Development of
Model Undergraduate
Curricula for Geographic
Information Science & Technology

The Strawman Report

Task Force on the Development of
Model Undergraduate Curricula

University Consortium for
Geographic Information Science

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Chapter 1

Overview

Geographic Information Systems (GIS) have developed an extremely broad area of application that extends well beyond the traditional boundaries of geography. From a curricular perspective, one of the most profound changes over the past decade has been the considerable broadening of the focus of GIS to include a substantial number of other academic disciplines. Since its early years, GIS has been most often identified with software systems rather than as either a science or a technology that has been used for spatial data handling and analysis for over thirty years. GIS today is far broader – so broad that we now prefer to refer to its domain as Geographic Information Science & Technology (GI S&T) – and it has become imbedded in many academic and practical fields, from business management to molecular biology.

We suggest that Geographic Information Science & Technology (GI S&T) education should not be defined by merely linking segments of the "traditional" domains (e.g., cartography, remote sensing, statistical analysis, locational analysis, etc.), but rather by placing the emphasis directly upon "concepts and methods for geographic problem solving in a computational environment." In so doing, we reject the notion that GIS is merely a collection of tools and techniques. Rather, the broad domain of GI S&T represents a body of knowledge that focuses in an analytic fashion upon various aspects of spatial and spatio–temporal information and therefore constitutes, in some of its aspects, a science. In other aspects, where the focus is largely upon the utilization of GI Science to attain solutions to real–world problems it has more of an engineering flavor with attention being given to both the creation and use of complex tools that embody the concepts of GI Science.

Institutions of higher education must be sensitive to the emergence of a range of GI S&T interests within existing disciplinary frameworks and they must ensure that their foundation courses in GI S&T effectively serve as wide an audience as possible. To that end, this report describes current efforts to define and develop closely articulated model undergraduate curricula in the area of GI S&T. The plural is deliberately used here since, as will be discussed later, we feel that the broad interdisciplinary nature of GI S&T precludes the existence of a single, "one size fits all," curriculum such as one might expect to encounter in a traditional academic discipline. Instead, we have adopted a view emphasizing a number of curricular "paths" that may enjoy a number of common features but lead to significantly different outcomes for the undergraduate student.

The integration over the last three decades of computer technology and geography in the form of the computer–based Geographic Information System (GIS) allows questions containing major geographic or spatial components to be answered more easily, cheaply and quickly than ever before. Although problems that require complex locational information and analysis are basically geographic in nature, the effective solution of this class of problems typically requires the application of concepts and skills derived from a number of disciplines. This fact is manifest in the many day–to–day attempts to solve these spatial problems, but it has not been generally reflected in the programs offered by many institutions of higher education.

Existing undergraduate programs involving GI S&T components are often deeply disciplinary in their focus and, within this narrow context, far too many of these choose to stress the attainment of rapidly outdated software manipulation skills at the expense of acquiring the conceptual knowledge necessary to cope with the continuing, rapid scientific and technological change that characterizes GI S&T. Academic approaches to GI S&T education have also characteristically exhibited some basic confusion regarding the way that the relevant scientific, engineering and application components of GI S&T relate to each other as well as to the scope and role of the traditional disciplines in GI S&T activities.

Undergraduate GI S&T programs need to offer substantially greater technical and conceptual depth as well as extending their breadth beyond often narrowly focused disciplinary views. To address this need, the University Consortium for Geographic Information Science (UCGIS), a group of some sixty colleges and universities, public agencies and private sector firms, is undertaking the development of flexible, broadly–based undergraduate curricula in GI S&T.[1] The term curriculum, as used in this document, refers to:

> A four–year course of study consisting of specified major and minor courses, together with specified prerequisites, general education courses and electives leading to one of the standard undergraduate degrees.

The interdisciplinary nature of GI S&T is reflected in the divergent academic outcomes that reflect the desires of students working in this area. Hence the rejection of the notion of a single GI S&T curriculum in favor of a group of curricular paths with a common origin and similar but divergent goals (e.g, a research career in GI Science as opposed to one spent in the software implementation of new tools and techniques or even one stressing the application of existing GI S&T concepts and tools to the solution of problems in a specific arena such as hydrology or archaeology).

The ultimate success of any such curricula development effort depends upon the active participation of a significant component of the GI S&T community including both academics and practitioners. By soliciting wide public participation, input from academic organizations outside of UCGIS, and conducting a close examination of similar curricula developed for related disciplines, it is hoped that dissemination and adoption of the curricula will result in more highly and relevantly educated graduates, greater consistency

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[1] For further information on UCGIS see: www.ucgis.org

in GI S&T degree–granting programs, and increased communication across academic disciplines with an interest in GI S&T.

Rationale for the GI S&T model curricula effort

It is imperative that we not only explore the ways in which we can advance GI S&T, but that we also introduce our students to these advancements in a comprehensive and directed manner. Too often, course development follows too far behind technological advancement. We recognize that it is difficult to teach at the 'bleeding' edge of technology because there are few supporting materials, the field changes rapidly, and course development redirects time and effort from our other academic endeavors, such as research. Nonetheless, if we want to produce geographically informed students within various disciplines who are aware of the nature of GI S&T, rather than just how to use a particular GIS software package, then we must actively participate in this curricular challenge. A directed response to the challenge will, in part, assure the future of the development of GI S&T by propagating the knowledge and nature of this domain within the next generation of GI S&T users and educators. Students need to learn that what GI S&T really offers is a holistic approach to understanding spatial data and spatial relations through computation and is not just another map production tool.

Use of the model curricula

The Task Force is working to define and prepare for implementation closely linked model curricula in GI S&T that are intended to provide a baseline for the restructuring of existing undergraduate programs in the area of GI Science & Technology in the United States as well as for the efficient establishment of new educational activities in this area. The current Model Curricula are being developed as an efficient, flexible, multi–path structure supporting four–year undergraduate programs in the United States.[2] The flexibility of multiple paths, each corresponding to some specific educational outcome ranging from general education on the one hand to the specialized education of professionals on the other, will addresses the needs of a number of interdisciplinary groups and permit easy adaptation to varying institutional goals and resources. It is also anticipated that future development of the Model Curricula will make them appropriate for community colleges and non–US universities and colleges.

The GI S&T Model Curricula are aimed at providing a fully documented and well structured approach to curriculum development for all sizes of colleges and universities. It is not anticipated that any single institution will choose to implement all of the possible curricular paths. The sample curricula may be utilized in the establishment of new

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[2] Although GI S&T education is clearly international in scope the resources available do not permit explicit consideration of educational solutions for non–U.S. environments. It is hoped that the work done on the present project will stimulate a multi–national extension at some later date.

interdisciplinary GI S&T programs as well as in the evaluation of existing GI S&T educational activities. The model curricula represent one result of the application of a top–down approach to the definition of a modular definition of the GI S&T "body of knowledge." The "knowledge areas" that make up this body of knowledge include traditional areas of expertise such as mapping and surveying, but also consist of broader academic and technological areas (e.g., development of computer systems, ethical and legal challenges, cognition of geographic elements) that reflect the increasing interdisciplinary nature of GI S&T. In sum, they span the domain of what is defined at a specific point in time as GI S&T.

Some modules that make up the various knowledge areas will be central to all, or nearly all, of the outcome paths that comprise the model curricula; others will be specific to a single path or a closely related group of paths. This outcome oriented, modular structure will allow institutions to select and adhere to those portions of the model curricula that are relevant to local academic program objectives, while still fitting into the set of model curricula characterizing all GI S&T programs.

Uses of the document

The model curricula are designed to produce graduates who are equipped to function as GI S&T professionals at multiple levels. The intent is to reflect the needs of industry, government, and academia for competent professionals. The goal is to produce graduates who are not just trained in the use of software but rather toward developing individuals with a broader grasp of GI S&T, who are technically competent as well as able to work in teams, to communicate both orally and verbally, and to solve problems. To that end, this document will serve as a resource to those involved in the educational process at various levels, as well as those who may be hiring the graduates from institutions with GI S&T programs and, of course, the students enrolled in those programs.

This document is intended to be used as a guide in the development or revision of programs in GI S&T in undergraduate institutions in the United States. Intended users of the curricula are Academic Executives, Academic Heads of Departments where GI S&T may be housed, faculty, practitioners, and students.

- ***Academic Executives*** will be able to use this document in reviewing faculty qualifications and professional development recommendations in decisions regarding faculty and staff review and promotion; evaluating the allocation of computing facilities and physical space recommendations between departments, library support, and staff support for departments that house GI S&T programs or components of GI S&T programs.

- ***Academic Heads of Departments*** where GI S&T may be housed will be able to use this document to establish faculty qualifications for hiring and promotion, allocation of physical space within the department, allocation of other departmental resources, establishment of necessary staff support levels within the department, and to review the relationships between departmental curricula.

- ***Faculty*** will be able to use this document in the design and development of local GI S&T curricula, to evaluate existing course content and materials, evaluate student progress, make recommendations for space and resource allocation, make recommendations for library and computing resources, and design GI S&T lab facilities.
- ***Practitioners*** will be able to use this document to evaluate the qualifications of prospective employees, prepare job descriptions for existing staff, evaluate educational institutions offering programs in GI S&T, evaluate skill levels in their current GI S&T work force, justify GI S&T practices or prospective practices within the workplace, and to evaluate corporate support for academic endeavors.
- ***Students*** will be able to use this document to evaluate prospective GI S&T programs by comparing existing facilities and courses to those suggested in the relevant model curricula and in clarifying their academic and employment objectives.

Structure of the remainder of this document

This report describes the efforts to date and outlines the basic approach for further development of the model curricula in GI S&T. The central goal of this effort is to define and prepare for implementation articulated model curricula in GIScience that may be used to restructure current undergraduate curricula in the area of GI S&T in the United States.

GIS&T has expanded and changed dramatically over the past decade – one of our first tasks, therefore, was to identify the nature and scope of those changes. The evolution of computing and the effect of that evolution on GIS and GIS&T curricula are described in Chapter 2. The question of the increasing breadth of the domain and its impact on curricula design are discussed in Chapter 2. The changes are part of the rationale for development of the curricula – other justifications area also elucidated in Chapter 2.

Our consideration of the changes over the past decade and the overall broadening of the domain have led us to articulate a set of guidelines that have directed the Task Force in preparing this report. Those principles are enumerated in Chapter 3 and applied to the specific concern of curricula design in Chapter 4.

Chapter 4 describes historical development of the curricula in order to place into context the top-down approach used and the body of knowledge that is central to the curricula. Strategic discussions of various aspects of the GIScience curricula, basic concepts associated with the curricula, as well as components and architecture of the curricula is also described in this chapter.

Chapter 5 presents an overview of the GI S&T knowledge areas with a much more extensive discussion available in Appendix A. Additionally, development of the curricula includes a set of pedagogical focus areas that relate to successful adoption of the curricula. Levels of mastery associated with various skills and their relation to Learning Outcomes are also discussed. Finally, paths through the curricula that lead through the common core courses to advanced courses and ultimately to desired outcomes for the students are described.

Chapter 2

The Need for GI S&T Curricula Development

Why curricula development now?

Following substantial development efforts over three decades, GI S&T has evolved from the level of unsophisticated software packages designed to support simple manipulations of map–like data to a rapidly growing and highly specialized analytic field that is increasingly linked to the general area of Information Technology. More and more GI S&T applications focus upon obtaining analytical solutions to spatial and spatial–temporal problems of substantial size and complexity and upon the use of advanced scientific visualization approaches to enhance these analytical results and to make them more easily understood.

The increasing power and scope of GI S&T has led to its widespread adoption in many scientific, public and private activities. A sampling of these applications reveals applications providing near real–time analysis of service outages in electrical networks, numerous applications in military intelligence and operations, homeland defense planning and operations, investigating the environmental impact of proposed dams, selecting optimal new business locations, organizing property tax and ownership records, and optimizing truck routing for solid waste pickup in urban areas. The rate of growth in the use of GI S&T approaches may be seen in the attendance patterns at the annual user conference of one of the larger firms supplying GI S&T technology. Recently this event attracted over 11,000 individuals representing dozens of countries – only twenty years ago there were just over a hundred persons in attendance.

Based upon this strong growth, a compelling demand has developed in both the public and private sectors to enlist the aid of scientists and technologists in order to address these spatial and spatial–temporal problems. The fact that the issues are geographic in nature requires that the individuals involved have special knowledge in order to understand fully the scientific and technological implications of these societal problems. Colleges and universities have developed a wide variety of courses and programs that attempt to come to grips with the issues. Students are currently flocking to these programs in response to the rapidly increasing demand and the challenging and interesting nature of the problems that are involved.

However graduates of existing academic programs often find themselves ill–equipped when they seek employment in one of the many public and private sector activities making substantial use of GIS. Among the difficulties that they encounter are: an inadequate knowledge of the critical computer science/information technology basis of GIS, a weak understanding of the special characteristics of spatial data; insufficient knowledge pertaining to the current theoretical and practical status of spatial analysis as well as to the capabilities of the technology that is currently available; inadequate understanding of both the nature of spatial data and the methods by which it is acquired, and insufficient training in the identification of the spatial components of problems and in the subsequent specification of potential solutions to these problems.

One source of these difficulties may be found in many existing academic approaches to GI S&T education. First, many programs focus only upon GIS (one component of GI technology) to the exclusion of other aspects of GI S&T. There has also been some substantial confusion regarding the way in which the relevant scientific, engineering and application components of GI S&T relate to each other and to the role of the traditional disciplines within a broader GI S&T context. These, and similar problems, have played a significant role in the persistence of undergraduate programs that provide insufficient technical depth as well focusing too narrowly upon a single disciplinary approach to GI S&T.

The need to go substantially beyond present educational levels has been noted, with respect to the more general IT workforce – and this also applies directly to most components of the GI S&T community – in a recent GAO statement to Congress:

> More and more, the work that federal agencies do requires a knowledge–based workforce that is sophisticated in new technologies, flexible, and open to continuous learning. This workforce must be adept both at delivering services directly and at effectively managing the cost and quality of services delivered by third parties on the government's behalf. [Walker, p. 4]

It is the view of many professionals within the GI S&T community that the time has come to synthesize, articulate, and put into appropriate intellectual context the recent advances of GI scientists and technologists. It is for this reason that we present what we believe to be a flexible and coherent curricula development approach that is specifically designed to aid in the development of an adequate supply of well–educated and well–prepared GI scientists and technologists in a variety of higher education environments.

An integrated view of Geographic Information Science & Technology

Before we can begin specification of the content of GI S&T curricula, we must have a clear view of the intellectual domain that is involved. The original term "GIS" has become more and more difficult to use in any effective fashion as both its intellectual and practical domains have expanded far beyond its original meaning. It has even, thankfully only in a very few cases, even acquired a verb form, as in "We GISed our data ..." Today, we find that the level of confusion can be substantially reduced if we elect to view the traditional "GIS" as only one component of a larger, articulated structure.

In defining this structure we begin by singling out a bundle of complementary spatial technologies consisting of the traditional "GIS" software components, the newer primary data acquisition (PDA) technologies as well as the classic ones, in addition certain aspects of scientific visualization to constitute an sub–domain that can be conveniently referred to as *Geographic Information Technology* (GI Technology). This is the first of three sub–domains that constitute GI S&T.

Continuing, it proves convenient to separate those activities pertaining mainly to the basically engineering problems of designing, constructing and testing components of GI Technology from the increasingly large number of *Applications of GI Technology* whose primary concern lies almost entirely with the use of existing GI Technology in the solution of real–world spatial and spatial–temporal problems. This applications domain becomes the second of the three GI S&T sub–domains.

Our ability to develop effective GI Technology and to efficiently apply this technology to the solution of critical societal problems is based upon the research contributions of a number of scientific disciplines concerned in whole or in part with the acquisition, handling, analysis and visualization of spatial and spatial–temporal data. This complex, interdisciplinary area is becoming commonly referred as *Geographic Information Science* (GI Science) that we will define as the third and final GI S&T sub–domain. Some of the disciplines contributing to GI Science have a principal focus upon spatial and spatial–temporal factors (e.g., geography) while in others these concerns represent only one specialized part of a much larger whole (e.g., operations research). This mixture of levels of interests has led, in the past, to significant complexities in the establishment of clear research goals and directions.

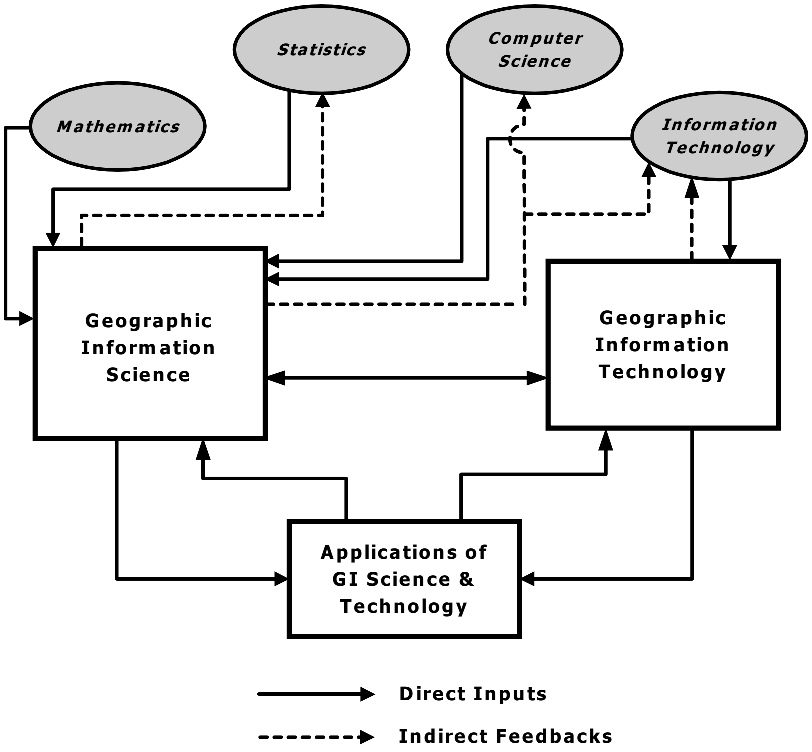

Figure 1
Geographic Information Science & Technology

Based upon these three major components a unified view of the domain of *Geographic Information Science & Technology* (GI S&T) has begun to coalesce over the last few years. Figure 1 presents a structural view based upon the integration of the three, closely–linked components (*Geographic Information Science*, *Geographic Information Technology*, and *Applications of GI Science & Technology*). The first of these provides the broad scientific basis for the other two; the second deals with the engineering creation and testing of tools based largely upon concepts drawn from GI Science, and the third involves the application of concepts and tools drawn from the first two areas to the identification and efficient solution of a variety of real–world spatial and spatial–temporal problems.

External to the defined domain of GI Science & Technology, and those disciplines heavily involved with and directly contributing to GI Science, we also see critical cross–domain associations with the disciplines of mathematics, statistics, computer science and information technology. It is interesting that the rich problem domain of GI Science & Technology also has assisted in defining augmented problem domains in at least three of these four associated fields (e.g., the contributions made by spatial statistics, spatial econometrics and geostatistics to the general field of statistics).

Because of the large size and complexity of many real–world spatial problems, we have also seen, since the early days of GIS, a strong flow of problems seeking theoretical solutions and effective implementations (such as those requiring the explicit incorporation of true volumetric and temporal components into traditional spatial analysis) passing from users of GIS Technology at the application level to those who are professionally engaged in scientific investigation and GI tool development. These problem–induced feedbacks represent an important complement to the flow of solutions encountered in the traditional *science* → *engineering* → *users chain*.

GIS has undergone major evolutionary changes in its relatively rapid transformation into Geographic Information Science & Technology. These changes will clearly continue as the substantial extensions of theory that have already been identified in subjects such as spatial statistics, location–allocation and transport system modeling, the amplification of purely spatial modeling to a full spatial–temporal domain, etc., are accomplished. The subsequent incorporation of these new theoretical advances into new components of GI Technology capable of operating effectively within a rapidly changing computational environment that includes full object orientation, a growing focus on Internet–based solutions, etc., poses an interesting series of challenges — challenges that can be met only by a properly educated GI S&T workforce.

GI S&T and changes in technology and culture

Much of the change that affects GI S&T comes from two interrelated sources. The first certainly comes from a natural maturation of the field and development of a body of knowledge through experience and research. The second, as in all computer–related fields, arises from continuing advances in computing itself, as an enabling technology. Exponential increases in available computing power continues as a long–term phenomenon that has made possible the solution of problems that would have been out of reach just a few years before. The relatively sudden availability of the Web as a means of sharing resources and communication has fundamentally changed how spatial data can be shared and maintained, analytical tasks performed, and the results distributed. Such technological changes underlie the need for GI S&T professionals whose education and training (both initial and continuing) permit them to successfully adapt to rapid technological innovation.

The development of separate raster and vector database representations, respectively, in the 1960's and 1970's shifted to integrated raster/vector systems, followed by recent research on location (or field)–based and object–based approaches that include explicit consideration of human space–time cognition. Thus, change in GI S&T, as in any field, occurs in both revolutionary and evolutionary steps. And both of these affect the scope of the body of knowledge and the technology that must be addressed in GI S&T activities and in the supporting educational process. Technology change has an effect in a number of general ways upon GI S&T education, including the following:

Changing importance of topics. Advancement in all of the GI S&T sub–domains over the past decade has resulted in a number of new topics rising to prominence and importance. These include dynamic visualization and multimedia, web mapping, distributed database design and data warehousing, data mining and exploratory data analysis, and theoretical foundations for representation. As these topics increase in prominence, it is tempting to include them as undergraduate, as well as graduate, requirements. However the restrictions of most degree programs make it difficult to add new topics without either taking others away or reducing their emphasis. However, we must also recognize that the importance of some topics has arguably faded with time, such as manual digitizing and certain forms of traditional spatial data collection and entry.

Greater acceptance of GI S&T by academic institutions. In its early years GIS, computer cartography, and many other areas of what we now view as GI S&T were forced to struggle for legitimacy in many academic institutions. It was, after all, a new interdisciplinary area without the historical, and in many aspects, the theoretical foundations that support most academic fields. The battle for legitimacy has largely been won. This, however, has been partly a result of the general entry of computing technology into the cultural and economic mainstream. The development of a fundamental framework and related theoretical issues within GI S&T needs to continue apace and to be integrated into the various curricula at both the undergraduate and graduate levels. The problem today is to find effective ways to meet the demand for elements of the GI S&T workforce at both the undergraduate and graduate levels.

Broadening of the GI S&T domain. As GI S&T has grown and gained legitimacy, it has also significantly broadened its scope. In its early years, GIS primarily focused on solving fairly straight–forward, practical spatial problems. Also, until relatively recently, developments continued to be centered on incremental, ad–hoc improvements to traditional cartographic and spatial analysis approaches. Nevertheless, over the years an increasing number of fields have become part of a much larger, more encompassing interdisciplinary area of GI S&T. This Task Force believes that understanding how the various specialties and areas of knowledge that have evolved fit together and how the broadening of the discipline affects GI S&T education is a critical component of our work.

GI S&T education is also affected by changes in the cultural and sociological context in which it occurs. The following changes, for example, have all had an influence:

Changes in pedagogy enabled by new technologies. The technological changes that have driven the recent expansion of computing have also had direct impacts upon the culture of education. Computer networks, for example, make distance education a practical option, leading to enormous growth in this area. Networks also make it much easier to share curricular material among widely distributed institutions. Technology also affects the nature of pedagogy. Computer projection equipment, powerful individual laboratory stations, the Web, and sophisticated presentation software have made a significant difference in all forms and levels of teaching. This has been particularly advantageous in the teaching of GI S&T as well as other computer–related fields.

The dramatic growth of computing throughout the world. Computing has expanded enormously over the last decade. For example, in 1990, few households — even in the United States — were connected to the Internet. A U.S. Department of Commerce study revealed that by 1999 over a third of all Americans had Internet access from some location. Similar growth patterns have occurred in most other countries as well. The explosion in the access to computing, in terms of hardware, software and data, brings with it many changes that affect education. One of these involves a greater dependence upon and interest in locational information, which in turn requires an understanding of the unique characteristics of that type of information. There has also been an overall increase in the familiarity of undergraduate students with computing in general and its applications, along with a widening gap between the skill levels of those that have had prior access and those who have not.

The growing economic influence of computing technology. The continuing excitement surrounding the use of information technology has had significant effects on education and its available resources. The enormous demand for expertise in the use of GI S&T tools and approaches has attracted many more students to courses in this area, both as an adjunct to their main course of study and as their main focus. This includes some who have little intrinsic interest in the material but rather see it simply as an employment opportunity. At the same time, the demand from industry has resulted in many colleges and universities investing in major new information technology programs. Although often derived from some combination of elements from management and business, engineering and computer science, such programs may, upon occasion, include GIS to a minor degree. Demand from industry has also made it harder for most institutions to attract and retain faculty in information technologies generally, imposing significant limits on the capacity of those institutions to meet the demands of industry for properly educated and trained graduates.

Chapter 3

Principles Guiding the Development of the Model Curricula

The following guidelines and principles were developed following extensive discussions within the Task Force and have provided a foundation for the Task Force in its approach to the model curricula. These guidelines reflected our analysis of past curricula reports and the significant changes that have taken place in the GI S&T arena in the recent past.

1. *The model curricula must be structured so as to effectively serve the needs and interests of a variety of people involved in undergraduate programs in GIS&T in different disciplines.*

   GI S&T covers a substantial number of disciplinary areas concerned with spatial and spatial–temporal problem solving. The initial intent of the model curricula effort is to define a common interdisciplinary area that will be capable of significantly augmenting each of the existing disciplines and providing viable paths to different outcomes desired by their students.

2. *The model curricula must ensure a broad and common understanding of basic GI S&T concepts and tools among all students through the definition of a core curriculum that will be common to all paths*.

   The lack of consistent skills and a common language among GI S&T graduates has been one of the drivers for development of the model curricula. Each of the paths, in addition to meeting its overall educational objectives, must also define and instill a body of consistent foundation knowledge among GI S&T students, regardless of the institution or discipline where a particular instance of the model curricula is implemented.

3. *The model curricula must foster students' ability to identify problems with spatial and spatial–temporal components, to develop potential solutions to these problems, and to effectively apply existing GI S&T concepts and tools to their solution. It must emphasize the importance of laboratory, field and practical applications of GI S&T.*

   It is essential for academic programs to emphasize the practical aspects of the GI S&T domain along with the theoretical ones. Today, much of the practical knowledge associated with GI S&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 GI S&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. Central to all paths is the development of problem identification and problem solving capabilities.

4. *The model curricula must be capable of adaptation to a wide variety of institutional missions, including close articulation with technical GI S&T programs at the community college level.* curricula

   Institutions are expected to adopt and present elements of the model curricula according to their local goals and capabilities. The flexibility to accommodate this must be keep in mind at all stages of the development of model curricula. In addition, community colleges serve a variety of non--traditional educational needs and their needs and interests must be kept in mind in the development of model GIS&T Curricula.

5. *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.*

   Any implementation of portions of the model curricula will take place within a complex institutional and intellectual environment. Mere specification of what should be done intellectually falls far short of what is actually required to make the model curricula viable.

6. *The model curricula should reflect the inputs of as much of the GI S&T community as possible, including practitioners as well as academics.*

   Most students who graduate from undergraduate GI S&T programs take positions in industry, often without seeking more advanced education. To ensure that graduates are properly prepared for the demands they will face in those positions, we believe it is essential to actively involve practitioners in the design, development, and implementation of the model curricula.

7. *The model curricula must be able to accommodate the incorporation of rapid technological changes and all aspects must be subject to continual review and modification.*

   Given the pace of change in our discipline, the notion of updating the model curricula discussed here once every decade or so is unworkable. The professional associations in the GI S&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.

Chapter 4

Defining the Model Curricula

In this chapter, we briefly describe the history of the Geographic Information Science and Technology (GI S&T) curricula. In developing this report, the Task Force did not have to start completely from scratch. We have been significantly assisted by past curriculum studies and are indebted to the authors of those studies for their dedicated efforts. Although no other efforts have been undertaken to develop a comprehensive GI S&T curriculum, we have learned much from studies in related disciplinary areas, including *IS '97: Model Curriculum Guidelines for Undergraduate Programs in Information Systems* and from *Computing Curricula 2001* that was well underway when we began our work.

Additionally, we reviewed and considered the outcomes of various smaller curriculum projects in GIS. As part of our work on the model curricula for GI S&T, we looked carefully at how these previous studies have influenced GI S&T education. By identifying which aspects of previous efforts have been successful and which have not, we can structure the model curricula report in such a way as to maximize its impact. This chapter offers an overview of the earlier reports and the lessons we have taken from them.

History of the GI S&T model curricula

The current Task Force was formed to address two widely recognized problems that have developed in GI S&T within the present decade: (1) the growing desire to conceptually integrate work in modern spatial analysis with that in GIS, and (2) a massive scarcity of properly educated professionals within the public and private users of GIS technology and among those firms developing an integrated software approach to GIS and GI S&T.

The keynote address given by Marble at the GIS in Higher Education meeting in the Fall of 1997 served to focus for a small group of individuals who met in January 1998 to examine possible solutions to these problems (Marble, 1998). That meeting was organized by Marble with support from Jack Dangermond of ESRI. At that meeting, it was concluded that a long-term effort to develop and implement a model GI S&T curriculum was the only real solution. Many of those involved in the original meeting, including Richard Wright (then Chair of the UCGIS Education Committee), felt that the UCGIS was the most appropriate sponsor for such an activity.

At the 1998 Park City Assembly of the UCGIS, both the Education Committee and the Assembly discussed the proposal for a model curricula, and the UCGIS subsequently voted to formally support the activity. Since then, the Task Force has met on several occasions to continue developing the model curricula.

A top–down design approach

In the past there have been a number of attempts to provide generic assistance to GI S&T educators. Perhaps the most well known of these is the now outdated "Core Curriculum in GIS," a product of the NSF–funded National Center for Geographic Information and Analysis (NCGIA) (NCGIA, 1990). This product was not really a curriculum as we use the term here, but rather a collection of lecture units of variable depth that were loosely organized into three unarticulated "courses." Many of the units contained very useful material, particularly at a time when there was a nearly complete absence of introductory texts, but the greatest use of the "curriculum" was as a source of materials for individual lectures rather than as a defining structure for GIS education.

A later attempt was made to expand the NCGIA initial effort into a more ambitious revised edition in digital form focused on GIScience concerns. While portions of this are online, it does not appear to been actively expanded or updated since 2000. NCGIA also undertook to prepare a similar set of technical units for the community college community; this effort is also incomplete and currently inactive. The NCGIA materials have been useful to GIS educators, largely within the context of particular topics, but they were not developed to provide guidance with respect to those competencies that should characterize the graduate of a program. In addition, because of the rapid technological advancements that impact GI S&T, the materials do not reflect the current educational needs of most students.

The NCGIA activities are representative of a *bottom–up* design approach to curriculum development where a set of lecture topics is combined into courses and the collection of courses defines a *defacto* curriculum. However, such an approach has the potential to overlook critical topics as well as to miss the significant interdependencies that must be explicitly recognized in a truly effective curriculum.

Marble (1998) offered an alternative to the bottom–up attempts at solutions that had not proven wholly effective, and were also proving to be extremely difficult to adapt to rapidly changing situations. In his keynote address to the 1997 GIS in Higher Education meeting, he called for a substantial rethinking of our approach to education in this area and strongly urged the adoption of an outcome–directed, top–down strategy in building a new and much more scientifically oriented curriculum. The GIS community warmly received his suggestion, and as a direct result, the present initiative to create model curricula for GI S&T was begun.

Development of a GI S&T body of knowledge

After substantial discussion, the Task Force agreed to adopt a modified version of the highly successful curriculum development methodology that has been utilized for several decades in the areas of computer science, information technology and project management. This top-down design approach begins with a comprehensive exposition of the relevant body of knowledge (BoK) for the area of concern. The BoK views the intellectual domain under consideration as being composed of *knowledge areas* that are capable of subsequent decomposition into *units* and *topics*. BoK components at the topic level are normally utilized as building blocks for both the specification of academic path content and in the operational definition of courses.

Following standard terminology, as used by a number of organizations, the approach to the defined task is organized around three reporting versions. These are identified as the *Strawman*, *Ironman* and *Steelman* versions. The initial version is the Strawman that typically addresses the concerns that generated the activity and, in particular, the disciplinary changes that now require curriculum modification. Where a prior version of the BoK exists, necessary modifications are set forth. Following the release of the *Strawman* document, extensive discussion of its contents takes place within the relevant community. Based upon this discussion, extensive work takes place to create the *Ironman* document; this can be viewed as a hopefully final draft but it is also subject to extensive review by the relevant community. Following this final community review, the last, or *Steelman*, version is created. In the best case, there are no major changes required between the last two versions.[3]

The disciplines that have utilized this approach over time have found it easy to modify as the particular disciplinary area evolves. In GI S&T, however, no definition of the BoK existed when the Task Force began its work. Creating an initial draft BoK has been a challenging and time consuming task, but before the results can be effectively utilized in creation of the GI S&T model curricula they must be verified and validated by the broader GI S&T community.

As noted earlier, in the curriculum development process adopted here, the knowledge areas will be further broken down into units (representing individual thematic modules within the areas). Each unit will then be further subdivided into a set of topics representing the lowest level of the hierarchy and which will be used as the building blocks to construct instructional modules. Model courses will be developed by combining a set of modules, quite possibly taken from different knowledge areas. The Task Force will also seek to identify a minimal GI S&T core consisting of those topics for which there is a broad consensus identifying them as containing material essential to students in all of paths within the model curricula.

An example of the resulting structure may be seen in Figure 2 which has been extracted from the *Computing Curricula 2001* Steelman report. Here the CS knowledge areas and their unit structure are displayed. Units that are underlined are defined as part of the overall CS "core" curriculum. Note that there is no requirement that all knowledge areas be represented in the "core" nor, for that matter, that all unit and topic level items be made available at the undergraduate level. A full description of each of these items, including their topic level breakdowns is available in the CS Steelman report noted earlier.

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[3] In the case of very large and complex projects (e.g., the development of the ADA programming language) other stages may be inserted. For example, a *Woodman* and *Tinman* stage may appear between the *Strawman* and *Ironman* versions.

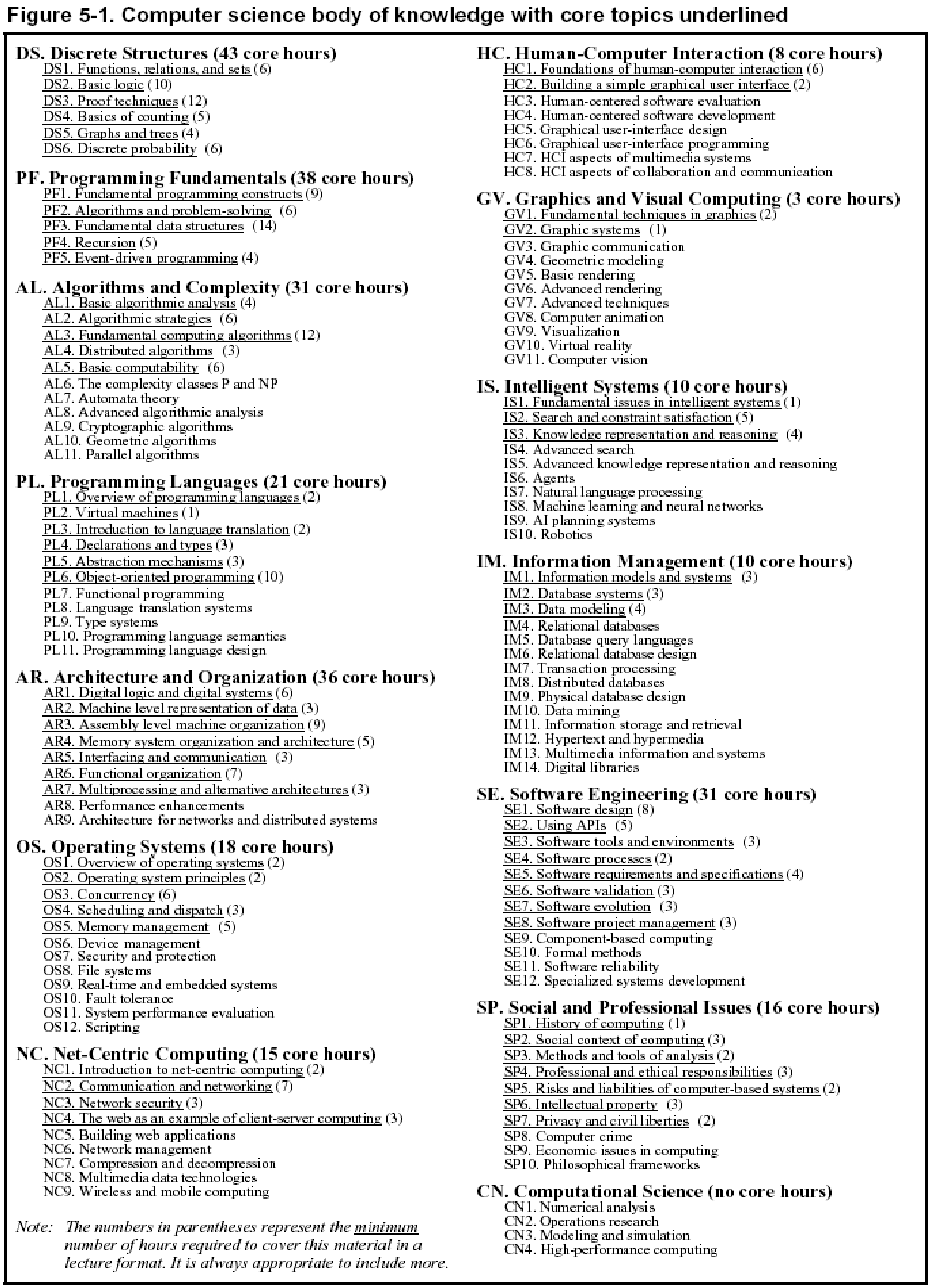


Figure 5-1. Computer science body of knowledge with core topics underlined

DS. Discrete Structures (43 core hours)
- DS1. Functions, relations, and sets (6)
- DS2. Basic logic (10)
- DS3. Proof techniques (12)
- DS4. Basics of counting (5)
- DS5. Graphs and trees (4)
- DS6. Discrete probability (6)

PF. Programming Fundamentals (38 core hours)
- PF1. Fundamental programming constructs (9)
- PF2. Algorithms and problem-solving (6)
- PF3. Fundamental data structures (14)
- PF4. Recursion (5)
- PF5. Event-driven programming (4)

AL. Algorithms and Complexity (31 core hours)
- AL1. Basic algorithmic analysis (4)
- AL2. Algorithmic strategies (6)
- AL3. Fundamental computing algorithms (12)
- AL4. Distributed algorithms (3)
- AL5. Basic computability (6)
- AL6. The complexity classes P and NP
- AL7. Automata theory
- AL8. Advanced algorithmic analysis
- AL9. Cryptographic algorithms
- AL10. Geometric algorithms
- AL11. Parallel algorithms

PL. Programming Languages (21 core hours)
- PL1. Overview of programming languages (2)
- PL2. Virtual machines (1)
- PL3. Introduction to language translation (2)
- PL4. Declarations and types (3)
- PL5. Abstraction mechanisms (3)
- PL6. Object-oriented programming (10)
- PL7. Functional programming
- PL8. Language translation systems
- PL9. Type systems
- PL10. Programming language semantics
- PL11. Programming language design

AR. Architecture and Organization (36 core hours)
- AR1. Digital logic and digital systems (6)
- AR2. Machine level representation of data (3)
- AR3. Assembly level machine organization (9)
- AR4. Memory system organization and architecture (5)
- AR5. Interfacing and communication (3)
- AR6. Functional organization (7)
- AR7. Multiprocessing and alternative architectures (3)
- AR8. Performance enhancements
- AR9. Architecture for networks and distributed systems

OS. Operating Systems (18 core hours)
- OS1. Overview of operating systems (2)
- OS2. Operating system principles (2)
- OS3. Concurrency (6)
- OS4. Scheduling and dispatch (3)
- OS5. Memory management (5)
- OS6. Device management
- OS7. Security and protection
- OS8. File systems
- OS9. Real-time and embedded systems
- OS10. Fault tolerance
- OS11. System performance evaluation
- OS12. Scripting

NC. Net-Centric Computing (15 core hours)
- NC1. Introduction to net-centric computing (2)
- NC2. Communication and networking (7)
- NC3. Network security (3)
- NC4. The web as an example of client-server computing (3)
- NC5. Building web applications
- NC6. Network management
- NC7. Compression and decompression
- NC8. Multimedia data technologies
- NC9. Wireless and mobile computing

Note: The numbers in parentheses represent the minimum number of hours required to cover this material in a lecture format. It is always appropriate to include more.

HC. Human-Computer Interaction (8 core hours)
- HC1. Foundations of human-computer interaction (6)
- HC2. Building a simple graphical user interface (2)
- HC3. Human-centered software evaluation
- HC4. Human-centered software development
- HC5. Graphical user-interface design
- HC6. Graphical user-interface programming
- HC7. HCI aspects of multimedia systems
- HC8. HCI aspects of collaboration and communication

GV. Graphics and Visual Computing (3 core hours)
- GV1. Fundamental techniques in graphics (2)
- GV2. Graphic systems (1)
- GV3. Graphic communication
- GV4. Geometric modeling
- GV5. Basic rendering
- GV6. Advanced rendering
- GV7. Advanced techniques
- GV8. Computer animation
- GV9. Visualization
- GV10. Virtual reality
- GV11. Computer vision

IS. Intelligent Systems (10 core hours)
- IS1. Fundamental issues in intelligent systems (1)
- IS2. Search and constraint satisfaction (5)
- IS3. Knowledge representation and reasoning (4)
- IS4. Advanced search
- IS5. Advanced knowledge representation and reasoning
- IS6. Agents
- IS7. Natural language processing
- IS8. Machine learning and neural networks
- IS9. AI planning systems
- IS10. Robotics

IM. Information Management (10 core hours)
- IM1. Information models and systems (3)
- IM2. Database systems (3)
- IM3. Data modeling (4)
- IM4. Relational databases
- IM5. Database query languages
- IM6. Relational database design
- IM7. Transaction processing
- IM8. Distributed databases
- IM9. Physical database design
- IM10. Data mining
- IM11. Information storage and retrieval
- IM12. Hypertext and hypermedia
- IM13. Multimedia information and systems
- IM14. Digital libraries

SE. Software Engineering (31 core hours)
- SE1. Software design (8)
- SE2. Using APIs (5)
- SE3. Software tools and environments (3)
- SE4. Software processes (2)
- SE5. Software requirements and specifications (4)
- SE6. Software validation (3)
- SE7. Software evolution (3)
- SE8. Software project management (3)
- SE9. Component-based computing
- SE10. Formal methods
- SE11. Software reliability
- SE12. Specialized systems development

SP. Social and Professional Issues (16 core hours)
- SP1. History of computing (1)
- SP2. Social context of computing (3)
- SP3. Methods and tools of analysis (2)
- SP4. Professional and ethical responsibilities (3)
- SP5. Risks and liabilities of computer-based systems (2)
- SP6. Intellectual property (3)
- SP7. Privacy and civil liberties (2)
- SP8. Computer crime
- SP9. Economic issues in computing
- SP10. Philosophical frameworks

CN. Computational Science (no core hours)
- CN1. Numerical analysis
- CN2. Operations research
- CN3. Modeling and simulation
- CN4. High-performance computing

Figure 2

A closely related curriculum activity involves the need to specifically identify, and sequence, those components of supporting technical curricula (e.g., those in computer science, mathematics and statistics) that are need to be integrated with the GI S&T curricula.

Additional concepts

While the knowledge areas form the initial foundation from which the model GI S&T curricula are to be built, the Task Force has also identified some other aspects that need to be specified. These fall into three major areas that we have identified as cross–cutting themes, pedagogy and the concept of *levels of mastery*. Each of these is addressed in the following sections.

The crosscutting themes

Crosscutting themes are important general topics that occur in more than one unit or knowledge area. Their significance lies in their presence in several knowledge areas but their role in each may vary. For example, scale in visualization refers to the relationship between the real world and its graphical representation; space–time conceptualizations can be at national, regional or other scales; scale in a data structure sense may mean how well it can scale up to handle larger amounts of data. While more crosscutting themes may be defined as the knowledge areas are discussed, initial deliberations identified the following significant crosscutting themes as ones that should be taken into account in some form in all or nearly all of the knowledge areas: scale, error, uncertainty, generalization, verification/QC, validation/QA, metadata, interoperability, and language.

The pedagogy areas

Defining a body of knowledge for a discipline or an interdisciplinary area to form the basic for curriculum development is not sufficient. It is also important to take a more holistic view of the curricula that transcends the traditional boundaries of what is to be taught and to whom. Four pedagogy areas have been identified by the Task Force:

P1. *Supporting topics and courses – (work in, for example, geography, mathematics, statistics, computer science and information technology)*

This area addresses the prerequisite knowledge needed to begin study within each of the knowledge areas and correlates this with the content of related disciplines to determine prerequisite courses. It is suggested that this concern be addressed as a direct part of the model GI S&T curricula development process.

P2. *Integrative experiences – (structured internships, capstone experiences, etc.)*

This area addresses the means by which students can integrate, in an operational context, individual topics learned and gain experience in spatial problem–solving through cross-cutting, real–world projects. The integration of spatial problem solving should be encouraged at all levels and in most courses within the model curricula paths. In addition, explicit attention should be given to the creation of modules that provide the student with guided internships, capstone research and problem solving experiences, etc.

P3. *Supporting infrastructure for the model curricula*

This area addresses the wide range of supporting infrastructure necessary to provide appropriate education in this quickly evolving field. For example, the area addresses such concerns as necessary laboratory facilities and required library resources (including traditional, map, document and data libraries, as well as digital and non-digital libraries). It also considers the need for faculty to be more broadly focused through access to relevant continuing educational opportunities. These include workshops, institutes, conference attendance, and training sessions. Also, faculty promotion and tenure issues in this non–traditional, interdisciplinary field need to be acknowledged.

P4. *Implementation and dissemination of the model curricula*

In order for the model GI S&T curricula to be implemented, coordination will be needed with a number of disciplines. This may require changes in their traditional programs in order to accommodate students in the discipline who desire additional GI S&T program content as well as recognition within GI S&T programs of the constraints and opportunities provided by other programs. One method to address these concerns might be to define sample implementations of several curricula in GI S&T that address this need for coordination.

While P1 can, and should, be explicitly incorporated into the model curricula generation process, the remaining three, when taken together, pose a significant number of difficult questions. The Task Force feels that these can best be addressed through the explicit creation of a "Model Curricula Development and Support Plan" as a separate activity that will run in parallel with the curricula development itself (see Chapter 6).

Paths through the curricula

There is a growing feeling in all sectors of the GI S&T community that calls for the establishment of an innovative and flexible interdisciplinary educational activity that:

Defines a clear set of academic paths, each of which leads to a specific GI S&T related educational outcome for the interested undergraduate;

Addresses the problems of breadth vs depth and of consistent basic knowledge levels among graduates by defining a set of basic or core courses that are common to all paths and that can be offered to students from a number of disciplines while making effective use of scarce institutional resources;

Assists existing academic disciplines concerned with GI S&T topics in constructing their own advanced GI S&T courses that build upon the common interdisciplinary core;

Produces graduates with significantly enhanced technical backgrounds who are capable of dealing with the increasing sophistication of all areas within GI S&T;

Is interoperable with the model curricula of critical supporting disciplines including computer science, information systems, mathematics and statistics; and

Is flexible enough to be adapted to a variety of institutional circumstances and that is capable of being adopted by individual institutions either in part, e.g., selected paths and not others, as well as a whole.

Figure 3 provides an overview of such a hypothetical structure. Desired GI S&T graduation outcomes are generalized and a curricular path is defined that leads to each of the generalized outcomes. Examples of such possible generalized outcomes might include disciplinary GI S&T user, disciplinary GI S&T application developer, GI S&T software developer, or GI science specialist. For each such path, those things that the graduate is expected to know, and at what level of competence, are clearly defined. Not all desired outcomes are attainable at the undergraduate level since currently much of GI Science requires some level of graduate education (e.g., the unattainable 'X' in Figure 3). However completion of a GI

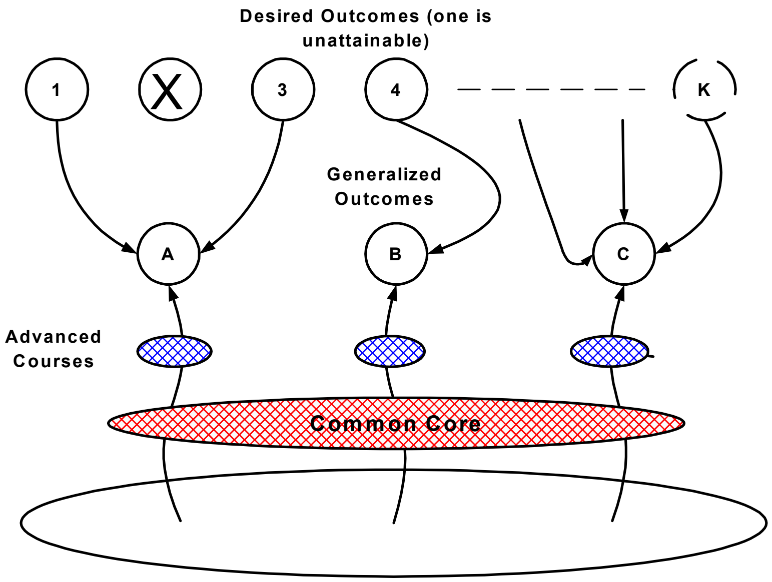


Figure 3
Multiple Paths Within the GI S&T Curricula

S&T undergraduate path that is explicitly directed toward further advanced study will significantly increase the quality of entering graduate students who are oriented toward GI S&T activities in many disciplines.

The various curricular paths share a common core of knowledge (core courses may be defined at introductory, intermediate or advanced levels since commonality of interest does not necessarily imply simplicity with respect to content) and students will also be involved in specialized, advanced courses that are tailored to their chosen curricular path and discipline. Not all the courses contained in the GI S&T multi–path curriculum will represent new offerings since some will be drawn from the body of existing courses (e.g., Introduction to Database Systems is already found in most CS/IT curricula). The inclusion in most of the paths of a structured, upper–division internship program that is closely articulated with, and not merely appended to the undergraduate GI S&T curriculum is also considered to be highly desirable since it promotes integrative use of acquired knowledge and tool skills by the student and assists in career decisions.

Levels of mastery

Clearly, students embarked upon different paths will require differential knowledge of the components of GI S&T. It is not enough to simply state that a specific knowledge unit should be a component of a particular path. The requirements with respect to a particular knowledge unit contained in each path must be defined for the student at some specific level. The Task Force has identified five interconnected levels of capability. Each of these levels should, in most circumstances, be assumed to build upon all lower levels. The five proposed levels are:

Awareness**.** This person is cognizant of or able to identify the relevant knowledge area. The student has limited practical experience but has heard of or read about the topic and can communicate about it in a limited but coherent fashion. This level of knowledge should be obtainable from within introductory course work, basic outside reading, and/or informal exposure to the material through the experiences of others.

Literacy. In addition to possessing a basic awareness of the knowledge area, this person is able to identify specific problems and settings where this knowledge might be necessary, and is able to formalize how it might be addressed in a computer environment. The literacy level assumes some hands-on experience and a limited degree of first had experience with the material. Beyond being able to communicate about the topic the student should be able to demonstrate a working knowledge of the topic when presented with structured problem sets and situational environments.

Use**.** In addition to possessing the skills at the literacy level, this person is able to demonstrate a level of independence in terms of recognizing the broader linkages of the knowledge area to other knowledge areas. Additionally the student should have the capability to apply the knowledge to both formal (directed) and informal (non–directed) situations. An important aspect of knowledge at this level is the ability to generate independent applications and to adapt to changing problems and settings at, as a minimum, a rudimentary level.

***Application Development*.** In addition to possessing the skills at the use level, this person is able to analyze complex problem requirements. Beyond those requirements he or she should be able to create a conceptual design, establish software specifications, design a software solution, and implement the solution. This level of knowledge assumes a familiarity with the available toolkits for the knowledge area, a high level of adaptability with regard to problem identification, and an ability to recognize problem similarities among applications and settings.

***Mastery*.** In addition to possessing the skills at the application development level, this person is able to design and develop overall solutions from start to finish, recognizes the interactions of the other knowledge areas to such a solution, and to demonstrate an ability to work independently. This person can demonstrate an ability to develop basic software systems, to augment existing software systems, and to manage GI S&T operations. Attainment of this level is not considered common at the undergraduate level.

Core modules and sample courses.

The model curricula in GI S&T must identify a relatively small set of core knowledge modules that incorporate concepts and skills that are required of all GI S&T students. The Task Force has agreed that the core should consist of those topics for which there is a broad consensus that each topic is essential to all undergraduate degrees that include GIS, GIScience, and other similarly named programs. This definition is meant to encompass the essential requirements common to all undergraduate programs. At the same time, it must be understood that the core modules do not in themselves constitute a complete undergraduate curriculum, but must be supplemented by additional modules that may vary by institution, field of study, or individual student. As part of the *Ironman* activity sample courses will need to be developed to incorporate these core modules.

Chapter 5

The GI S&T Body of Knowledge

In developing model curricula for undergraduate study in Geographic Information Science & Technology (GI S&T), one of the critical steps is to identify and organize the material that is to be included. Another is to specifically identify the components of supporting curricula (e.g., computer science, mathematics and statistics) that are needed to serve as foundations for the GI S&T curricula. This section of the document addresses the first of these, the identification of *knowledge areas* within the interdisciplinary scope of GI S&T. Recall that the concept of knowledge areas rests upon the domain definition of GI S&T.

Once identified, the knowledge areas are further broken down into *units* representing individual thematic modules within the areas. Each unit is further subdivided into a set of *topics* representing the lowest level of the hierarchy and which will be used as building blocks to construct model *courses*. The Task Force, during the *Ironman* activity, will also identify a minimal *core* consisting of those units for which there is a broad consensus that the corresponding material is essential, at some level of mastery, to everyone who is seeking an undergraduate degree with a significant GI S&T component.

The table on the following two pages summarizes an activity that has occupied a substantial portion of the time of the Task Force. It displays the twelve GI S&T knowledge areas as well as their unit level breakdowns. Appendix A goes into substantially more detail on the GI S&T Body of Knowledge providing written descriptions at the knowledge area and unit levels as well as suggested topic level breakdowns and suggested learning objectives.

In creating the body of knowledge document, the Task Force has had substantial assistance from a number of persons both inside and outside of UCGIS. In particular we should mention the panel group at the Monterey meetings of the Western Regional Science Association, a similar panel at last years ESRI User Conference and, of course, the numerous UCGIS delegates and others who provided comments at the Buffalo and Athens summer assembly meetings.

How should one approach this draft version of the GI S&T Body of Knowledge? One way is to scan it completely to see of there are any missing or “misplaced” units and topics from the standpoint of your own educational experience. Another is to select a research area of interest to you and attempt to map it into the Body of Knowledge. In addition to its educational uses, the GI S&T Body of Knowledge also serves as a definition of the research areas that are found within GI S&T. What if your attempted mapping fails or you have other suggestions? Please contact the Task Force and let us know!

A Unit Level View of the Strawman GI S&T Knowledge Areas

CS. Conceptualization of space
- CS1 Characteristics of space
- CS2 Spatial thinking
- CS3 Field–based vs. object–based views of geographic space
- CS4 Spatial relationships

FS. Formalizing spatial conceptions
- FS1 Effects of scale
- FS2 Data modeling
- FS3 Representation of inexact information

SM. Spatial data models and data structures
- SM1 Basic storage and retrieval structures
- SM2 DBMS & the relational model
- SM3 Tessellation data models
- SM4 Vector data models
- SM5 Multiple scale representation/models
- SM6 Object–based models
- SM7 Temporal representation/models
- SM8 Query operations & query languages
- SM9 Metadata
- SM10 Data exchange & interoperability

DE. Design aspects of GI S&T
- DE1 Scientific modeling in a spatial context
- DE2 GI S&T applications: I – Conceptual system design
- DE3 GI S&T applications: II – System implementation design

DA. Spatial data acquisition, sources and standards
- DA1 Remote sensing
- DA2 Field data collection
- DA3 Sample design
- DA4 Data quality
- DA5 Surveying
- DA6 Photogrammetry

DM. Spatial data manipulation
- DM1 Data format conversions
- DM2 Generalization and aggregation
- DM3 Transaction management of spatio–temporal data

EA. Exploratory spatial data analysis
- EA1 GIS analytic functionality
- EA2 Descriptive spatial statistics
- EA3 Scientific visualization
- EA4 Data mining

[continued on next page]

A Unit Level View of the Strawman GI S&T Knowledge Areas

[continued]

CA.	**Confirmatory spatial data analysis**	
	CA1	Spatial statistics
	CA2	Geostatistics
	CA3	Spatial econometrics
	CA4	Analysis of surfaces
	CA5	Transportation modeling and operations research
	CA6	Simulation and dynamic spatial modeling
CG.	**Computational geography (geocomputation)**	
	CG1	Uncertainty
	CG2	Computational aspects of dynamic spatial modeling and neurocomputing
	CG3	Fuzzy sets
	CG4	Genetic algorithms and agent–based models
CV.	**Cartography and visualization**	
	CV1	Conceptualizing spatial visualizations and presentations
	CV2	Building spatial visualizations and presentations
	CV3	Evaluating spatial visualizations and presentations
OI.	**Organizational and institutional aspects of GI S&T**	
	OI1	Managing GIS operations and infrastructure
	OI2	Organizational structures and procedures
	OI3	GI S&T workforce themes
	OI4	Institutional aspects
PS.	**Professional, social, and legal aspects of GI S&T**	
	PS1	Aspects of information and law
	PS2	Public policy aspects of geospatial information
	PS3	Economic aspects of geographic information science & technology
	PS4	Legal and ethical responsibility for the generation and use of information
	PS5	Control of information – Information as property
	PS6	Control of information – Dissemination of information

Availability on the Internet

The full text of this document, in PDF format, may be found on the UCGIS web site. In addition, the page containing the download link for this document contains a link pointing to a site where comments upon all or part of the document are solicited.

Chapter 6

IRONMAN – The Next Phase of the Model Curricula Development

The next or *Ironman* phase of the development of the Model Curricula in Geographic Information Science & Technology (GI S&T) is a critical one, and a substantial effort will be required in order to insure its effective and timely completion. The primary purpose of the *Ironman* phase is to clearly bridge the gap between the *Strawman* creation of a general development plan and an initial draft of the GI S&T Body of Knowledge, on the one hand, and the delivery of the details of the specific curricula paths and the implementation and support plan that will make up the final *Steelman* document on the other.

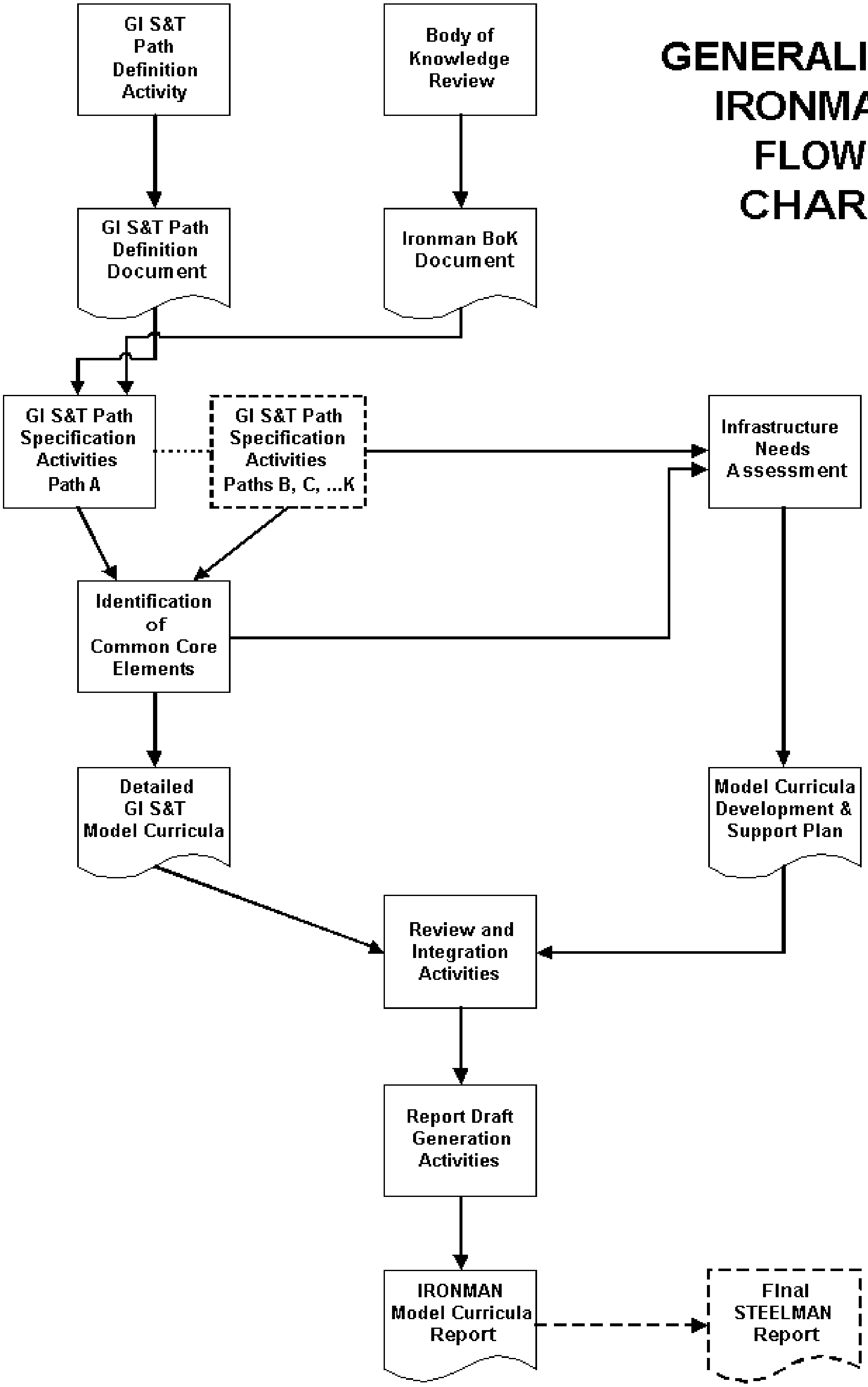
The *Ironman* Task Force can anticipate the need to accomplish several challenging and interrelated tasks. These include:

1 Initially insuring that the *Strawman* Body of Knowledge materials are widely reviewed by both academic and professional components of the GI S&T community. (Initial components of this review will be set in motion by the present *Strawman* team.) The incorporation of these external comments will lead to a modified *Ironman* version of the Body of Knowledge that, hopefully, will be representative of the views of a majority of the broad GI S&T community.

2. The two main *Ironman* development streams that follow reflect the need, on the one hand, to identify in some depth the various *paths* that individuals can take through the undergraduate portion of the GI S&T curricula. Each of the generalized paths that are identified needs to be formally analyzed to determine its most appropriate GI S&T content. The required content to be associated with each of these paths will be specified in terms of (A) a carefully selected subset of the elements of the GI S&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.

   On the other hand, it is also necessary to place the materials developed within the first stream firmly within the context of an operational *Curricula Development and Support Plan* that addresses infrastructure needs by suggesting possible solutions to critical support problems such as faculty retraining, the provision of necessary laboratory and library resources, start–up approaches for new GI S&T programs and the evaluation and revision of existing ones, the common provision of selected basic and advanced curricula elements via distance learning and other Internet–based approaches, etc.

GENERALIZED IRONMAN FLOW CHART



3. With respect to the first of the two *Ironman* development streams, the contents of each identified path through the Model Curricula must be defined at a substantial level of detail and with each of its components having associated with it a carefully determined level of competence (see Chapter XXX). The level of detail to be specified is generally reflected in the *topic* level breakdowns that are found in the GI S&T Body of Knowledge.

   All of the GI S&T curricular paths exist within the broader context of general undergraduate education and the GI S&T portion of each of the student's overall program of study must be augmented with explicit references to necessary supplemental knowledge that is to be acquired by the student as a result of contact with other undergraduate curricula — such as those defined in computer science, information technology, mathematics and statistics.[4] It will also be necessary, in many cases, for the path description to explicitly sequence the non–GI S&T curricula elements with the GI S&T elements contained in the path. For example, general computer science elements on data structures, algorithms, etc., may reasonably be expected to be encountered by the student prior to his or her instruction with regard to their spatial equivalents).

   Nearly all U.S. undergraduate programs operate within a series of overreaching college– or university–wide general education requirements. In the case of some of the paths, it may be useful for the GI S&T path description to present helpful suggestions to the student and/or advisor with respect to the useful selection of alternatives among various general education offerings. For example, it might be suggested that a student embarking upon a path that emphasized work in remote sensing would find it efficient to select an introductory physics course instead of one in the introductory biological sciences as part of his or her general education science requirements.

4. Activities within the second *Ironman* development stream are no less important than the path structures being identified within the first stream. This should be obvious since enjoining people as to what should be done without addressing relevant questions of the ways and means such actions may be accomplished is generally ineffective. A number of practical, operational problems must be both identified and subjected to an analysis in order to develop one or more suggested approaches to the solution of each identified implementation problem.

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[4] Relatively straightforward links can be made to elements of the Computer Science Model Undergraduate Curriculum and the similar document for Information Technology. These curriculum documents have recently been completely revised and their revisions are based upon the same basic methodology that has been utilized for the GI S&T Model Curricula work. See: http://www.computer.org/education/cc2001/final/cc2001.pdf for computer science and http://www.acm.org/education/is2002.pdf for information technology.

The need for a comprehensive *Curricula Development and Support Plan* has been demonstrated in nearly every open discussion that has taken place during the course of the Strawman phase. Questions such as the following have been raised :

> "How can we implement a selected portion of the GI S&T Model Curricula when our institution does not have a geography (or whatever) department?"
>
> "Our faculty agree that more technical depth is required in our GI S&T program but they feel that their own backgrounds are not adequate to provide it. How can this situation be remedied?"
>
> "What can we do to incorporate formally structured GI S&T intern programs into the undergraduate experience at a level above that of 'just get a part–time job'?"
>
> "How much will these changes cost?"

Concerns such as these continue to reappear and suggested solutions must be provided if the GI S&T Model Curricula are to have any real impact upon the general problems that were identified at the start of the design activity.

Approaching the *Ironman* Activity

The *Strawman* activity was a particularly arduous one due to the difficulties faced in developing an operational methodology that would effectively service the broad, interdisciplinary domain of Geography Information Science & Technology. This was followed by the need to couple the wide domain definition with a well structured, domain–specific Body of Knowledge. This latter activity had not been addressed previously and the creation of the initial *Strawman* draft imposed a heavy burden upon all the members of the Task Force as well as a number of others who volunteered to assist with specific portions of the material.

The *Ironman* activity, on the other hand, benefits from a much more well defined structure and the great majority of the tasks involved can not only be run in parallel but the responsibility can be effectively delegated to individuals or small groups instead of requiring an "all hands" approach. To accomplish its goal, it is strongly suggested that the Ironman Task Force be organized as follows:

- One individual to act as overall coordinator of the effort and to serve as Chair of the Task Force.
- Two individuals to serve as Stream Coordinators. One of these individuals would be principally concerned with the path selection and path definition

operations while assisting with the BoK revision. The second individual would initially assume primary responsibility for generation of the *Ironman* version of the GI S&T Body of Knowledge and, when this was complete, he or she would assume then assume responsibility for the work required to create the draft Development and Support Plan.

- These three individuals, together with the Chair of the UCGIS Education Committee and either the President of UCGIS or a formally appointed member of the UCGIS Board would compose the *Ironman* Steering Committee.

- The Steering Committee would be responsible for the identification of specific activities within each of the development streams and for the recruitment of GI S&T professionals (drawn from academic, government and industry) to accept responsibility for the work to be done on each activity. These individuals would then be encouraged to invite a very limited number of others to assist them.

- The Stream Coordinators, with the assistance of the other members of the Steering Committee, would be responsible for establishing a realistic time line for work on the defined activities and for monitoring the progress that is being made on each of them.

Resources will be required in order to effectively complete the *Ironman* activity. Support for the *Strawman* effort has come largely from ESRI and other UCGIS affiliates. It is hoped that they will continue their support for this next phase. It has also been suggested that the Body of Knowledge review and update (which is initially being carried out via the Internet) would benefit from the focused attention that could be directed toward it by the participants in a one or two day workshop. These individuals would be representative of the broad GI S&T community and would be given ample opportunity prior to the workshop to review not only the draft Body of Knowledge but also the comments on it that had been generated over the Internet. Such a workshop could also be conceived of as research definition activity and, as such, it might be sponsored by the research side of the National Science Foundation or some other funding organization.

The primary resource required, is of course, the time donated by the volunteers who will be doing most of the work. 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. This is in sharp contract to the attitude of the organizations involved in supporting both the computer science and information technology undergraduate curriculum efforts.

What About the *Steelman* Report?

One final activity, the *Steelman*, follows the *Ironman* work. In contrast to the two previous reports this basically represents the generation of a revised document based upon public comments on the *Ironman* report. As such, it can be completed in a much shorter period of time and with smaller resource commitments. Assuming a four month review and comment period, the final revision should be able to be completed in no more than an additional 90 days.

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Appendix A

The GI S&T Strawman Body of Knowledge

This statement of the Geographic Information Science & Technology (GI S&T) *Body of Knowledge* represents an initial attempt to define the domain and content of the broad, but highly interrelated, interdisciplinary area of GI S&T. The domain of GI S&T has been divided into twelve (12) distinct **Knowledge Areas**. Each of these knowledge areas is further subdivided into a series of **Units**, and each unit is broken down still further into a series of **Topics**. The topics will form the building blocks of the subsequent course development process.

The Twelve GI S&T Knowledge Areas

CS.	Conceptualization of space
FS.	Formalizing spatial conceptions
SM.	Spatial data models and data structures
DE.	Design aspects of GI S&T
DA.	Spatial data acquisition, sources and standards
DM.	Spatial data manipulation
EA.	Exploratory spatial data analysis
CA.	Confirmatory spatial data analysis
CG.	Computational geography (geocomputation)
CV.	Cartography and visualization
OI.	Organizational and institutional aspects of GI S&T
PS.	Professional, social, and legal aspects of GI S&T

This version of the GI S&T Body of Knowledge (BoK) is referred to as the *Strawman BoK* following the long established tradition of creating *a candidate definition or statement presented to invite discussion, critique and modification*. Substantial discussion of this material among all components of the GI S&T community, including industry, government and academia, is necessary to support the creation of a modified *Ironman* version of the BoK that will be generally accepted by all components of the GI S&T community and that will form the basis for GI S&T curricula development.

The subsequent *Ironman* version of the Body of Knowledge will form the basis for the explicit and detailed development of a series of model curricula paths setting forth, at the topic level, the critical areas of the GI S&T Body of Knowledge necessary in order to attain the desired outcome of a specific curricular path. These curricular paths will differ not only in terms of their desired outcomes but also in terms of the depth of knowledge that is required of the student with respect to each of the identified topics. It is suggested elsewhere in this report that five categories of depth of knowledge be utilized: *Awareness, Literacy, Use, Application Development* and *Mastery* (in order of complexity).

CS. Conceptualization of space

The GI S&T perspective is grounded in spatial and spatio–temporal thinking. The aim is to develop in the individual the ability to recognize, identify and appreciate the explicit space and space-time components of the environment at the ontological level. This involves understanding the nature of space and time as a context for earth-related phenomena. Space-time conceptualization includes such notions as different views of space and time for differing applications and different disciplines (e.g., absolute vs. relative space-time and alternatives to Euclidean space). This area also includes development of an understanding of scale, pattern, location, and region, and forms the basis for understanding the other knowledge areas. On a more advanced level, this area incorporates issues of spatial thinking and representation.

Suggested unit breakdown

CS1. Characteristics of space

Examination of the perceived properties or traits of space and space–time, particularly those properties that distinguish data with a spatial or space-time component from other forms of data. This includes absolute vs. relative, discrete vs. continuous, (and for time, cyclical vs. linear) and their implications for spatial analysis.

Suggested topic level breakdown:

- CS1–1 The perceived world
  - Selection and interpretation
  - Abstraction and generalization
  - How representation can guide action
  - Linguistic and graphic storage and communication of geographic information
  - Spatial learning through direct and indirect observation
- CS1–2 Breaking down the world into elements
  - Spatial ontology: things and groups of things
  - Continuous vs. discrete
  - Points, lines, areas, locations
  - Hierarchies
  - Attribute information
- CS1–3 Similarities of space and time
  - Gradual change is typical (fuzzy boundaries)
  - Alternative potential paths
- CS1–4 Differences of space and time
  - The forward arrow of time
  - The universal now
  - Units of measurement

CS1–5 Differing views of spatial phenomena
    Absolute vs. relative space, absolute vs. relative time
    Cyclical vs. linear time

Learning objectives:

1. Understand that there are different views of the world, depending on level of experience and application context.
2. Understand that perception of reality, and stored information about reality in *any* form is necessarily an abstraction.
3. Describe the basic process involved in learning about our environment
4. Describe the basic elements used to describe spatial phenomena.
5. Understand the difference between discrete and continuous views and give examples of point, line, and areal features
6. Explain how viewing time as "the fourth dimension" is inherently limiting with respect to geographic understanding.
7. Explain the notion of categorization as it applies to how people conceptually organize spatial knowledge

CS2. Spatial thinking

This unit is concerned with developing spatial awareness and an understanding of the importance of viewing elements in our world from a spatial perspective. This includes development of the ability to describe geographic phenomena and compare differing specific examples using basic principles.

Suggested topic level breakdown

CS2–1 Spatial vs. geographic scale
    What is "geographic scale"?
    The importance of scale
CS2–2 Location as an explanatory attribute
    Shape & size
    Spatial association
        Distance & Tobler's law (distance decay)
        Aggregation & spatial clustering
        Spatial pattern - regular, clustered, random
        The "region"
CS2–3 Using geographic frames of reference
    Lat/long, street addresses
    Relative vs. absolute
CS2–4 Comparing maps

Learning objectives:

1. Understand the meanings of terms such as orientation, arrangement, pattern, dispersion and spatial association and be able to use them when discussing geographic phenomena.
2. Illustrate how geographic elements often occur at specific scales, but that these are often part of larger processes with elements operating at a hierarchy of scales.
3. Illustrate the impact of scale on our perception of the world.
4. Use some geographic frame of reference to describe relative location, spatial associations and pattern within a given real-world context..
5. Be able to identify regions on the basis of specified criteria.
6. Describe differences in pattern and spatial relationships by comparing two maps.

CS3. Field–based vs. object–based views of geographic space

Deals with the two basic modes of conceptualizing the perceived world, as either a location–based view, with space–time being the basis of the representation, or an entity–based view, with ‘things,’ or discrete entities, being the basis of the representation. This knowledge unit stresses the duality of these two basic views, with addition of a third for portraying dynamics.

Suggested topic level breakdown

CS3–1	The location–based view Focusing on “where” Space as a container
CS3–2	The object–based view Focusing on “what” Describing space as an attribute
CS3–3	A time–based view Focusing on “when” Storing events relative to a time line
CS3–4	“Where”, “what” and “when” as complementary and necessary for complete representation

Learning objectives:

1. Describe real-world examples of location–based, object–based, and time–based views.
2. Explain how any single view can portray all information with regard to a specific spatial context, but how this is inherently limiting.
3. Explain how the location–-based and object–based views are logical duals of each other.
4. Describe how location–based and object–based views correspond to the idea of discrete and continuous types of representation.

CS4. Spatial relationships

Examines the various types of associations or linkages between different space-time entities or locations and their significance in describing space–time phenomena and solving geospatial problems.

Suggested topic level breakdown

CS4–1	Absolute vs. relative measurement Distance & direction Proximity & connectedness
CS4–2	Geometric vs. proximal regions
CS4–3	Topology
CS4–4	Planar graphs
CS4–5	Simplices and cell complexes

Learning objectives

1. Describe the difference between absolute and relative spatial relationships and be able to give examples.
2. Explain the basic idea of topological relationships.
3. Understand the idea of planar graphs, simplices and cell complexes, and how they apply to elements in geographical space.

FS. Formalizing spatial conceptualizations

The aim of this knowledge area is to impose an explicit logical structure upon those ideas identified as components of space-time conceptualization. Formalizing involves casting our conceptual view of space and time into a specific, logical-level organizational structure from a given ontological view or application perspective. Formalization incorporates a set of specifications to measure, reference, and locate spatial and spatio-temporal conceptualizations. Elements include modes of measurement, coordinate systems, map projections, spatial relationships, topology, object and object-type categories, diffusion, and network flows. Considerations of error and data quality (e.g., MAUP) are included within this knowledge area.

Suggested unit breakdown

FS1. Effects of scale

This first unit is concerned with how the size of an object or location as represented in a database, map or other form relates to the thing represented.

Suggested topic level breakdown

FS1–1	Effects of scale on spatial sampling
FS1–2	The Modifiable Areal Unit Problem (MAUP)
FS1–3	Map generalization

Learning objectives

1. Understand how the scale of data capture affects portrayal of a phenomenon in a stored database.
2. Understand the possible impact of putting data portrayed on differently scaled maps into a single database.

FS2. Data modeling

Deals with the process of designing a data model or database model from the abstract, conceptual level to the implementation level. Specific topics include examination of the varying levels involved, the overall process, and specific techniques and tools used in the data modeling process.

Suggested topic level breakdown:

FS2–1	Storing information in a computer
FS2–2	Databases, data models, and levels of representation
FS2–3	Suiting the representation to the application
FS2–4	Top–down design as a means of gradual refinement

FS2–5	E-R analysis & UML

Learning objectives

1. Explain why the data modeling process can impact subsequent analysis of the stored data.
2. Explain why there is no such thing as the “perfect” data model.
3. Describe levels of representation as it applies to the geographic context.
4. Describe what data models and databases are, and the differences between them.
5. Describe the E-R analysis process.
6. Illustrate the use of UML in a simple example.

FS3. Representation of inexact information

Examines methods and strategies for representing, both conceptually and in computer data models, information that (a) by nature cannot be defined with sharp boundaries or categorization criteria or (b) is not completely known at the needed level of detail.

Suggested topic level breakdown:

FS3–1	Fuzziness
FS3–2	Uncertainty
FS3-3	Grouping in geographical and attribute space
FS3–4	Membership functions
FS3–5	Artificial discretization and the MAUP
FS3–6	Fuzzy set theory, rough sets and probability

Learning objectives

1. Explain the idea of artificial discretization and the impact on accuracy in geographic databases.
2. Be familiar with different membership functions that could be used to group or discretize locational or attribute information.
3. Describe fuzzy set theory, rough sets and probability and how these can be used to represent inexact information.

SM. Spatial data models and data structures

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 (e.g., 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. DBMS and the Relational Model and their application for spatial data are included within this knowledge area, as well as the notion that not all data models need to be represented in a computational environment, but they are complementary in a shared database. Data structures represent the operational implementation of data models within a computational environment.

Suggested Unit Breakdown

SM1. Basic storage and retrieval structures

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

Suggested topic level breakdown:

SM1–1 Review of basic file structures
- Simple lists, ordered sequential, indexed
- Direct vs. indirect access
- Pointers
- Hashing

SM1–2 Hierarchical structures
- Basic terms: node, parent/child
- B-trees

Learning objectives

1. Understand basic terminology, such as record and field, parent/child.
2. Distinguish between a data model, data structure and file structure as it relates to levels of representation.
3. Describe the differences between direct and indirect access, and the advantages and disadvantages of each.
4. Compare and contrast the complexity/efficiency tradeoffs in using various basic file structures.

SM2. DBMS and the relational model

This unit is concerned with the use of Database Management Systems in a geographic context, in particular, the role of modern Relational Database Management Systems.

Suggested topic level breakdown:

SM2–1	Evolution of DBMS and GIS
SM2–2	Hierarchical and network DBMS
SM2–3	Relational DBMS and SQL
SM2–4	Uses and limitations of “standard” DBMS
SM2–5	Efforts to extend the relational model to accommodate the geographic context.

Learning objectives

1. Be familiar with the terminology of relational database management systems including such terms as tuple, relation, foreign key, SQL, and relational join.
2. Explain the differences among network, hierarchical and relational database structures, and their uses/limitations for geographic data storage and processing.
3. Know the basic operations provided within a Relational DBMS, such as relational join, and explain how they work.
4. Know how DBMS are currently used in conjunction with GIS.

SM3. Tessellation data models

Looks at the class of computer data model, based on the field–based view, that quantizes space into a regular or irregular tessellation. This knowledge unit, as well as the four following, deals with both conceptual data models and computer data structures. Specific examples are examined and compared on the basis of suitability for varying types of problems with regard to specific factors including algorithmic simplicity and efficiency.

Suggested topic level breakdown:

SM3–1	Regular tessellations
SM3–2	The grid model
SM3–3	The raster as a type of grid/rectangular tessellation
SM3–4	Grid cell resolution and its implications
SM3–5	Grid compression methods
SM3–6	The hexagonal model
SM3–7	The TIN model: an irregular tessellation

Learning objectives

1. Describe the relationship between tessellations and the location-based view.
2. Enumerate the three types of regular tessellations and the advantages and disadvantages of each for geographic data storage and analysis.
3. Enumerate the types of tessellation models that have been used in GIS and why.
4. Describe the difference between a tessellation, a grid and a raster data model.
5. Explain the impact of grid cell resolution on the quality of the information portrayed and the implications for analytical application.
6. Describe methods for compressing gridded data.
7. Describe the hexagonal model and its past and potential uses, compared to the grid model.
8. Describe the TIN model and its uses.

SM4. Vector data models

Looks at the class of computer data model, based on the object–based view, that represents discrete space -time entities by delineating points, lines, boundaries and nodes as sets of coordinate values. Specific historical examples are examined as prototypes. These are also compared on the basis of suitability for varying types of problems with regard to specific factors including algorithmic simplicity and efficiency.

Suggested topic level breakdown:

SM4–1	The spaghetti model
SM4–2	The topological model
SM4–3	Tree and network structures
SM4–4	GBF/DIME
SM4–5	Hierarchical vector structures - PolyVrt
SM4–6	TIGER
SM4–7	Freeman–Huffman chain codes

Learning objectives

1. Describe the spaghetti model, as well as the topological model, GBF/DIME, PolyVrt, TIGER and Freeman–Huffman chain codes.
2. Explain the topological characteristics of tree and network structures, and their applications.
3. Explain the relative advantages and disadvantages of each major type of vector model.
4. Describe the relationship between the GBF/DIME and TIGER structures, the rationalization for their design, and their intended primary uses.
5. Describe uses for Freeman-Huffman chain codes and their relation to the raster model.

6. Identify conceptual models used in current specific GIS products as they relate to the given prototypes.

SM5. Multiple scale representation/models

Deals with hierarchical data models in handling data at multiple spatial and conceptual scales. Issues relating to irregular vs. regular progression of spatial scale in such representations is addressed, particularly in relation to scales of pre–existing data sources (including archival map documents). Emphasis is placed on the capabilities/limitations of each on the basis of simplicity, efficiency, and effectiveness for geographic analysis.

Suggested topic level breakdown:

SM5–1 The quadtree model
SM5–2 Quadtree variants
    Hex–tree
    Pyramid
    R-tree
SM5–3 Addressing techniques
    Pointers
    Morton addressing

Learning objectives

1. Describe the quadtree model and its advantages/disadvantages for geographic database representation.
2. Explain addressing options for the quadtree data model and its extensions and the advantages/disadvantages of each.
3. Describe the particular advantages of Morton addressing relative to geographic data representation.
4. Discuss how specific multiple scale representation models might be used in various practical situations for dealing with very large data volumes.

SM6. Object–based models

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. This knowledge unit deals with both conceptual data models and computer data structures.

Suggested topic level breakdown:

SM6–1 From vectors to objects — beyond lines–on–maps
SM6–2 Object hierarchies

SM6–3	Categorization of objects in geographic space
SM6–4	Object–oriented representation vs. object oriented programming
SM6–5	Inheritance
SM6–6	Combining and generalizing objects
SM6–7	Recent examples of object–based representations for geographic data
SM6–8	Standards efforts utilizing or incorporating an object–oriented approach

Learning objectives

1. Explain the differences between object–based models and vector models.
2. Describe the notion of 'objects' as things in space and how these are grouped into classes, or categories of things, from a cognitive perspective.
3. Describe the principle of inheritance both from the standpoint of human, cognitive, categorization and how this can be implemented using an object-oriented programming approach.
4. Compare and contrast recent examples of object–based representations with an example of a vector–based representation.
5. Identify specific issues relating to why standards efforts are incorporating an object–oriented approach for geographic data representation.

SM7. Temporal representation/models

Is concerned with how geospatial conceptual representations and data models can be extended into the temporal dimension and why this is important. Specific issues dealing with the temporal dimension in space–time representation are examined and why this is currently considered a difficult research problem. Emphasis for examples developed to-date is placed on the capabilities/limitations of each on the basis of simplicity, efficiency, and effectiveness for geospatial analysis.

Suggested topic level breakdown:

SM7–1	Why is this a difficult problem? Time is different yet similar Increasing dimensionality/complexity Data–related issues
SM7–2	Related efforts in temporal DBMS
SM7–3	Examples of space–time models – beyond the snapshot
SM7–4	Implications for multi–representation geographic databases

Learning objectives

1. Describe the advantages and limitations of the snapshot model for space-time data representation.
2. Explain the type of analyses/queries relating to time and change that cannot be accomplished in current GIS.
3. Discuss the specific properties of the temporal dimension that make representation of change in geographic space as a 3–D (or perhaps 4–D) cube advantageous yet inherently limiting.
4. Name one or two SQL extensions for including time.
5. Describe examples of existing space–time models and their advantages/limitations.

SM8. Query operations & query languages

Examines the specific operations used in GI S&T and how they are used for geospatial analysis, some analysis tasks requiring a complex dialogue of many individual operations. Besides appropriate use, there is also emphasis on how these operations function algorithmically (i.e., inside the 'black box' of GI Technology).

Suggested topic level breakdown:

SM8–1	Set theory
SM8–2	Spatial relationships & query operations unique to the spatial context
SM8–3	Spatial algebra
SM8–4	Temporal relationships
SM8–5	SQL and extensions (spatial and temporal)

Learning objectives

1. Describe set theory and how it relates to spatial queries.
2. Enumerate spatial (and temporal) relationships and the differences between absolute and relative relations .
3. Understand how multiple operations can be combined, including spatial and non-spatial operations.
4. Explain the basic rationale behind SQL, its basic syntax and operators.

SM9. Metadata

Is concerned with documentation describing the data, its importance, its use, and current efforts toward standardization for geospatial data. Emphasis is on what documentation about data should be captured during the database construction process and represented within the database (and how it is represented), as well as what metadata should be expected as part of distributed data products.

Suggested topic level breakdown:

SM9–1	Metadata – what it is and what it includes
SM9–2	How metadata should be represented
SM9–3	The uses/value/importance of metadata
SM9–4	The use of metadata in data management
SM9–5	Metadata resources and standardization efforts

Learning objectives

1. Explain what metadata is and its importance.
2. Describe what metadata should be expected in any data set / in generally distributed data sets.
3. Cite some important resources for creating metadata and some federal-level standardization efforts.

SM 10. Data exchange and interoperability

Examines issues of converting data from one data model/structure to another, as well as combining capabilities of more than one software system, the difficulties encountered in data exchange, and the pro's/con's of standardization. This includes data exchange from one GIS to another and use of standard digital products as well as the notion of data warehouses. This knowledge unit also examines issues relating to the use of computer applications software within differing software contexts without the need to reprogram (i.e., a modular software approach). Specific efforts of various national and international organizations are covered within this unit.

Suggested topic level breakdown:

SM10–1	Data warehouse vs. database
SM10–2	The value of being "open"
SM10–3	Issues of data model/structure conversion
SM10–4	The evolution of database and software standards
SM10–5	Web–based GIS & web-based geo–services
SM10–6	The Open GIS Consortium (OGC)

Learning objectives

1. Discuss the advantages and disadvantages of data standards and standardization.
2. Compare and contrast the concept of a database and a data warehouse.
3. Describe the idea of web–based GIS and their advantages.
4. Identify the conceptual and practical difficulties associated with data model/structure conversion.
5. Explain the basic idea of web–based GIS, their advantages/disadvantages, and name some current examples.

6. Discuss the purpose of the OGC and describe its efforts.

DE. Design aspects of GI S&T

Proper design, and the validation and verification of design activities, are critical components of work in all areas related to GI S&T. Design failures can negate the best efforts of members of the GI S&T community to apply GI S&T concepts and technology to the solution of real–world problems. While sharing a number of concerns with general systems analysis, the unique and complex spatial elements of GI S&T provide significant additional challenges.

Viable design methodologies are required in GIScience, in the tool building and testing that characterizes GI Technology, and most clearly in the application of GI S&T to the reduction of real–world problems. These design activities fall into three general classes:

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;

System Design addresses the development of conceptual models of GI systems that combine existing geographic information science concepts and geographic information technology to march carefully derived requirements that reflect specific, operational spatial problems; and

Spatial and Spatial–Temporal Database Design concerns the optimal organization of the necessary spatial data in a computer environment in order to efficiently sustain desired GI S&T activities.

Suggested unit breakdown

DE1. Scientific modeling in a spatial context

Suggested topic level breakdown:

DE1–1	Spatial processes and the scope and structure of the model
DE1–2	Establishing the effective spatial domain of the model
DE1–3	The interaction between tools and problems: the case of the GIS
DE1–4	Selected case studies of the development of spatial models

Learning objectives

1. Be able to isolate the spatial components of a problem, and to understand the linkage(s) between the spatial and non–spatial elements of the problem.

2. In a specific problem situation, intelligently discuss the interactions between spatial problems and relevant models and between spatial models and currently available tools and data.
3. Be capable of (a) identifying a spatial problem at a nominal level of difficulty, (b) suggesting a modeling approach to its solution, and (c) identifying relevant, off–the–shelf GI S&T tools and data that may be useful in the solution of the problem.

DE2. GI S&T applications: I – Conceptual system design

Suggested topic level breakdown:

DE2–1	Establishing the nature of the problem and its bounds
DE2–2	Identification of the potential users of the GI application
DE2–3	Identifying individual user views of requirements and related spatial data needs
DE2–4	User view integration – the creation of a single integrated and consistent view of user requirements and spatial data needs
DE2–5	Evaluation of the impact of potential technical and data constraints and the establishment of system priorities
DE2–6	Examination of both user–specific and overall costs and benefits
DE2–7	Generation of a final, prioritized set of requirements and data needs that are feasible within the context of the overall set of economic and technical constraints

Learning objectives

1. Develop a firm understanding of the role of structured design in the creation of successful GI S&T applications.
2. Be able to derive specific geospatial data needs from user descriptions of desired Spatial Information Products. Demonstrate, while doing so, a basic grasp of the special design tools (e.g., Data Flow Diagrams) that are used.
3. Be capable of applying the view integration approaches used to create a viable and prioritized global view from individual user statements of their desired Spatial Information Products.
4. Understand the concept of the system life cycle and its application to GI S&T.
5. Experience, if possible, within a laboratory or structured internship environment, the full range of activities making up the GI S&T conceptual design process.

DE3. GI S&T applications: II – System implementation design

Suggested topic level breakdown:

DE3–1 Moving from the conceptual model to a general spatial database design
DE3–2 Finding common operational components within the conceptual model.
DE3–3 Design of application–level software components and user interfaces.
DE3–4 Matching the enhanced conceptual model to available GI S&T technology.
DE3–5 Planning for implementation (staffing, space, equipment, etc.).
DE3–6 Planning for spatial database implementation and update.
DE3–7 Developing an implementation time line.
DE3–8 Verification and validation of conceptual and implementation design activities
DE3–9 GI S&T system design and evaluation as a continuing process.

Learning objectives

1. Display a firm understanding of the wide range of problems encountered in moving from conceptual design to actual implementation.
2. Be able to compare and contrast the wide range of different operational configurations permitted by modern GI S&T technology.
3. Discuss and demonstrate the close relationship between traditional software engineering approaches and the operational configuration of GI S&T technology.
4. Perform an effective evaluation of a conceptual design and implementation plan developed by others.

DA. *Spatial data acquisition, sources and standards*

The importance of this knowledge area lies in developing an understanding of the sources and types of spatial and spatio-temporal data – coordinate location, text, tables, images, derived data layers – with their associated levels of accuracy. Data acquisition is required for the development of fundamental data layers within a GIS. These 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 (air photography, satellite imaging), the global positioning system (GPS), work logs (e.g., police accident reports), and surveys. Secondary spatial or spatial–temporal data can be acquired by digitizing and scanning analog maps as well as from other sources, such as governmental agencies.

In data acquisition, spatial–temporal location measures and measurement of attributes are both important. For example, the description of a hazardous waste site at a specific location and point in time can also include a description of the nature of the hazard. Data standards for spatial data, images, and metadata exist to document data quality, lineage and appropriate use. An understanding of these is required to permit effective integration of primary and secondary data from diverse sources. Some of the prevalent data standards are provided by organizations such as the Federal Geographic Data Committee (FGDC) and International Organization for Standards (ISO).

Suggested unit breakdown

DA1. Remote sensing

Topics include dimensions of remotely sensed data, sensor platforms, sensor characteristics, electromagnetic radiation, and many more.

Suggested topic level breakdown:

DA1–1 Dimensions of remotely sensed data.

Examine the spatial, temporal, radiometric, and spectral dimensions of remote sensing. T

Relate these dimensions the context of the larger GI S&T body of knowledge.

DA1–2 Platforms and Sensors

Examine the relationships between the platforms (e.g. aerial versus satellite) and the capabilities of the actual sensor systems.

DA1–3 The natural setting of remote sensing

The nature of electromagnetic radiation and of the physical environments that are to be sensed.

Interactions between the capabilities of the platforms and sensors and the physical environment to provide decision products.

Terrain and shadow effects, atmospheric interaction, surface roughness, etc.

DA1–4 Algorithms and processing

Algorithms used to rectify, correct, enhance, and classify remotely sensed imagery.

Linkage to other spatial temporal data within a GIS.

DA1–5 Ground verification and accuracy assessment

Existing methods of ground verification, and computational methods of accuracy assessment. [See also DA4.]

DA1–6 Applications and settings

Selected applications and case studies

Learning objectives:

1. List and provide a concrete example of each of the dimensions of remote sensing.
2. For each major platform, explain the characteristics such a platform has and how it relates to the imagery obtainable.
3. Describe the characteristics of sensor systems and their relationships to the platforms.
4. Relate the dimensions of remote sensing to the available platforms and sensors.
5. Suggest appropriate combinations of sensor systems, platforms, and their related dimensionality to a variety of natural and anthropogenic sensing tasks. [See DA1–1.]
6. Describe and explain the algorithms used in remote sensing for rectification, correction, enhancement, and classification of remotely sensed imagery.
7. Describe the problems associated with incorporating remotely sensed data with non–remote sensing–based GIS datasets.
8. Explain the techniques of ground verification and their role in the overall functioning of a GI system or project based largely on remotely sensed data.

DA2. Field data collection

Topics include field data collection methods (discipline specific), preparation of survey documents, transects, field plots, point sampling, sampling design (see below).
include the use of soil augers for soils and geomorphological work; plant presses, tree corers, and sampling grids for vegetation

Suggested topic level breakdown:

DA2–1	Field data methods	A general discussion of the tools and methods of collecting data in the field. This topic is very broad and may analysis; and a host of others. Each will be covered in the detail appropriate to the individual discipline. It may be covered within the context of individual, discipline specific, field courses, or through project–oriented GI S&T laboratory settings.
DA2–2	Automation techniques for field data	Discussions of the newer technologies available to add GPS, vocalization, digital photography, and digital video to traditional field data collection methods through the use of PDA / I-PAQ, and Digital Imaging devices.
DA2–3	Survey document preparation	Special attention is given to the development of unbiased, understandable, and utilitarian survey documents for surveys of human attitudes and views. Additional attention may be applied to the development of on–line e–surveys, together with the increasing availability of third–party statistical analysis.

Learning objectives:

1. For your own discipline demonstrate your ability to apply the appropriate sampling tools within a spatial sampling environment.
2. Explain why the spatial nature of the data collected through field methods must first be considered to be useful in a GIS context.
3. Demonstrate the application of new technologies to the sampling and recording of sample data for your own discipline.
4. Prepare a survey document and examine its strengths and weaknesses to obtain the desired, unbiased data.
5. Provide examples of on–line survey documents and discuss the merits and problems associated with their implementation.

DA3. Sample design

Topics include sample size selection, sample types (random, stratified, systematic and hybrid), information theory, modifiable area unit problem, etc.

Suggested topic level breakdown:

DA3–1	Sample size selection	Examines the methods of determining appropriate sample sizes necessary for inferential statistics. Special consideration is given to spatial size selection.
DA3–2	Spatial sample types	Discusses point, line, and quadrat methods within the context of random, stratified, systematic and hybrid sampling schemes. Review the pluses and minus of each method within selected sampling regimes.
DA3–3	Sample intervals	Units here include information theory and its relevance to sampling within a spatial environment, the problems associated with the modifiable area unit problem, relationships between study area shape and complexity and what is being sampled, minimum mapping unit considerations, etc.

Learning objectives:

1. Describe the methods available for determining the necessary sample size.
2. Discuss the parameters necessary to make a decision on sample size for inferential statistics.
3. Provide concrete examples of samples whose sizes you might question in view of their ability to provide appropriate inferences for the population.
4. Discuss the unique nature of spatial sampling as opposed to non–spatial sampling.
5. Diagram and discuss the appropriate situations (within your discipline) where point, line, or quadrat methods might best be applied.
6. Explain the pluses and minuses of different spatial sampling schemes and discuss the appropriateness of each for your own data types and discipline.
7. Describe the concept of the minimum mapping unit and explain its relationship to database development.
8. Explain with diagrams and text the modifiable area unit problem and demonstrate actual situations in which it could result in extremely varied results.

9. Provide a diagram that illustrates the limitations of a purely information theory–based sampling structure, particularly with regard to unusually shaped features.

DA4. Data quality

Topics include accuracy assessment, uncertainty, temporality, classification accuracy, classification appropriateness, error interaction, etc.

Suggested topic level breakdown:

DA4–1 Spatial accuracy

Fundamentals of absolute survey locational accuracy, standards, context (e.g. legal), and consequences of poor geodetic framework.

DA4–2 Temporal interactions

Data age versus accuracy particularly with regard to land ownership and changes in the landscape being modeled or incorporated into the software system. Data age related to classification systems will also be a topic here but will be covered in more detail in DA4–3.

DA4–3. Classification accuracy

Nominal and quantitative classification accuracy. Special attention is given to the integration of multiple datasets, particularly as the classifications reflect both reality and the given problem for which they are to be used. Attention will be paid to the role of aging classification systems as they affect dataset integration.

DA4–4 Error interactions

Latest theory regarding how error or uncertain data will interact within a GI S&T modeling environment. Error tracking and modeling. Weakest link hypothesis versus weighting methods.

Learning objectives:

1. Discuss the importance of a good geodetic framework and the problems associated with not having one.
2. Describe several situations in which poor absolute location could lead to serious problems in subsequent applications of the data.
3. Hypothesize about the impact of out–of–date spatial data within land records administration and taxation. Within your own discipline.

4. Construct scenarios in databases with nominally scaled map layers whose out of date data cause problems and explain how you might correct this.
5. Provide scenarios in which ordinal, interval, ratio, or scalar dataset interaction is compromised because of data classification problems.
6. Discuss the weakest link hypothesis and explain its limitations.
7. Describe some existing methods of tracking error in a GIS.
8. Discuss the difficulties associated with tracking error in complex modeling situations.
9. Explain the difference between error and uncertainty.

DA5. Surveying

Topics include GPS and radio navigation methods, plane surveying, coordinate geometry, land records, etc.

Suggested topic level breakdown:

DA5–1	Survey theory and traditional methods The basics of coordinate geometry, plane survey and basic survey methods in both 2–D and 3--D (terrain inclusive) environments.
DA5–2	Land records The history and importance of land records, their uses, inventory methods and problems of tracking ownership and change detection. Problems of land records, including missing records, incorrect codes, old or outdated information, etc.
DA5–3	Modern tools of the surveyor The use of GPS and radio navigation in setting up and maintaining a survey. This topic will typically include the basics of the technology itself as well as their operational application in setting up a geodetic framework.

Learning objectives:

1. Describe and illustrate the basic methods of plane surveying (e.g. traverse, triangulation, trilateration).
2. Explain the relationship between the Pythagorean Theorem and the Distance Theorem.
3. Demonstrate the use of modern survey equipment (especially the GPS unit).
4. Provide concrete examples of problems associated with the development and maintenance of land records databases.

DA6. Photogrammetry

Topics include history of aerial photographic interpretation, aerial camera systems and platforms, geometry of aerial photography, stereoscopy, orthophotography and elements of mission planning.

Suggested topic level breakdown:

DA6–1	Evolution of aerial imagery	A short history of the evolution and uses of aerial photography, especially as they are applied to mapping. The basic methods of aerial photo interpretation, elements of aerial photo interpretation, *apriori* and *aposteriori* methods, etc.
DA6–2	Systems and platforms	Relationships of platform characteristics and their impacts on the imagery produced, its accuracy and interpretability; image blur, scale, vignetting, etc. Film–filter basics and combination effects.
DA6–3	Stereoscopy and orthophotography	The basics of parallax and its utility for measuring elevation. Correcting for variable elevation and vignetting effects. Tools and measurement methods of stereoscopy.
DA6–4	Mission planning	Flight planning, flight line identification, timing, scale and overlap considerations for aerial photography particularly as it applies to the development of stereo pairs to be used for vertical measurements.

Learning objectives:

1. Through practical demonstration illustrate the application of all of the elements of aerial photo interpretation.
2. Explain the differences between apriori and aposteriori methods of aerial photo interpretation.
3. Discuss the advantages and disadvantages of the two basic methods of aerial photo interpretation for mapping.
4. Using several scenarios discuss the appropriate use of several film–filter combinations for mapping from aerial photography.
5. Define what parallax is and its importance in creating stereo pairs.
6. Demonstrate the use of available tools to measure vertical objects on aerial photographs.

7. Calculate the resolution of imagery under different conditions.
8. Demonstrate the ability to identify a flight line from a set of aerial photographs.

DM. Spatial data manipulation

This knowledge area pertains to the manipulations of spatial and spatio–temporal data that involve the transformation of the data into formats that facilitate subsequent analysis. Users frequently need to make decisions on when and how to engage in data manipulation. Examples of data manipulation include vector–to–raster conversion, line generalization, attribute aggregation, projection transformation, and transaction management.

Suggested unit breakdown

DM1. Data format conversions

Other knowledge areas have identified different forms of data structure, data models, projections, and other forms of spatio–temporal data representation. These differences present very real opportunities as well as creating limitations for analysis and modeling. The ability to change from one format to another, in a manner that is as lossless as possible, can enhance the analysis and visualization of spatio–temporal data.

Suggested topic level breakdown:

DM1–1	Vector–to–raster and raster–to–vector conversions
DM1–2	Impacts of conversion on practical use and visualization
DM1–3	Questions of locational and attribute accuracy
DM1–4	Projection changes: forward and inverse
DM1–5	Appropriate algorithms and questions of data loss

Learning objectives

1. Understand the algorithms used for vector/raster/vector conversions.
2. Be able to compare and contrast the impacts of different conversion approaches.
3. Be able to discuss the need for projection changes and the impact of these operations upon accuracy of the data set.

DM2. Generalization and aggregation

Maps and other spatio–temporal data frequently come into the GIS in pre–processed formats based on how they were collected, packaged, classified, and aggregated.

These present both accuracy and uncertainty issues, but more to the current topic, have serious impacts on GIS modeling.

Suggested topic level breakdown:

DM2–1	Approaches to point, line, and area generalization
DM2–2	Traditional cartographic questions of feature elimination and simplification
DM2–3	Geospatial data measurement levels (i.e., nominal, ordinal, etc.) and their relation to spatial modeling
DM2–3	Aggregation of the attributes of spatial entities
DM2–4	Generalization and aggregation impacts on the structure and operation of spatial models

Learning objectives

1. Be able to discuss traditional approaches to cartographic generalization and their impact upon the creation of digital data sets from analog originals.
2. Understand the interactions between questions of scale, generalization, and the results obtained from spatial modeling.

DM3. Transaction management of spatio–temporal data

In many circumstance, for example 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.

Suggested topic level breakdown:

DM3–1	Establishment of initial (baseline) condition of the database
DM3–2	Identification of the nature of the change traffic and of the user requirements for monitoring change in the database
DM3–3	Establishing and structuring the change component of the database
DM3–4	Reconciliation of change information within the database
DM3–5	Structuring queries dealing with dynamic systems
DM3–6	Problems of on–line (near real–time) vs off–line change data management

Learning objectives

1. Be able to discuss the problems of managing and analyzing dynamic systems from a spatial database point of view.
2. Understand the different approaches used to incorporate both discrete and continuous patterns of change into the spatial database.
3. Be able to contrast and compare the problems encountered in both data management and data retrieval operations in standard spatial databases and real–time transaction–oriented systems.

EA. Exploratory Spatial Data Analysis

This knowledge area refers to a wide variety of operations whose objectives are to 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. We call the exploration process *data driven* analysis, that is, it is the spatial and/or spatio-temporal data that arouse our curiosity and motivate us to want to learn more about its nature. Another phrase is often used in this context: "Let the data speak for themselves." Those units listed below cover many of the subject areas that emphasize spatial data exploration.

Suggested Unit Level Breakdown

EA1. GIS analytic functionality

In terms of data description it is useful to understand the capabilities of GIS software. These systems offer a myriad of data manipulation techniques that help in extracting meaning from sets of data.

Suggested topic level breakdown:

EA1–1	Definition of interactive and exploratory data analysis
EA1–2	Spatial queries
EA1–3	Overlays
EA1–4	Spatial proximity: adjacency and connectivity
EA1–5	Distances and lengths
EA1–6	Buffers
EA1–7	Shapes, slope, and aspect
EA1–8	Transformations
EA1–9	Graphic operations

Learning Objectives

1. Understand what is meant by spatial analysis.
2. Develop a sense of the range of queries possible with a GI S&T context.
3. Learn the methods for measuring length, shape, area, and other properties.
4. Show how the fundamental concepts of length, direction, and connection can be described.
5. Understand what is meant by spatial proximity and implement the various ways to measure it.
6. Understand the rudimentary transformations that manipulate objects to create new ones.

7. Determine geometric relationships between objects
8. Demonstrate the graphic operations used to explore characteristics of maps.

EA2. Descriptive spatial statistics

Traditional statistical methods are used to describe the central tendency, dispersion, and other characteristics of data. In addition to those methods, specialized techniques are particularly well suited to extract information from spatial data.

Suggested topic level breakdown:

EA2–1	Tobler's law
EA2–2	Scatterplots, histograms, boxplots, q–q plots, variograms
EA2–3	Distance decay: inverse distance weighting
EA2–4	Measures of spatial dependence
EA2–5	Measures of heterogeneity
EA2–6	The spatial weights matrix
EA2–7	Data classification schemes
EA2–8	Kernels and density estimation techniques

Learning Objectives

1. Understand the significance of Tobler's Law.
2. Demonstrate the description of data using a variety of graphs and plots.
3. Relate distance decay to a variety of phenomena.
4. Justify, compute, and test the significance of the join count statistic for a pattern of objects.
5. Compute Moran's I and Geary's c for a pattern of attribute data.
6. Determine the appropriate measures to differentiate varying degrees of heterogeneity.
7. Construct a spatial weights matrix for lattice, point, and area patterns.
8. Discuss the differences between a variety of data classification schemes.
9. Create kernels and explain their use for estimating object density.

EA3. Scientific Visualization

Given the ever-improving technology available for the manipulation of data, an array of visualization techniques have been created. These aid in the further understanding of the nature of data and allow the use to visually spot patterns. Static as well as dynamic schemes can be viewed to develop hypotheses and gain a deeper understanding of the nature of spatial data.

Suggested topic level breakdown:

EA3–1	Visualization of spatial distributions
EA3–2	Multivariate mapping; parallel coordinate plots and other devices
EA3–3	Object and field representations
EA3–4	Graphic primitives
EA3–5	Visual transformations
EA3–6	Cartograms
EA3–7	Dynamic mapping

Learning Objectives

1. Understand the rudiments of effective data display.
2. Describe how mapping can mislead.
3. Demonstrate how displays are customized to the requirements of particular applications.
4. Describe the graphic primitives and demonstrate their usefulness.
5. Demonstrate a visual representation of a multivariate scene.
6. Show how a visual transformation can change the interpretation of data.
7. Create one or more cartograms.
8. Consider the methods used to show dynamic representations.
9. Outline the visualization techniques of density estimation.

EA4. Data mining

In recent years, algorithms have been developed to scan and search through extremely large data sets in order to find relevant patterns within the data. These data mining and knowledge discovery techniques have been expanded to the spatial case.

Suggested topic level breakdown:

EA4–1	Large spatial databases: non-stationarity
EA4–2	Geographical analysis machines
EA4–3	Knowledge discovery
EA4–4	Data mining approaches, including cluster analysis
EA4–5	Pattern recognition and matching
EA4–6	Machine learning
EA4–7	Contaminated data

Learning Objectives

1. Explain the rationale needed for employing data mining techniques.
2. Appreciate the difficulties in dealing with large spatial databases, especially spatial heterogeneity.
3. Discuss the principles of knowledge discovery using data mining techniques.
4. Implement data mining algorithms on spatial data.
5. Explain the principles of pattern recognition and the techniques used.
6. Learn how to recognize and deal with contaminated data.

CA. Confirmatory Spatial Analysis

This knowledge area includes the techniques of spatial analysis where the goal is to create and test spatial and spatio-temporal process models. This may also be called *model–driven analysis.* In general, this is an advanced knowledge area where previous experience with exploratory spatial data analysis would constitute a desired prerequisite. This area is tied directly to specialized problems studied in the social, behavioral, and physical sciences. For example, the environmental modeler would want to learn the confirmatory analytic procedures particularly well suited for modeling a spatial environmental process such as air or water pollution.

Suggested Unit Level Breakdown

CA1. Spatial statistics

The field of spatial statistics forms the backbone for the testing of hypotheses about the nature of pattern, spatial dependency and heterogeneity. The techniques are special to GI Science & Technology and are widely used in both exploratory and confirmatory spatial analysis.

Suggested topic level breakdown:

CA1–1	Spatial association statistics
CA1–2	Pattern analysis
CA1–3	Nearest neighbor statistics
CA1–4	K–functions
CA1–5	Global statistics
CA1–6	Local statistics
CA1–7	Spatial sampling

Learning Objectives

1. Explain what is meant by spatial association statistics. Demonstrate their mathematical form.
2. Define point pattern analysis and list the conditions that are necessary for it to make sense to undertake it.
3. Suggest measures of pattern based on first and second order properties.
4. Define a number of descriptive measures for point patterns.
5. Describe and carry out a spatial cluster detection example.
6. Introduce pattern methods that will help detect when space-time clusters of events occur.
7. Identify differences between global and local statistics and their uses.

8. Demonstrate the operations for determining global and local statistics.
9. Identify a number of different ways spatial sampling should be carried out. Determine their strengths and weaknesses.

CA2. Geostatistics

The field of geostatistics is especially well suited to the problems of the physical scientist, especially those that use continuous spatial variables such as levels of precipitation in a region. The fundamental structure of geostatistics is based on the nature of variograms and its use for spatial prediction (kriging).

Suggested topic level breakdown:

CA2–1 Principles of variogram construction.
CA2–2 Variogram modeling
CA2–3 Problems of spatial nonstationarity
CA2–4 Principles of kriging
CA2–5 Simple and ordinary kriging
CA2–6 Universal kriging
CA2–7 Co–kriging
CA2–8 Disjunctive kriging

Learning Objectives

1. Discuss the theory leading to the assumption of intrinsic stationarity.
2. Learn how to construct a variogram.
3. Describe the various popular variogram models and identify the often–used concepts, e.g., variogram cloud.
4. Discover how variograms react to spatial nonstationarity.
5. Identify the relationship between the variogram and kriging.
6. Explain why it is important in kriging to have a good model of the variogram.
7. Know why kriging is preferred over other interpolation methods.
8. Identify the various forms of kriging and discuss their particular uses.
9. Implement a geostatistical analysis from data description to final error map.

CA3. Spatial econometrics

The estimation of the parameters of spatial autoregressive models is the motivation for the field of spatial econometrics. Many problems of the social sciences can be expressed in terms of spatial regression analysis. There is theory and a body of specialized techniques that form the basis of spatial econometrics.

Suggested topic level breakdown:

CA3–1	Principles of spatial econometrics
CA3–2	Spatial weights matrices
CA3–3	Spatial lag and error models
CA3–4	Likelihood estimation
CA3–5	Diagnostic tests
CA3–6	Filtering
CA3–7	Spatial expansion
CA3–8	Geographically weighted regression

Learning Objectives

1. Understand the basic principles of spatial econometrics.
2. Identify the many types of spatial weights matrices and list the appropriateness of each kind for a set of spatial econometric problems.
3. Describe the general types of spatial econometric models.
4. Be able to implement a maximum likelihood estimation procedure for determining key spatial econometric parameters.
5. Distinguish between a series of spatial econometric diagnostic tests.
6. Discuss the several methods for spatial filtering and implement a spatial filtering procedure.
7. Identify the characteristics of the spatial expansion method.
8. Explain the principles of geographically weighted regression. Perform an analysis using this technique. Discuss the techniques' appropriateness under various conditions.

CA4. Analysis of surfaces

While this topic is perhaps most commonly referred to as terrain analysis, there is a wide range of phenomena that can be studied using a set of techniques, and the GI S&T tools that implement those techniques, that are designed to help understand the characteristics of continuous surface data or relative aspects within such data. Applications of these models, using terrain data, encompass a wide range of overland transport and siting tasks.

Suggested topic level breakdown:

CA4–1	What is a statistical surface?
CA4–2	Sampling the statistical surface
CA4–3	The Digital Elevation Model (DEM)
CA4–4	TINs and lattices

CA4–5	Slope and aspect
CA4–6	Intervisibility
CA4–7	Profiles
CA4–8	Shaded relief
CA4–9	Friction surfaces; impedance, barriers and least-cost surface

Learning objectives:

1. Describe a given statistical surface and interpret the derived forms within the particular application context.
2. Perform a siting analysis using specified visibility, slope and other surface-related constraints.
3. Describe profiling, or traversals, and explain how they can be used.
4. Apply the principles of friction surfaces in the calculation of a least-cost path.
5. Compare the various ways that terrain can be graphically represented and discuss their relative advantages.

CA5. Transportation modeling and operations research

A wide variety of optimization techniques are now solvable within the GIScience paradigm. New models and complex software tools allow for the solution of transportation routing, facility location, and a host of other location modeling problems.

Suggested topic level breakdown:

CA5–1	Introduction to operations research modeling and location modeling
CA5–2	Network analysis
CA5–3	Linear programming
CA5–4	Integer programming
CA5–5	Location–allocation modeling; p–median problems
CA5–6	Discrete multiple criteria evaluation
CA5–7	Simulated annealing
CA5–8	Accessibility modeling
CA5–9	Facility location
CA5–10	Transportation routing
CA5–11	Capacity analysis

Learning Objectives

1. Explain the principles of operations research modeling and location modeling and their relationship to spatial decision support systems.

2. Be able to implement a network analysis.
3. Develop a location allocation model and assess it using learned spatial analysis techniques.
4. Demonstrate the structure of a linear program. Implement its use for a spatial allocation problem. Recognize the nature of objective functions.
5. Distinguish between a linear program and an integer program.
6. Identify the rationale for and usefulness of simulated annealing.
7. Implement various types of operations research models in a spatial setting.
8. Use transportation software to allocate vehicles to highways.
9. Study the structure of origin–destination matrices. Develop models based on these data.

CA6. Simulation and dynamic spatial modeling

Given the increased speed and capacity of computers, the value of simulations is being felt in a wide variety of fields. In GI S&T, representations of complex process models that are rooted in spatial variables can now be studied by means of simulation techniques. One of these, cellular automata, is a way of simulating the evolution of a lattice pattern where simple rules can give rise to global structures.

Suggested topic level breakdown:

CA6–1	The principles of spatial process models
CA6–2	Simulation construction
CA6–3	Model robustness
CA6–4	Parameter ranges
CA6–5	Cellular automata

Learning Objectives

1. Explain the role of simulation for the construction of spatial process models.
2. Learn the rules and techniques for simulation modeling.
3. Implement a simulation approach to a process model.
4. Study the characteristics of simulation evaluation.
5. Interpret parameter ranges in the context of relevant simulation problems.
6. Carry out a cellular automata approach to simulation.

CG. Computational Geography (geocomputation)

This knowledge area emphasizes the application of computationally intensive approaches to the study of the geosciences. The focus of geocomputation is a variety of methods designed to model and analyze a range of highly complex, often non–deterministic, non–linear problems. These tend to be computationally intensive and have only become feasible for study with the advent of modern computing capabilities. Computational geography has been aided by the continuing development of new types of analysis. These include a variety of techniques; a selection of two or three would engage a student for a semester or quarter. For the most part, these methods are advanced and should be reserved for senior undergraduates and graduate students. The previous two knowledge areas are suitable prerequisites for this knowledge area.

Suggested Unit Level Breakdown

CG1. Uncertainty

Computers allow for the specification of more and more complex spatial models. The work associated with them is subject to a certain degree of uncertainty, both because of the nature of data input 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.

Suggested topic level breakdown:

CG1–1	Definitions within a conceptual model of uncertainty
CG1–2	Error
CG1–3	Problems of scale and zoning
CG1–4	Propagation of error in spatial modeling
CG1–5	The theory of error propagation

Learning Objectives

1. Understand the differences between such concepts as vagueness and ambiguity, well defined objects and poorly defined objects, discord and non-specificity.
2. Identify the different types of errors and their causes.
3. Learn how to control uncertainty.
4. Explain the modifiable areal unit problem and its consequences.
5. Understand how errors can be propagated through GI S&T methods.
6. Define stochastic error models

7. Implement the Taylor series method
8. Evaluate and compare error propagation techniques.

CG2. Computational aspects of dynamic spatial modeling and neurocomputing

Taking advantage of parallel processing, super computers and other high performance devices, spatial analysis can be brought to a new level of insight, detail, and diversity. Neural net techniques and analysis takes advantage of intensive computation, and is especially well suited for complex spatial classification problems.

Suggested topic level breakdown:

CG2–1	High performance computing
CG2–2	Computational intelligence
CG2–3	Non–linearity and non–Gaussian distributions
CG2–4	Pattern identification
CG2–5	Spatial data classification
CG2–6	Multi–layer feed–forward neural networks
CG2–7	Recurrent neural networks
CG2–8	Space–scale algorithms
CG2–9	Rule learning

Learning Objectives

1. Understand the nature of supercomputing and its capabilities.
2. Recognize the potential for embedded systems to expand performance of specialized spatial analysis functions.
3. Identify the various artificial intelligence tools and computational intelligence methods.
4. Define non–linear and non–Gaussian distributions in a spatial data environment.
5. Understand the principles and operations of neural networks. Define rule learning.
6. Differentiate the various architectures, such as the difference between feed–forward versus recurrent.
7. Implement a neural network classification scheme for a massive data set.
8. Understand how training strategies are adjusted in light of network weights.
9. Evaluate the success of various neural network schemes.

CG3. Fuzzy Sets

The field of fuzzy sets casts a new light on the way data are viewed. Not all classification schemes can be considered crisp, in the sense of definitive. Fuzzy logic and fuzzy set techniques allow for the spatial analysis of a more nuanced approach to data analysis.

Suggested topic level breakdown:

CG3–1	Fuzzy logic
CG3–2	Fuzzy measures
CG3–3	Fuzzy aggregation operators
CG3–4	Standardization
CG3–5	Weighting schemes
CG3–6	Multi–criteria evaluation

Learning Objectives

1. Understand the purposes and logic of fuzzy sets. [Also see FS3.]
2. List geographical phenomena that cannot be modeled satisfactorily by crisp entities.
3. Identify fuzzy measures and aggregation operators.
4. Develop a standardization criterion that recasts values into a statement of fuzzy set membership.
5. Implement an ordered weighting scheme in a multiple-criteria aggregation.
6. Evaluate a fuzzy weighting scheme in terms of uncertainty and error propagation.

CG4. Genetic Algorithms and Agent–Based Models

Among the new artificial intelligence techniques are those pertaining to genetic algorithms. Evolution of natural life is very much a trial and error process. Adaptation and mutations are central to this area of concern. The algorithms that mimic evolution have now been applied to spatial phenomena such as the location of optimal habitat sites.

Suggested topic level breakdown:

CG4–1	Global search methods
CG4–2	Cross breeding, mutation, competition, and selection
CG4–3	Logical operations
CG4–4	Ways to create rules for representing evolutionary processes
CG4–5	Agent–based models and artificial societies

Learning Objectives

1. Understand the principles of genetics as it applies to agent–based models.
2. Devising ways to translate principles to working simulations.
3. Evaluating algorithm outcomes with fitness criteria.
4. Recognizing dysfunctional results and making improvements.
5. Determine how agent–based models may be used to create artificial societies.
6. Distinguish between cellular automata and agent–based models.

CV. Cartography and Visualization

This knowledge area addresses the complex questions involved in the creation and effective interpretation of graphic representations of spatial data sets and of the results of spatial analysis activities. Sophisticated visualizations, when viewed by a trained spatial analyst may also serve as a source of hypothesis generation.

Suggested Unit Level Breakdown

CV1. Conceptualizing spatial visualizations and presentations

The aim of this unit is to develop in the individual an ability to recognize, identify and appreciate the explicit geographic and graphic components that relate to visualization and presentation. These concepts include such notions as scale, projections, generalizations, and symbolization, which form the basis for understanding, building, and evaluating visualizations and presentations. Visual and other sensory representations of space and space–time data, as well as cartographic and other forms of graphic design are considered.

Suggested topic level breakdown:

CV1–1 History of Cartography and Visualization

Considers the impact of changing ideas and technology on the history of cartography and visualization; major turning points in the history of mapping, the sequence of map development, and implications of emerging technologies.

CV1–2 Basic Geographic Concepts

Fundamentals of spatial logic underlying spatio–temporal representation. Advanced topics include the foundations of spatial representation from mathematics, computer science, philosophy, and cognitive science as they relate to visual and other sensory forms of geographic presentation and visualization.

CV1–3 Projections

Classification and selection of map projections and map transformations for small scale and large scale maps, including projections used by the U.S. Geological Survey, and coordinate data transformations for computer graphics.

CV1–4 Coordinate Systems

Geographical (latitude and longitude) and planar (state plane and universal transverse mercator) coordinate systems used to express locational information with reference to a datum. Datum reference includes discussion of the geoid and ellipsoids with particular discussion of coverage and use of coordinate systems in spatial reference frameworks.

CV1–5 Graphic Design Principles

Fundamental issues in designing maps and visual displays, including audience objectives, components of design (balance, legibility, clarity, visual contrast, figure-ground organization, hierarchal organization), and basic elements that determine symbolization; different design considerations for various media (e.g., paper, computer screens, slides, overheads); multisensory presentation (virtual reality, mixed reality, haptics).

CV1–6 Graphic Typologies

Basic types of point, line, area, and volume data (includes raster data) depicting patterns in spatial data.

CV2. Building spatial visualizations and presentations

The aim of this unit is to develop in the individual an understanding of the methodological and computational issues involved in building space and space–time representations. This involves understanding both the way in which representations are built and the media used to convey them. Examples of topics include mapping methods, animated and dynamic displays, computational requirements for visualization, and human–computer interfaces. This knowledge area also relates to delivery methods (CD, multimedia, presentations, Internet, verbal directions in navigation, etc.) and media issues such as virtual environments, immersive environments, and augmented reality.

Suggested topic level breakdown

CV2–1 Source Materials

The materials used in compiling and updating maps through manual means and digital data sets; review relationship to topics in measurement sciences such as surveying and photogrammetry; advanced topics include analysis and appraisal of materials, geographic coverage, and aspects of data quality for mapping purposes.

CV2–2 Data Collection

The digitizing process, including both manual and automated techniques.

CV2–3 Compilation and Integration

The process of compiling digital data sources, including both digital and analog (hard copy map) data sources; includes data in map, flat file, image, and other formats; particular attention to resolving divergent and potentially incompatible sources for presentation and visualization.

CV2–4 Multi–dimensional Processing

Manipulating point, line, area, and volume data to derive other point, line, area, and volume data, including conversions from one to another (includes raster data); used for displaying spatial pattern as a data distribution across a surface, and spatial process as the change in patterns over time.

CV2–5 Symbolization

Basic concepts of symbolization (measurement levels, visual variables, feature dimensionality); different types of point, line, area, and volume symbols generated from the use of graphic design principles; principles of multivariate data representation and symbolization; principals and methods for dynamic/interactive mapping; concepts and methods of spatialization; map methods (choropleth, dasymetric, graduated symbol, isarithm, and dot maps).

CV2–6 Generalization

Techniques and procedures used to reduce the amount of detail in a database, a map, or a visual display. Different methods apply to point, line, and area data, including both geometric and attribute procedures such as selection, classification, simplification, and filtering operators.

CV2–7 Error and Consequences

Types of errors that exist in spatial data and their influence on spatial presentations and visualizations and the decisions derived from such displays; visualizing all testable components of data quality including positional and attribute accuracy, logical consistency, and completeness.

CV2–8 Map Production

Strategies for digital map production, including feature and color separates, feature and map composites; basic issues in black and white and four-color processing with computers; output options (print, computer display, verbal descriptions).

CV2–9 Map Reproduction

Methods for making few copies (reflection original, transmission original, digital original), methods for making many copies (lithography, platemaking, presswork), methods for digital media.

CV2–10 Computational Issues

Issues relating to computation (interoperability, optimization) in the production of geographic presentations and visualizations; issues relating to the Internet; human computer interface design.

CV3 Evaluating spatial visualizations and presentations

This unit deals with understanding the effectiveness of visualizations and presentations, an activity that occurs before, during, and after the building phase of visualization. Cognitive issues are central to this knowledge area, as are issues that relate to testing, such as usability and effectiveness testing and critiques. Also considered in this unit are interpretation of the presentations and map reading.

Suggested topic level breakdown:

CV3–1 Interpretation

This topic deals with the process of perception and understanding of graphics information on a map or a graphic display. Included are the processes of perception and recall from short term and long term memory; the use of cognitive principles in database design and geographic modeling.

CV3–2 Evaluation and Testing

Issues relating to evaluation of presentations and visualizations; evaluating error/uncertainty in the data and the displays, evaluating the effectiveness of visualization and presentations, evaluating human computer interfaces, evaluating usability; methods for critiques.

CV3–3 Map Use

Issues relating to map reading (the map abstraction process, statistical maps, land surface maps, maps and time, maps on the Internet), map analysis (cartometrics, pattern comparison, GPS and wayfinding, map accuracy), and map interpretation (interpreting the physical environment, interpreting the human environment, and interpreting interactions between humans and their environment); maps and reality.

OI. Organizational and Institutional Aspects of GI S&T

This knowledge area addresses those organizational and institutional aspects of GI S&T activities that go beyond systems design and implementation, including the overall management of those tasks within an organizational context. Many of these subjects are drawn from or are characteristic of non–GIS S&T tasks, so the emphasis is upon basic principles and the adaptations required by GIS S&T.

The distinction between GI S&T and GI systems, programs, and projects is important in this knowledge area. In particular, a *GI system* – such as an enterprise GIS in a local government – is a specific semi–closed system of hardware and software, people, policies and procedures with defined interfaces and expansion guidelines. (Other organization, or even one with an enterprise GIS, may also have various GI S&T components.) One important aspect of the current knowledge area is the ability to recognize, define, and develop such a GI system, program, or project for a specific organization or application. Therefore, in the suggested unit breakdown the terms GI system, program, and project will be used where appropriate and distinct from GI S&T in general.

Suggested unit breakdown

OI1. Managing GIS operations and infrastructure

This unit addresses the main tasks and issues involved in managing GI S&T implementation and operations within an organization. The emphasis is on understanding basic approaches and models and adapting them appropriately to a specific organization and its GI S&T needs and activities. Perspectives on developing and managing GI S&T assets and infrastructure are also important.

Suggested topic level breakdown:

- OI1–1 Managing the GI S&T implementation process
  - Structured GI S&T implementation processes
  - Determining and defining GI projects, programs, systems, and enterprise approaches
  - Integrating components (managing tasks referenced in DE2 and DE3)
- OI1–2 Requirements analysis – initial and ongoing (also see DE2 and PS2)
  - Business process analysis
  - Incorporating spatial data and GI S&T into work processes
  - Evaluating internal spatial data sources and handling activities
  - Finding and evaluating external spatial data sources

- OI1–3 Planning and budgeting—initial and ongoing
  - Cost/benefit analysis and justification [See DE2–6. Also PS3 for broader economic aspects of GI S&T.]
  - Developing an implementation plan [See DE3–5 through DE3–9.]
- OI1–4 Database administration
  - Maintenance [Also see PS3 & PS6.]
  - Developing and applying standards
  - Responsibilities
  - Procedures
  - Access
  - Security
  - Metadata – developing, adopting, and applying useful metadata
- OI1–5 System management
- OI1–6 User support
- OI1–7 Integrating GI S&T with an organization's existing IT infrastructure and business processes

Learning objectives:

1. Describe the GI S&T implementation process and how it can be adapted to different circumstances.
2. Explain GI S&T requirements analysis methods and how to incorporate new spatial data activities into business processes.
3. Describe the approaches and issues involved in GI S&T cost/benefit analysis and justification.
4. Explain the major aspects of geospatial data administration and how they are related.
5. Describe the tasks and issues involved in GI S&T system management and user support.
6. Explain the important issues involved in integrating GI S&T into an organization's information technology infrastructure.

OI2. Organizational structures and procedures

GI S&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 GI systems and programs. Although topics refer to structures, the related procedures are equally important.

Suggested topic level breakdown:

OI2–1 Organizational models for GI S&T management
  - Enterprise approaches
  - Support or service center approaches
  - Independent GIS operations and projects

OI2–2 Organizational models for coordinating GI system and/or program participants and stakeholders
  - Committees and teams
  - Adaptations to GI S&T – kinds of representation needed
  - Roles and relationships of GI S&T support staff
  - Making GI S&T relevant to top management

Learning objectives:

1. Describe different organizational models for managing GI S&T within an organization and how to select and adapt an appropriate model.
2. Describe different organizational models for coordinating GI S&T participants and stakeholders.

OI3. GI S&T workforce themes

This unit addresses GI S&T staff and workforce issues within an organization – particularly as they relate to ensuring that GI S&T is appropriately used and supported. Broader GI S&T workforce and professional issues would be addressed in PS.

Suggested topic level breakdown:

OI3–1 GI S&T staff development
  - Determining GI S&T support requirements—based on system characteristics, users, and organization. [See DE3–5.]
  - Staff design and organization.
  - Staffing levels and types

OI3–2 GI S&T positions

OI3–3 GI S&T training and education

OI3–4 Incorporating GI S&T into other positions

Learning objectives:

1. Understand how GI S&T support needs relate to the characteristics of the GI system, the users, and the organization.
2. Develop a support staff design appropriate to a particular GI S&T implementation and type of user and organizational support.
3. Understand GI S&T training needs and how they vary by user.
4. Identify the types of GI S&T training and/or education required for different types of GI S&T development, use, and management activities.
5. Understand the role of GI S&T activities in a variety of professional positions.

OI4 Institutional aspects

Institutional aspects related to GI S&T activities within an organization. Broader institutional aspects are covered in knowledge area PS.

Suggested topic level breakdown:

OI4–1	Spatial data infrastructures
OI4–2	Adoption of standards (also ref PS4)
OI4–3	Technology transfer
OI4– 4	Spatial data sharing among organizations Policies [Also see PS6.] Procedures
OI4–5	Balancing data access and security and privacy (also ref PS5 & PS6)

Learning objectives:

1. Understand spatial data infrastructures.
2. Describe issues involved in the adoption of standards.
3. Describe issues and practices involved in data access and data sharing among organizations.

PS. Professional, Social, and Legal Aspects of GI S&T

This knowledge area addresses legal regimes and administrative practices that govern the management, useful application, distribution, and economic support for the application of Geographic Information Science & Technology. Legal regimes determine the nature and extent of (a) property rights in spatial information, (b) use of spatial information for land management and other decisions by both public and private actors, and (c) distribution of the spatial information. Administrative practices are concerned with the nature and extent of how organizations and agencies are organized to manage the information and its application. Both activities require economic support for implementation of legal and administrative goals.

The legal regime also determines who can claim the exclusive right to hold and use the spatial information, determine the conditions under which others may have access to the material, and what subsequent uses are permitted. The regime is informed by the difficult issue of information economics including who benefits from the use of geospatial information and how the power to allocate the use of this information is or should be distributed among members of a society.

Administrative practices addresses the crucial details of how an organization or agency, with specific mandates or goals, is organized to efficiently and effectively use its resources to manage its spatial data, hardware, software, personnel, and procedures in a manner consistent with its mandates or goals.

Suggested Unit Level Breakdown

PS1 Aspects of information and law

This unit examines those aspects of spatial information that 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.

Suggested topic level breakdown:

PS1–1	General attributes of spatial information
PS1–2	Specific attributes of spatial information
PS1–3	Incentives and barriers to the establishment of a property regime dealing with spatial information

Learning Objectives

1. Compare and contrast information as a commodity with other commodities more amenable to legally protected exclusive rights.
2. Create a list of spatial information attributes consistent with its treatment as a commodity.
3. Describe the difficulties in making information into a legally controlled object.

PS2 Public policy aspects of geospatial information

This unit considers the role of information in a democratic societies where individuals, groups, and organizations expect to participate in governance generally and in allocation of the use of land and its resources particularly. Several common models of that role are introduced and their attributes described.

Suggested topic level breakdown:

PS2–1	Major uses of spatial information and of land information
PS2–2	The general role of citizens in legislative and administrative decision making in a democratic society
PS2–3	The role of land information in land administration
PS2–4	The specific process of public participation in legislating and administrating
PS2–5	Individual, group, and societal perspectives on the role and impact of spatial information and information systems in land administration. [Also see OI1.]

Learning Objectives

1. Describe security, aesthetic/scientific, and management uses of information.
2. Discuss universal/deliberative, pluralist/representative, and participatory models of citizen participation in governance.
3. Describe the sources and role of spatial and other data and information in the allocation of land and its resources.
4. Describe the administrative process where interested parties participate in land use decisions.
5. Describe different views on the role and impact of GI S&T–related processes on individuals and groups in society and the impact of these views on GI S&T activities.

PS3 Economic aspects of Geographic Information Systems

This unit examines several specific aspects of GI S&T activities at different levels of agency and organizational activity. Models of these benefits are introduced and described.

Suggested topic level breakdown:

PS3–1	Economics and the role of information and spatial information within economics
PS3–2	The problem of identifying and measuring the benefits of information in general and spatial information in particular
PS3–3	Venues for identification of the benefits of land and other geographic information systems
PS3–4	Models of benefits
PS3–5	Agency, organizational, and individual perspectives [Also see OI1.]

Learning Objectives

1. Define economics and the general role of information in economics.
2. Identify practical problems in defining and measuring the specific role of spatial information in decisions generally and in land decisions specifically.
3. Identify and distinguish operational, organizational, and societal levels of activity where geospatial and land information is used.
4. Select and describe recent models of the benefits of GI S&T applications.
5. Identify and discuss perspectives on the nature and scope of system benefits among agency officials, organizational personnel, and citizens.

PS4 Legal and ethical responsibility for generation and use of information

This unit discusses the legal problems that can arise when geospatial is used for land management. Several sources of problems with data and information are introduced. The response by the legal system is described in the form of assigned liability for the harm that results from use of problematic information or misuse of information. The role of ethical duties is also discussed.

Suggested topic level breakdown:

PS4–1	The legal concept of liability
PS4–2	Liability for geospatial and other information in the age of computers
PS4–3	Legal duties and responsibilities
PS4–4	Ethical duties and responsibilities

PS4–5 Specific problems with the use of GI S&T concepts and systems that can result in legal liability, ethical reproach, and professional sanction [Also see OI4.]

PS4–6 Effect of problems with geospatial information on policy and organizational activity

PS4–7 Possible remedies for problems associated with geospatial information

Learning Objectives

1. Describe the nature of tort law generally and nuisance law specifically.
2. Identify and discuss cases that demonstrate the law of liability for the use and misuse of geospatial information.
3. Identify the duties and responsibilities arising from formal (e.g., legal and professional) requirements.
4. Identify performance expectations arising from ethical standards.
5. Identify and describe cases that demonstrate errors, misrepresentations, and misuse of geospatial data.
6. Identify and describe problems that may occur when decisions depend on upon poor or inappropriate geospatial information.
7. Describe the creation, adoption, and use of legal standards, ethical expectations, and professional guidelines for GI S&T practitioners.

PS5 Control of information — information as property

This unit describes legal regimes that attempt to make geospatial data and information into an object of exclusive control like other commodities. Regimes governing private and public information are considered.

Suggested topic level breakdown:

PS5–1 Public and private interests in geospatial data and information

PS5–2 Public and private division of control over geospatial data and information

PS5–3 Other aspects of geospatial data and information control

PS5–4 Mechanisms for control of geospatial data and information

PS5–6 Balancing security and access of geospatial data and information in a legal context [Also see OI1 and OI4.]

Learning Objectives

1. Classify ways that geospatial information are used by agencies, organizations and individuals.

2. Compare and contrast how control of information is divided among public and private groups.
3. Determine and discuss specific problems of access, confidentiality and economic sustenance of GI S&T applications that arise from differing interests in control of geospatial information.
4. Identify and describe specific laws that determine control of geospatial data and information (copyright, freedom of records, privacy protection, cost recovery, etc.).
5. Identify and discuss the way that a legal regime balances the need for security of specific geospatial data with the desire for open access.

PS6 Control of information — dissemination of information

This unit focuses specifically on those aspects of geospatial data and information that determine who can obtain data and information, under what conditions, and at what price. The legal relations between public and private organizations and individuals are considered.

Suggested topic level breakdown:

PS6–1	Incentives and barriers to sharing geospatial and other data
PS6–2	Data sharing among public and private agencies, organizations, and individuals
PS6–3	Legal mechanisms for geospatial data sharing [Also see OI1.]
PS6–4	Balancing security and open access to geospatial data and information in the context of operating agencies and organizations [Also see OI1 and OI4.]

Learning Objectives

1. Identify and discuss political, economic, administrative, and other social forces in agencies, organizations, and citizens that inhibit or promote sharing of geospatial and other data.
2. Identify and discuss specific examples of formal and informal arrangements that promote geospatial data sharing (FGDC, ESDI, memoranda of agreements, informal access arrangements, targeted funding support, etc.).
3. Identify and discuss contracts, licenses, and other mechanisms for general data sharing.
4. Identify forces for confidentiality and for openness in the institutional and economic circumstances that exist for organizations and agencies and the practices driven by these forces.

Appendix B

UCGIS Task Force on the Model Curricula

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