientists and contractors assess the accuracy of the National Land Cover Dataset
- Evaluate the thematic accuracy of a given soils map

Topic GD11-5 Applications and settings

- Outline a plausible workflow used by MDA Federal (formerly EarthSat) to create the high-resolution GEOCOVER global imagery and GEOCOVER-LC global land cover datasets.
- Outline a plausible workflow for habitat mapping, such as the benthic habitat mapping in the main Hawaiian Islands as part of the NOAA Biogeography program
- Describe how sea surface temperatures are mapped
- Explain how sea surface temperature maps are used to predict El Niño events

Unit GD12 Metadata, standards, and infrastructures (*core unit*)

Governments and businesses alike invest large sums to produce the geospatial data on which much of their operations depend. To maximize returns on these investments, organizations seek to minimize redundancies and facilitate reuse of data resources. One way to achieve efficiencies is to standardize the methods by which organizations encode, structure, document, and exchange geospatial data. See also Unit OI6 Coordinating organizations and Unit GS5 Dissemination of geospatial information.

Topic GD12-1 Metadata

- Define “metadata” in the context of the geospatial data set
- Explain the ways in which metadata increases the value of geospatial data
- Outline the elements of the U.S. geospatial metadata standard
- Interpret the elements of an existing metadata document
- Identify software tools available to support metadata creation
- Use a metadata utility to create a geospatial metadata document for a digital database you created
- Formulate metadata for a graphic output that would be distributed to the general public
- Formulate metadata for a geostatistical analysis that would be released to an experienced audience
- Compose data integrity statements for a geostatistical or spatial analysis to be included in graphic output
- Explain why metadata production should be integrated into the data production and database development workflows, rather than treated as an ancillary activity

Topic GD12-2 Content standards

- Differentiate between a controlled vocabulary and an ontology
- Describe a domain ontology or vocabulary (i.e., land use classification systems, surveyor codes, data dictionaries, place names, or benthic habitat classification system)
- Describe how a domain ontology or vocabulary facilitates data sharing
- Define “thesaurus” as it pertains to geospatial metadata
- Describe the primary focus of the following content standards: FGDC, Dublin Core Metadata Initiative, and ISO 19115
- Differentiate between a content standard and a profile
- Describe some of the profiles created for the Content Standard for Digital Geospatial Metadata (CSDGM)

Topic GD12-3 Data warehouse

- Differentiate between a data warehouse and a database
- Discuss the appropriate use of a data warehouse versus a database
- Differentiate the retrieval mechanisms of data warehouses and databases
- Describe the functions that gazetteers support

Topic GD12-4 Exchange specifications

- Explain the purpose, history, and status of the Spatial Data Transfer Standard (SDTS)
- Describe the characteristics of the Geography Markup Language (GML)
- Identify different levels of information integration
- Identify the level of integration at which the Geography Markup Language (GML) operates
- Describe the geospatial elements of Earth science data exchange specifications, such as the Ecological Metadata Language (EML), Earth Science Markup Language (ESML), and Climate Science Modeling Language (CSML)
- Import data packaged in a standard transfer format to a GIS software package
- Export data from a GIS program to a standard exchange format

Topic GD12-5 Transport protocols

- Explain the relevance of transport protocols to GIS&T
- Describe the characteristics of the Simple Object Access Protocol (SOAP)
- Describe the characteristics of the Z39.50 protocol
- Describe the characteristics of the Open Digital Libraries (ODL) protocol
- Describe the characteristics of the Open Digital Resource Description Framework (RDF) protocol
- Describe the characteristics of the Open-source Project for a Network Data Access Protocol (OPeNDAP)
- Describe the characteristics of the Web Ontology Language (OWL)
- Describe the characteristics of the Global Change Master Directory (GCMD)
- Describe the characteristics of the Web Feature Services (WFS) protocols
- Describe the characteristics of the Web Mapping Services (WMS) protocols
- Describe the characteristics of the Web Catalog Services (WCS) protocols
- Create a service that delivers geospatial data over the Internet using a standard transport protocol
- Create an application that consumes Web services using standards transport protocols

Topic GD12-6 Spatial data infrastructures

- Explain the vision, history, and status of the U.S. National Spatial Data Infrastructure
- Explain the vision, history, and status of the U.S. National Map
- Compare and contrast U.S. initiatives to European geographic information infrastructures
- Explain the vision, history, and status of the Global Spatial Data Infrastructure
- Obtain data from a spatial data infrastructure for a particular application

GD Key readings

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Knowledge Area: GIS&T and Society (GS)

Geographic Information Science and Technology exists to serve the society, but it is not a panacea. The history of its development is the sum of fragmented efforts, which have still not been fully integrated. Its potential benefits are often constrained and its potential impacts are not fully understood.

Institutional and economic factors limit access to data, technology, and expertise by some of those who need it to make better decisions. Political, ideological, and personal issues aside, organizations invest in GIS&T when estimated benefits outweigh estimated costs. Evaluating costs and benefits is difficult, however, and too often leads to nothing being done. For some individuals and groups, costs are prohibitive even though potential benefits are compelling.

The legal framework provides a structure for regulating a number of key aspects of geographic information science, technology, and applications. Legal regimes determine who can claim the exclusive right to hold and use geospatial data, the conditions under which others may have access to the data, and what subsequent uses are permitted. Political struggles arise from conflicting proprietary and public interests about who benefits from geospatial information, and how the power to allocate the use of this information is, or should be, distributed among members of a society. The need to choose among conflicting interests sometimes poses ethical dilemmas for GIS&T professionals.

Because so many public agencies and private organizations rely upon GIS&T for planning, decision-making, and management, GIS&T increasingly affects and is used to direct daily life. Critical approaches to understanding the role of GIS in society equip practitioners to employ GIS&T reflectively. The critical approach specifically questions the assumptions and premises that underlie the economic, legal, and political regimes and institutional structures within which GIS&T is implemented. Related concerns are considered in Knowledge Area OI: Organizational and Institutional Aspects.

Unit GS1 Legal aspects

Legal problems can arise when geospatial information is used for land management, among other activities. Geospatial professionals may be liable for harm that results from flawed data or the misuse of data. Understanding of contract law and liability standards is essential to mitigate risks associated with the provision of geospatial information products and services.

Topic GS1-1 The legal regime

- Discuss ways in which the geospatial profession is regulated under the U.S. legal regime
- Compare and contrast the relationship of the geospatial profession and the U.S. legal regime with similar relationships in other countries

Topic GS1-2 Contract law

- Differentiate “contracts for service” from “contracts of service”
- Identify the liability implications associated with contracts
- Discuss potential legal problems associated with licensing geospatial information

Topic GS1-3 Liability

- Describe the nature of tort law generally and nuisance law specifically
- Differentiate among contract liability, tort liability, and statutory liability
- Describe cases of liability claims associated with misuse of geospatial information, erroneous information, and loss of proprietary interests
- Describe strategies for managing liability risk, including disclaimers and data quality standards

Topic GS1-4 Privacy

- Discuss the status of the concept of privacy in the U.S. legal regime
- Explain how data aggregation is used to protect personal privacy in data produced by the U.S. Census Bureau
- Explain how conversion of land records data from analog to digital form increases risk to personal privacy
- Compare and contrast geographic information technologies that are privacy-invasive, privacy-enhancing, and privacy-sympathetic
- Explain the argument that human tracking systems enable “geoslavery”

Unit GS2 Economic aspects

Most organizations insist that investments in GIS&T be justified in economic terms. Quantifying the value of information, and of information systems, however, is not a straightforward matter.

Topic GS2-1 Economics and the role of information

- Discuss the general role of information in economics
- Describe the role of economics in public and private production of geospatial information
- Describe the role of economics in the use of geospatial information

Topic GS2-2 Valuing and measuring benefits

- Distinguish between operational, organizational, and societal activities that rely upon geospatial information
- Identify practical problems in defining and measuring the value of geospatial information in land or other business decisions
- Describe the potential benefits of geospatial information in terms of efficiency, effectiveness, and equity
- Explain how cost-benefit analyses can be manipulated
- Compare and contrast the evaluation of benefits at different scales (e.g., national, regional/state, local)

Topic GS2-3 Models of benefits

- Describe recent models of the benefits of GIS&T applications
- Discuss the extent to which external costs and benefits enhance the economic case for GIS
- Explain how profit considerations have shaped the evolution of GIS&T
- Outline the elements of a business case that justifies an organization's investment in an enterprise geospatial information infrastructure

Topic GS2-4 Agency, organizational, and individual perspectives

- Describe perspectives on the nature and scope of system benefits among agency officials, organizational personnel, and citizens
- Discuss implications of unequal economic power on the kinds of organizations that use, and benefit from, GIS&T

Topic GS2-5 Measuring costs

- Explain how the saying “developing data is the largest single cost of implementing GIS” could be true for an organization that is already collecting data as part of its regular operations
- Outline the categories of costs that an organization should anticipate as it plans to design and implement a GIS
- Outline sources of additional costs associated with development of an enterprise GIS
- Describe some non-fiduciary barriers to GIS implementation
- Summarize what the literature suggests as means for overcoming some of the non-fiduciary barriers to GIS implementation

Unit GS3 Use of geospatial information in the public sector

Government agencies at local, state, and federal levels produce and use geospatial data for many activities, including provision of social services, public safety (police, fire, and E911), economic development, environmental management, and national defense. Public participation in governing, empowered by geospatial technologies, offers the potential to strengthen democratic societies by involving grassroots community organizations and by engaging local knowledge.

Topic GS3-1 Uses of geospatial information in government

- List and describe the types of data maintained by local, state, and federal governments
- Describe how geospatial data are used and maintained for land use planning, property value assessment, maintenance of public works, and other applications
- Explain the concept of a “spatial decision support system”
- Explain how geospatial information might be used in a taking of private property through a government's claim of its right of eminent domain

Topic GS3-2 Public participation in governing

- Differentiate among universal/deliberative, pluralist/representative, and participatory models of citizen participation in governing
- Compare the advantages and disadvantages of group participation and individual participation

- Describe the six “rungs” of increasing participation in governmental decision-making that constitute a “ladder” of public participation
- Describe the range of spatial scales at which community organizations operate
- Describe an example of “local knowledge” that is unlikely to be represented in the geospatial data maintained routinely by government agencies
- Defend or refute the argument that local knowledges are contested
- Explain how community organizations represent the interests of citizens, politicians, and planners
- Explain and respond to the assertion that “capturing local knowledge” can be exploitative
- Explain how legislation such as the Community Reinvestment Act of 1977 provides leverage to community organizations

Topic GS3-3 Public participation GIS

- Explain how geospatial technologies can assist community organizations at each rung of the ladder of public participation
- Explain why some community organizations may encounter more difficulty than others in acquiring geospatial data from public and private organizations
- Explain how community organizations’ use of geospatial technologies can alter existing community power relations
- Critique the assertion that public participation GIS promotes democracy
- Explain the challenge of representing within current GIS software local knowledge that is neither easily mapped nor verified
- Discuss advantages and disadvantages of six models of GIS availability, including community-based GIS, university-community partnerships, GIS facilities in universities and public libraries, “Map rooms,” Internet map servers, and neighborhood GIS centers.

Unit GS4 Geospatial information as property

The nature of information in general, and the characteristics of geospatial information in particular, make it an unusual and difficult subject for a legal regime that seeks to establish and enforce the type of exclusive control associated with other commodities. Geospatial information is in many ways unlike the kinds of works that intellectual property rights were intended to protect. Still, organizations can, and do, assert proprietary interests in geospatial information. Perspectives on geospatial information as property vary between the public and private sectors and between different countries.

Topic GS4-1 Property regimes

- Explain the legal concept “property regime”
- Describe organizations’ and governments’ incentives to treat geospatial information as property
- Argue for and against the treatment of geospatial information as a commodity
- Outline arguments for and against the notion of information as a public good
- Compare and contrast the U.S. federal government’s policy regarding rights to geospatial data with similar policies in other countries
- Compare and contrast the consequences of different national policies about rights to geospatial data in terms of the real costs of spatial data, their coverage, accuracy, uncertainty, reliability, validity, and maintenance

Topic GS4-2 Mechanisms of control of geospatial information

- Distinguish among the various intellectual property rights, including copyright, patent, trademark, business methods, and other rights
- Differentiate geospatial information from other works protected under copyright law
- Explain how maps may be protected under U.S. copyright law
- Explain how databases may be protected under U.S. copyright law
- Describe advantages and disadvantages of “open” alternatives to copyright protection, such as the Creative Commons
- Outline the intellectual property protection clause of a contract that a local government uses to license geospatial data to a community group

Topic GS4-3 Enforcing control

- Explain the concept of “fair use” with regard to geospatial information
- Identify types of copyright infringement
- Describe defenses against various claims of copyright infringement
- Discuss ways in which copyright infringements may be remedied

Unit GS5 Dissemination of geospatial information

Geospatial data are abundant, but access to data varies with the nature of the data, who wishes to acquire it and for what purpose, under what conditions, and at what price. Legal relations between public and private organizations and individuals govern data access. Complementary units in other Knowledge Areas include Unit GD12 Data standards and infrastructures, and Units OI5 Institutional and inter-intuitional aspects and OI6 Coordinating organizations.

Topic GS5-1 Incentives and barriers to sharing geospatial information

- Describe political, economic, administrative, and other social forces in agencies, organizations, and citizens that inhibit or promote sharing of geospatial and other data

Topic GS5-2 Data sharing among public and private agencies, organizations, and individuals

- Describe formal and informal arrangements that promote geospatial data sharing (e.g., FGDC, ESDI, memoranda of agreements, informal access arrangements, targeted funding support)
- Describe a situation in which politics interferes with data sharing and exchange

Topic GS5-3 Legal mechanisms for sharing geospatial information

- Describe contracts, licenses, and other mechanisms for sharing geospatial data
- Outline the terms of a licensing agreement with a local engineering consulting firm that a manager of a county government GIS office would employ if charged to recoup revenue through sale and licensure of county data

Topic GS5-4 Balancing security and open access to geospatial information

- Discuss the way that a legal regime balances the need for security of geospatial data with the desire for open access

Unit GS6 Ethical aspects of geospatial information and technology (*core unit*)

Ethics provide frameworks that help individuals and organizations make decisions when confronted with choices that have moral implications. Most professional organizations develop codes of ethics to help their members do the right thing, preserve their good reputation in the community, and help their members develop as a community.

Topic GS6-1 Ethics and geospatial information

- Describe a variety of philosophical frameworks upon which codes of professional ethics may be based
- Discuss the ethical implications of a local government's decision to charge fees for its data
- Describe a scenario in which you would find it necessary to report misconduct by a colleague or friend
- Describe the individuals or groups to which GIS&T professionals have ethical obligations

Topic GS6-2 Codes of ethics for geospatial professionals

- Compare and contrast the ethical guidelines promoted by the GIS Certification Institute (GISCI) and the American Society for Photogrammetry and Remote Sensing (ASPRS)
- Describe the sanctions imposed by ASPRS and GISCI on individuals whose professional actions violate the codes of ethics
- Explain how one or more obligations in the GIS Code of Ethics may conflict with organizations' proprietary interests
- Propose a resolution to a conflict between an obligation in the GIS Code of Ethics and organizations' proprietary interests

Unit GS7 Critical GIS

Many of the educational objectives used to define topics in this knowledge area, and in the *Body of Knowledge* as a whole, challenge educators and students to think critically about GIS&T. Since the 1990s, scholars have criticized GIS&T from a wide range of perspectives. Common among these critiques are questioned assumptions about the purported benefits of GIS&T and attention to its unexamined risks. By promoting reflective practice among current and aspiring GIS&T professionals, an understanding of the range of critical perspectives increases the likelihood that GIS&T will fulfill its potential to benefit all stakeholders. Philosophical, psychological, and social underpinnings of these critiques are considered in Knowledge Area CF: Conceptual Foundations.

Topic GS7-1 Epistemological critiques

- Explain the argument that GIS privileges certain views of the world over others
- Identify alternatives to the “algorithmic way of thinking” that characterizes GIS
- Discuss critiques of GIS as “deterministic” technology in relation to debates about the Quantitative Revolution in the discipline of geography
- Describe the extent to which contemporary GIS&T supports diverse ways of understanding the world
- Discuss the implications of interoperability on ontology

Topic GS7-2 Ethical critiques

- Defend or refute the argument that GIS&T professionals are culpable for applications that result in civilian casualties in warfare
- Defend or refute the argument that the “digital divide” that characterizes access to GIS&T perpetuates inequities among developed and developing nations, among socio-economic groups, and between individuals, community organizations, and public agencies and private firms
- Discuss the ethical implications of the use of GIS&T as a surveillance technology

Topic GS7-3 Feminist critiques

- Defend or refute the contention that the masculinist culture of computer work in general, and GIS work in particular, perpetuates gender inequality in GIS&T education and training and occupational segregation in the GIS&T workforce
- Explain the argument that GIS and remote sensing foster a “disembodied” way of knowing the world
- Discuss the potential role of agency (individual action) in resisting dominant practices and in using GIS&T in ways that are consistent with feminist epistemologies and politics

Topic GS7-4 Social critiques

- Explain the argument that, throughout history, maps have been used to depict social relations
- Explain how a tax assessor’s office adoption of GIS&T may affect power relations within a community
- Discuss the production, maintenance, and use of geospatial data by a government agency or private firm from the perspectives of a taxpayer, a community organization, and a member of a minority group
- Explain the argument that GIS is “socially constructed”
- Describe the use of GIS from a political ecology point of view (e.g., consider the use of GIS for resource identification, conservation, and allocation by an NGO in Sub-Saharan Africa)
- Defend or refute the contention that critical studies have an identifiable influence on the development of the information society in general and GIScience in particular

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Knowledge Area: Organizational and Institutional Aspects (OI)

This knowledge area considers the management of geographic information systems (GIS)—including hardware, software, data, and workforce—within and among private and public organizations. Mastery of the educational objectives in this knowledge area requires complementary competencies in the allied field of business administration. Also considered are local, national, and international organizations concerned with the coordination and effectiveness of GIS&T. The success of these organizations in helping to fulfill the potential of GIS&T to improve the quality of life depends upon the participation and cooperation of GIS&T professionals and the public. The knowledge area begins with a consideration of the emergence of GIS&T as a distinct community of practice.

This knowledge area uses the term “GIS” to refer to a particular, semi-closed system of hardware, software, people, and business rules, such as an enterprise GIS. Related topics are considered in Knowledge Area GS: GIS&T in Society and Knowledge Area DA: Design Aspects.

Unit OI1 Origins of GIS&T

Though the conceptual foundations of GIS&T originated much earlier, GIS emerged as a distinct technology less than fifty years ago. GIS&T is still only just becoming a coherent field. Practitioners’ awareness of the historical roots of their field contributes to its coherence and advancement.

Topic OI1-1 Public sector origins

- Identify some of the key federal agencies and programs that provided the impetus for the development of GIS&T
- Describe the role of NASA and the Landsat program in promoting development of digital image processing and raster GIS systems
- Explain how the federalization of land management in Canada led to the development of the Canadian Geographic Information System in the 1960s
- Discuss the role of the U.S. Census Bureau in contributing to the development of the U.S. geospatial industry
- Discuss the role of the U.S. Geological Survey in contributing to the development of the U.S. geospatial industry
- Describe the mechanical and computerized technologies used by civilian and military mapping agencies between World War II and the advent of GIS
- Trace the history of the relationship between the intelligence community and the geospatial industry
- Compare and contrast the initiatives of various countries to move their national mapping activities to geospatial data

Topic OI1-2 Private sector origins

- Identify some of the key commercial activities that provided an impetus for the development of GIS&T
- Discuss the emergence of the GIS software industry in terms of technology evolution and markets served by firms such as ESRI, Intergraph, and ERDAS

- Describe the influence of evolving computer hardware and of private sector hardware firms such as IBM on the emerging GIS software industry
- Describe the contributions of McHarg and other practitioners in developing geographic analysis methods later incorporated into GIS
- Evaluate the correspondence between advances in hardware and operating system technology and changes in GIS software
- Differentiate the dominant industries using geospatial technologies during the 1980s, 1990s, and 2000s

Topic OI1-3 Academic origins

- Identify the key academic disciplines that contributed to the development of GIS&T
- Discuss the contributions of early academic centers of GIS&T research and development (e.g., Harvard Laboratory for Computer Graphics, UK Experimental Cartography Unit)
- Evaluate the role that the Quantitative Revolution in geography played in the development of GIS
- Describe the major research foci in GIS and related fields in the 1970s, 1980s, 1990s, and 2000s
- Evaluate the importance of the NCGIA and UCGIS in coalescing GIScience as a sub-field of GIS&T

Topic OI1-4 Learning from experience

- Explain how knowledge of the history of the development of enterprise GIS can aid in an implementation process
- Discuss the evolution of isolated GIS projects to enterprise GIS
- Evaluate case studies of past GISs to identify factors leading to success and failure

Topic OI1-5 Future trends

- Identify future trends in computer science and information technology as they relate to GIS designs in organizations
- Assess the impact of technology convergence, such as spatial technologies with Web services, wireless, and grid computing
- Utilize resources (e.g., conferences, journals) to keep up to date on ongoing research in developing enterprise and intra-organizational GISs
- Discuss the evolution of enterprise GIS toward integrated business applications within, across, and between organizations
- Discuss the impact of the Internet on the geospatial industry since the mid-1990s
- Evaluate the possible implications of technologies (e.g., Google Earth, Microsoft Live Local, vehicle navigation systems) in popularizing GIS&T

Unit O2 Managing GIS operations and infrastructure

This unit addresses the main tasks and issues involved in managing GIS operations and infrastructure across an organization. The emphasis is on understanding basic approaches and models and adapting them appropriately to a specific organization and its GIS&T needs and activities. This unit is closely related to Units DA2 Project definition, DA3 Resource planning, and DA7 System implementation, which cover the initial budgeting and management tasks during the design and implementation of GIS. This is also closely related to Unit GS2 Economic aspects.

Topic OI2-1 Managing GIS operations and infrastructure

- Calculate the estimated schedule required to carry out all of the implementation steps for an enterprise GIS of a given size
- Describe the components of a needs assessment for an enterprise GIS
- Exemplify each component of a needs assessment for an enterprise GIS
- Indicate the possible justifications that can be used to implement an enterprise GIS
- List some of the topics that should be addressed in a justification for implementing an enterprise GIS (e.g., return on investment, workflow, knowledge sharing)

Topic OI2-2 Ongoing GIS revision

- Describe a method that allows users within an organization to access data, including methods of data sharing, version control, and maintenance
- Describe how internal spatial data sources can be handled during an implementation process
- Describe how spatial data and GIS&T can be integrated into a work flow process
- Develop a plan for user feedback and self-evaluation procedures
- Evaluate how external spatial data sources can be incorporated into the business process
- Evaluate internal spatial databases for continuing adequacy
- Evaluate the efficiency and effectiveness of an existing enterprise GIS
- Evaluate the needs for spatial data sources including currency, accuracy and access, specifically addressing issues related to financial costs, sharing arrangements, online/realtime, and transactional processes across an organization
- Illustrate how a business process analysis can be used to periodically review system requirements
- List improvements that may be made to the design of an existing GIS

Topic OI2-3 Budgeting for GIS management

- Describe various approaches to the long-term funding of a GIS in an organization
- Describe methods to evaluate the return on investment (ROI) of a GIS within an organization
- Develop a budget for ongoing re-design and system improvement
- Discuss the advantages and disadvantages of maintenance contracts for software, hardware, and data across an enterprise
- Evaluate the adequacy of current investments in capital (e.g., facilities, hardware, software) and labor for a GIS
- Justify changes to the investment in an enterprise GIS, including both cutbacks and increased expenses

Topic OI2-4 Database administration

- Describe how using standards can affect implementation of a GIS
- Describe effective methods to get stakeholders to create, adopt, or develop and maintain meta-data for shared datasets
- Explain how validation and verification processes can be used to maintain database integrity
- Summarize how data access processes can be a factor in development of an enterprise GIS implementation

Topic OI2-5 System management

- Demonstrate how the way people do their jobs can affect system management
- Describe how system management includes understanding people
- Describe methods for articulating user needs to internal technical support staff

Topic OI2-6 User support

- Develop a plan to provide user support to aid in the implementation process
- Illustrate how the failure of successfully engaging user support can affect the outcome of a GIS implementation project

Unit OI3 Organizational structures and procedures

GIS&T implementation and use within an organization often involves a variety of participants, stakeholders, users, and applications. Organizational structures and procedures address methods for developing, managing, and coordinating these multi-purpose, multi-user GISs and programs. Although topics refer to structures, the related procedures are equally important.

Topic OI3-1 Organizational models for GIS management

- Analyze how using GIS&T as an integrating technology affects different models of management
- Describe how GIS&T can be used in the decision-making process in organizations dealing with natural resource management, business management, public management, or operations management
- Differentiate an enterprise system from a department-centered GIS
- Explain how GIS&T can be an integrating technology
- Illustrate what functions a support or service center can provide to an organization using GIS&T

Topic OI3-2 Organizational models for coordinating GISs and/or program participants and stakeholders

- Describe the stages of two different models of implementing a GIS within an organization
- Describe different organizational models for coordinating GIS&T participants and stakeholders
- Compare and contrast centralized, federated, and distributed models for managing information infrastructures
- Describe the roles and relationships of GIS&T support staff
- Exemplify how to make GIS&T relevant to top management

Topic OI3-3 Integrating GIS&T with management information systems (MIS)

- Compare and contrast the prototypical corporate cultures of a MIS department and a GIS department
- Compare and contrast the readiness of GIS&T professionals to learn MIS skills versus the readiness of MIS professionals to learn GIS&T skills
- Describe the issues to consider when integrating with MIS in relation to personnel, hardware, software, and data
- Draw conclusions from previous cases of GIS&T and MIS integration, including successes and failures
- Make a business case for or against integrating GIS&T and MIS in the context of a particular organization

Unit OI4 GIS&T workforce themes

This unit addresses GIS&T staff and workforce issues within an organization, particularly as they relate to ensuring that GIS&T is appropriately used and supported. Related GIS&T professional issues are addressed in Knowledge Area GS: GIS&T in Society.

Topic OI4-1 GIS&T staff development

- Describe issues that may hinder implementation and continued successful operation of a GIS if effective methods of staff development are not included in the process
- Outline methods (programs or processes) that provide effective staff development opportunities for GIS&T

Topic OI4-2 GIS&T positions and qualifications

- Describe the differences between licensing, certification, and accreditation in relation to GIS&T positions and qualifications
- Discuss the status of professional and academic certification in GIS&T
- Discuss how a code of ethics might be applied within an organization
- Explain why it has been difficult for many agencies and organizations to define positions and roles for GIS&T professionals
- Identify the qualifications needed for a particular GIS&T position
- Identify the standard occupational codes that are relevant to GIS&T

Topic OI4-3 GIS&T training and education

- Compare and contrast training methods utilized in a non-profit to those employed in a local government agency
- Discuss different formats (tutorials, in house, online, instructor lead) for training and how they can be used by organizations
- Discuss the National Research Council report on *Learning to Think Spatially* (2005) as it relates to spatial thinking skills needed by the GIS&T workforce
- Find or create training resources appropriate for GIS&T workforce in a local government organization
- Identify the particular skills necessary for users to perform tasks in three different workforce domains (e.g., small city, medium county agency, a business, or others)
- Illustrate methods that are effective in providing opportunities for education and training when implementing a GIS in a small city
- Teach necessary skills for users to successfully perform tasks in an enterprise GIS

Topic OI4-4 Incorporating GIS&T into existing job classifications

- Explain how resistance to change and the need to standardize operations when trying to incorporate GIS&T can promote inclusion into existing job classifications
- Illustrate how methods for overcoming resistance to change can aid implementation of a GIS
- Select two effective methods of overcoming resistance to change

Unit OI5 Institutional and inter-institutional aspects (*core unit*)

As GIS&T use extends beyond the traditional in-house data warehouses and Web services (within one organization), the fuzzy boundary between formal and informal organizations and inter-institutional use will have societal and ethical implications within and beyond each organization (related issues are covered in Knowledge Area GS: GIS&T in Society).

Topic OI5-1 Spatial data infrastructures

- Explain how clearing houses, metadata, and standards can help facilitate spatial data sharing
- Explain how privacy and commoditization of data impact decisions regarding spatial data infrastructures

Topic OI5-2 Adoption of standards

- Compare and contrast the impact effect of time for developing consensus-based standards with immediate operational needs
- Explain how resistance to change affects the adoption of standards in an organization coordinating a GIS
- Explain how a business case analysis can be used to justify the expense of implementing consensus-based standards
- Identify organizations that focus on developing standards related to GIS&T
- Identify standards that are used in GIS&T

Topic OI5-3 Technology transfer

- Explain how an understanding of use of current and proposed technology in other organizations can aid in implementing a GIS

Topic OI5-4 Spatial data sharing among organizations

- Describe the rationale for and against sharing data among organizations
- Describe methods used by organizations to facilitate data sharing
- Describe the barriers to information sharing

Topic OI5-5 Openness

- Assess the status of openness in the GIS&T field
- Differentiate “open standards,” “open source,” and “open systems”
- Discuss the advantages and disadvantages of adopting open systems in the context of a local government
- In the role of a consultant or chief information officer, respond to a client's or colleague's question about the future prospects of open standards and systems in GIS&T

Topic OI5-6 Balancing data access, security, and privacy

- Assess the effect of restricting data in the context of the availability of alternate sources of data
- Exemplify areas where post-9/11 changes in policies have restricted or expanded data access

Topic OI5-7 Implications of distributed GIS&T

- Describe the advantages and disadvantages to an organization in using GIS portal information from other organizations
- Describe how inter-organization GIS portals may impact or influence issues related to social equity, privacy and data access
- Discuss how distributed GIS&T may affect the nature of organizations and relationships among institutions
- Suggest the possible societal and ethical implications of distributed GIS&T

Topic OI5-8 Inter-organizational and vendor GISs (software, hardware, and systems)

- Describe the advantages and disadvantages to an organization in using GIS portal information from other organizations or entities (private, public, non-profit)
- Describe how inter-organization GIS portals may impact issues related to social equity, privacy, and data access
- Discuss the mission, history, constituencies, and activities of user conferences hosted by software vendors
- Discuss the roles traditionally performed by software vendors in developing professionals in GIS&T
- Discuss the history of major geospatial-centric companies, including software, hardware, and data vendors

Unit OI6 Coordinating organizations (national and international) (core unit)

A number of organizations (public, private, and non-profit) exist to coordinate, inform, and support geospatial activities of professionals and entities using GIS&T. Informed geospatial professionals and organizations are familiar with the mission, history, constituencies, modes of operation, products, and levels of success of these organizations.

Topic OI6-1 Federal agencies and national and international organizations and programs

- Describe the data programs provided by organizations such as The National Map, GeoSpatial One Stop, and National Integrated Land System
- Discuss the mission, history, constituencies, and activities of international organizations such as Association of Geographic Information Laboratories for Europe (AGILE) and the European GIS Education Seminar (EUGISES)
- Discuss the mission, history, constituencies, and activities of governmental entities such as the Bureau of Land Management (BLM), United States Geological Survey (USGS) and the Environmental Protection Agency (EPA) as they related to support of professionals and organizations involved in GIS&T
- Discuss the mission, history, constituencies, and activities of GeoSpatial One Stop
- Discuss the mission, history, constituencies, and activities of the Open Geospatial Consortium (OGC), Inc.
- Discuss the mission, history, constituencies, and activities of the Nation Integrated Land System (NILS)
- Discuss the mission, history, constituencies, and activities of the Federal Geographic Data Committee (FGDC)

- Discuss the mission, history, constituencies, and activities of the National Academies of Science Mapping Science Committee
- Discuss the mission, history, constituencies, and activities of the USGS and its National Map vision
- Discuss the mission, history, constituencies, and activities of University Consortium of Geographic Information Science (UCGIS) and the National Center for Geographic Information and Analysis (NCGIA)
- Discuss the political, cultural, economic, and geographic characteristics of various countries that influence their adoption and use of GIS&T
- Identify National Science Foundation (NSF) programs that support GIS&T research and education
- Outline the principle concepts and goals of the “digital earth” vision articulated in 1998 by Vice President Al Gore
- Assess the current status of Gore’s “digital earth”

Topic OI6-2 State and regional coordinating bodies

- Describe how state GIS councils can be used in enterprise GIS&T implementation processes
- Determine if your state has a Geospatial Information Office (GIO) and discuss the mission, history, constituencies, and activities of a GIO
- Discuss how informal and formal regional bodies (e.g., Metro GIS) can help support GIS&T in an organization
- Discuss the mission, history, constituencies, and activities of National States Geographic Information Council (NSGIC)
- Explain the functions, mission, history, constituencies, and activities of your state GIS Council and related formal and informal bodies

Topic OI6-3 Professional organizations

- Compare and contrast the missions, histories, constituencies, and activities of professional organizations including Association of American Geographers (AAG), America Society for Photogrammetry and Remote Sensing (ASPRS), Geospatial Information and Technology Association (GITA), Management Association for Private Photogrammetric Surveyors (MAPPS), and Urban and Regional Information Systems Association (URISA)
- Discuss the mission, history, constituencies, and activities of the GIS Certification Institute (GISCI)
- Identify conferences that are related to GIS&T hosted by professional organizations

Topic OI6-4 Publications

- Describe the leading academic journals serving the GIS&T community
- Develop a bibliography of scholarly and professional articles and/or books that are relevant to a particular GIS&T project
- Select association and for-profit journals that are useful to entities managing enterprise GISs
- Select and describe the leading trade journals serving the GIS&T community

Topic OI6-5 The geospatial community

- Describe possible benefits to an organization by participating in a given society that is related to GIS&T

- Discuss the value or effect of participation in societies, conferences, and informal communities to entities managing enterprise GIS
- Identify conferences that are related to GIS&T

Topic OI6-6 The geospatial industry

- Assess the involvement of non-GIS companies (e.g., Microsoft, Google) in the geospatial industry
- Describe the U.S. geospatial industry including vendors, software, hardware and data
- Describe three applications of geospatial technology for different workforce domains (e.g., first responders, forestry, water resource management, facilities management)
- Explain why software products sold by U.S. companies may predominate in foreign markets, including Europe and Australia

OI Key readings

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VI Where is the UCGIS Model Curricula project headed?

Evolution of GIS&T

The GIS&T domain (Figure 1) is dynamic. National priorities related to homeland security, emergency management, geospatial intelligence, and health, among others, will continue to drive innovative research and development in GIS&T. The vigor of the Geographic Information Science community is evident in the quantity and quality of its contributions to scholarly publications, in the popularity of its specialist conferences, and in the activities of its professional societies. Meanwhile, civilian applications for GPS and location-based services are creating a mass market for geospatial information technology, even as the demand for innovative technologies and analytical techniques continues to increase among government agencies and private enterprises. Applications of GIS&T are increasingly diverse, increasingly critical to organizational missions, and increasingly tightly integrated with organizations' information infrastructures. Applications will continue to drive innovation, to fuel demand for GIS&T products and services, and to pose new ethical challenges for GIS&T professionals and the public. The body of knowledge that comprises the GIS&T domain is a moving target.

Evolution of the GIS&T education infrastructure

The GIS&T education infrastructure will continue to struggle with challenges of recruitment, of capacity, and of effectiveness. Recruiting the next generation of scientists, technologists, and engineers is an urgent priority for the GIS&T domain, as it is in allied fields. The increasing visibility of GIS&T on television, in video games, and on the Internet (e.g., Google Earth), combined with the current promotional campaign sponsored by the U.S. Department of Labor, may raise awareness of the excitement and power of GIS&T, and of associated career opportunities. The National Academies of Science report *Learning to Think Spatially* may succeed in raising the profile of GIS&T in primary and secondary school curricula and vocational programs. If so, the numbers of students seeking baccalaureate degrees with specializations in GIS&T may increase. The earlier students are exposed to informal and formal GIS&T

education, the more likely they will be prepared to contribute to the GIS&T enterprise at high levels as graduates.

Current federal government investments in two-year institutions seem likely to increase the capacity of the GIS&T education infrastructure to train and re-train GIS&T professionals. At the same time, however, decreasing public support for higher education makes it more difficult for many four-year institutions to respond to the expected increased demand for baccalaureate, graduate, and postbaccalaureate/ professional education in GIS&T. While baccalaureate degree programs with specializations in GIS&T seem likely to remain an important mechanism for preparing the future GIS&T workforce, the need to support continuing professional development through practice-oriented certificate and degree programs is also essential. To some extent, the ability of colleges and universities to realize new sources of revenue from continuing professional development programs will affect their ability to expand and enrich their core undergraduate programs. Accredited and non-accredited for-profit enterprises seem poised to supply some of the additional capacity that non-profit institutions are unable to provide.

The increasing sophistication of geospatial technologies and applications, and the resulting demands placed upon the GIS&T workforce, pose implications for U.S. national security and competitiveness in global information economy. The next generation of GIS&T scientists, technologists, and users will need to possess higher levels of analytical and technical competencies, as well as business and interpersonal competencies, than ever before. Education and training providers of all kinds will be challenged to strengthen both the breadth and depth of their offerings, while also accommodating the needs of older and busier clientele. And as educational outcomes are recognized as critical to society, calls for greater accountability are sure to follow. The demand for professional certification is already established; demand for more rigorous, competency-based certification may follow. Accreditation of academic programs is planned for geospatial intelligence certificate programs; if successful, it is not unreasonable to expect that similar initiatives will follow in other communities of practice.

In the future, the effectiveness of GIS&T education infrastructure may have less to do with the success of individual programs and institutions, and more to do with successful institutional collaborations. Consortia that enable students and advisors to design individualized curricular pathways that traverse collections of courses offered by multiple institutions – both online and in the classroom – may emerge as one way to increase the capacity and potency of GIS&T education infrastructure. A comparable student exchange initiative, called Erasmus, is already underway in Europe, and alliances like the UNIGIS and the Worldwide Universities Network have begun to foster “virtual” student-sharing partnerships among institutions based in the U.S., Europe, and beyond.

The Model Curricula vision remains relevant to the evolving GIS&T education infrastructure. A frequently revised *GIS&T Body of Knowledge*, as well as specifications of the curricular pathways that were envisioned in 2003 “Strawman Report,” will be needed to help educational institutions respond to needs of the dynamic GIS&T enterprise, and to facilitate relationships that lead to a more integrated and synergistic GIS&T education infrastructure. The following section outlines a series of practicable activities to

follow this publication of the *Body of Knowledge* that the editors believe will continue to advance the Model Curricula vision.

Future Model Curricula products and services

Program self-assessment: A self-assessment instrument for GIS&T certificate and degree programs should be derived from the *Body of Knowledge* (and with reference to the Geospatial Technology Competency Model for business and interpersonal competencies) in relatively short order. The editors recommend that such an instrument be developed in the near future, and that a sample of educators, trainers, and others who represent a variety of GIS&T application areas, be entrained to perform program assessments as soon as possible. Assessment results and implications for the GIS&T curriculum design and the Model Curricula project might be discussed in a subsequent sponsored workshop that informs improvements to the assessment process. The result of this activity could be a rigorous and transferable methodology for assessing strengths and weaknesses of existing GIS&T programs, for guiding curricular revisions, and for informing faculty hiring procedures. To the extent that is adopted by undergraduate institutions, the methodology has the potential to advance the Model Curricula vision by promoting reflective approaches to GIS&T curriculum development and maintenance.

Resources for professional certification and accreditation initiatives: The draft *Body of Knowledge* presented in the 2003 “Strawman Report” has been used to judge the eligibility of educational achievement point claims by applicants to Geographic Information Systems Certification Institute (GISCI). The editors recommend that the UCGIS Education Committee consult with GISCI as soon as possible to revise its procedures with reference to the first edition of the *GIS&T Body of Knowledge*. The *Body of Knowledge* could also serve as a basis for a test (or family of tests) that could be used to increase rigor of certification programs. The *Body of Knowledge* should also be recommended to ASPRS, for potential use in its Certified Mapping Scientist and Technologist programs, and to USGIF, to inform the accreditation standards and curriculum guidelines it is developing for geospatial intelligence certificate programs.

Exemplar pathways: The “Strawman Report” stated that a priority of the Model Curricula project is “to identify in some depth the various paths that individuals can take through the undergraduate portion of the GIS&T curricula” (Marble et al., 2003, p. 27). Given the variety of institutional circumstances in the undergraduate sector of the GIS&T education infrastructure, it may not be practical to specify a comprehensive set of paths in a timely fashion. It should be possible, however, to compile a set of exemplar pathways based on the experiences of a representative sample of U.S. undergraduate programs. The process might involve selection and recruitment of representative institutions, followed by program self-assessment as sketched above, and should result in an edited volume of essays that describe exemplar pathways leading to a range of educational outcomes. The recommended target date for this publication is 2010.

Second edition of the *GIS&T Body of Knowledge*: A field as dynamic as GIS&T demands frequent revision of its *Body of Knowledge*. Beginning with release of the complete draft manuscript in November

2005, the editors solicited comments from Advisory Board reviewers as well as from members of the GIS&T community at large. The editors suggest that a new editorial team or Task Force be empanelled within two years to consider methodologies for critique and revision that would lead to a second edition no later than 2012. (A six-year lag is comparable to the average period between the five editions of the Computer Science curricula from 1969-2005.) The editors also recommend that the Education Committee invite GISCI's and ASPRS' help in attracting greater participation from the practitioner community that is represented by certified geographic information systems professionals (GISPs) and certified mapping scientists and technologists.

Editors of future editions of the *Body of Knowledge* may wish to reconsider the conventional hierarchical outline structure that the first edition adopted from allied fields. One weakness of the hierarchical outline is that it tends to mask relationships and reoccurrences of topics in different knowledge areas. The "cross-cutting themes" idea presented in the "Strawman Draft" was one tactic for dealing with this shortcoming. The field of information visualization offers an intriguing alternative. A more powerful approach may be to construct a formal knowledge domain visualization (Hook and Börner, 2005) that represents not only the topics that comprise the GIS&T domain, but also relationships among topics. Although "knowledge maps" are typically rendered from bibliometric data, it would seem that transformation of the community-developed inventory of the domain may be an insightful exercise. Recent research and development by geographic information scientists on the spatialization of non-georeferenced information (e.g., Skupin, 2004) and development of tools that foster collaborative knowledge representation (e.g., MacEachren, Gahegan, and Pike, 2004) suggest that mapping may be an apt metaphor to guide future efforts to formalize the content of the GIS&T domain.

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