ON TEACHING GIS

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ABSTRACT

A large number of departments of Geography now offer classes in Geographic Information Systems (GIS). In a recent discussion of university curricula on GIS, Nyerges and Chrisman suggested that cartography and GIS have a substantial overlap in their intellectual content and listed twenty-one topics of joint interest. Among these are many traditionally associated with instruction in cartography, such as map projections, coordinate systems, and graphic design principles. These authors also noted that analytical cartography is the part of cartography closest to GIS. This paper discusses the areas of common intellectual interest between cartography and GIS. Differences as well as similarities are discussed, in an effort to answer the question "What is the difference between cartography and GIS?" Analytical cartography is presented as an interdisciplinary area of research with substantial influence over GIS development, and the scope of analytical cartography is defined with respect to the topics noted by Nyerges and Chrisman. Finally, the differences between the analytical cartography of 1989 and that outlined by Tobler in 1976 are examined and placed in a historical and a GIS context. To conclude, a blend of theoretical and practical training from existing university curricula is suggested as the best preparation for the prospective GIS analyst.

INTRODUCTION

There are few university departments of geography in the United States or Europe where there is not yet course work on Geographic Information Systems (GIS). As the GIS industry stands on the verge of going over $1 billion in sales of hardware and software alone, and as universities are awakening to the need to produce students for a rapidly expanding GIS job market, academic geographers have come to realize that university instruction in the principles and methods of GIS has fallen into their domain. In the last year, attention has turned to the type of university education that would best prepare undergraduate and graduate geographers as intelligent GIS users and as scientists capable of improving these systems.

The National Center for Geographic Information and Analysis has been given the role of providing, and eventually disseminating, a national curriculum for GIS instruction. Nyerges (1989) reported in an IGU-sponsored panel discussion on model GIS curriculum design. From the published reports to date, it is evident that geographers at universities have been reluctant to support certification of GIS studies. As a result, many programs have become highly individualized in terms of their content and scope. A national curriculum guide could eliminate these diferences, and as a result, many GIS educators are now turning their energies to defining the scope and content of the GIS curriculum.

Nyerges and Chrisman (1989) recently set forth in some detail the issues to be considered in the development of a GIS curriculum. They summarized a number of prior surveys of course offerings in cartography and GIS, and noted that about 125 American universities and colleges now offer a class in GIS. Of these classes, however, there seems little overlap in curriculum other than a set of topics best described as analytical cartography. Goodchild (1985) summarized three problems in GIS education. These were the lack of focus as regards level and content, the perception of GIS as a technique rather than as having theoretical content, and the tendency to focus on GIS as a "tool bag" similar to a statistical package. Cartography, according to Nyerges and Chrisman (1989), has not had the same problems, in spite of the computer revolution and sweeping methodological and intellectual changes in the discipline. The major cartographic organizations, such as the American Congress on Surveying and Mapping, have devoted considerable effort to the scope and content of

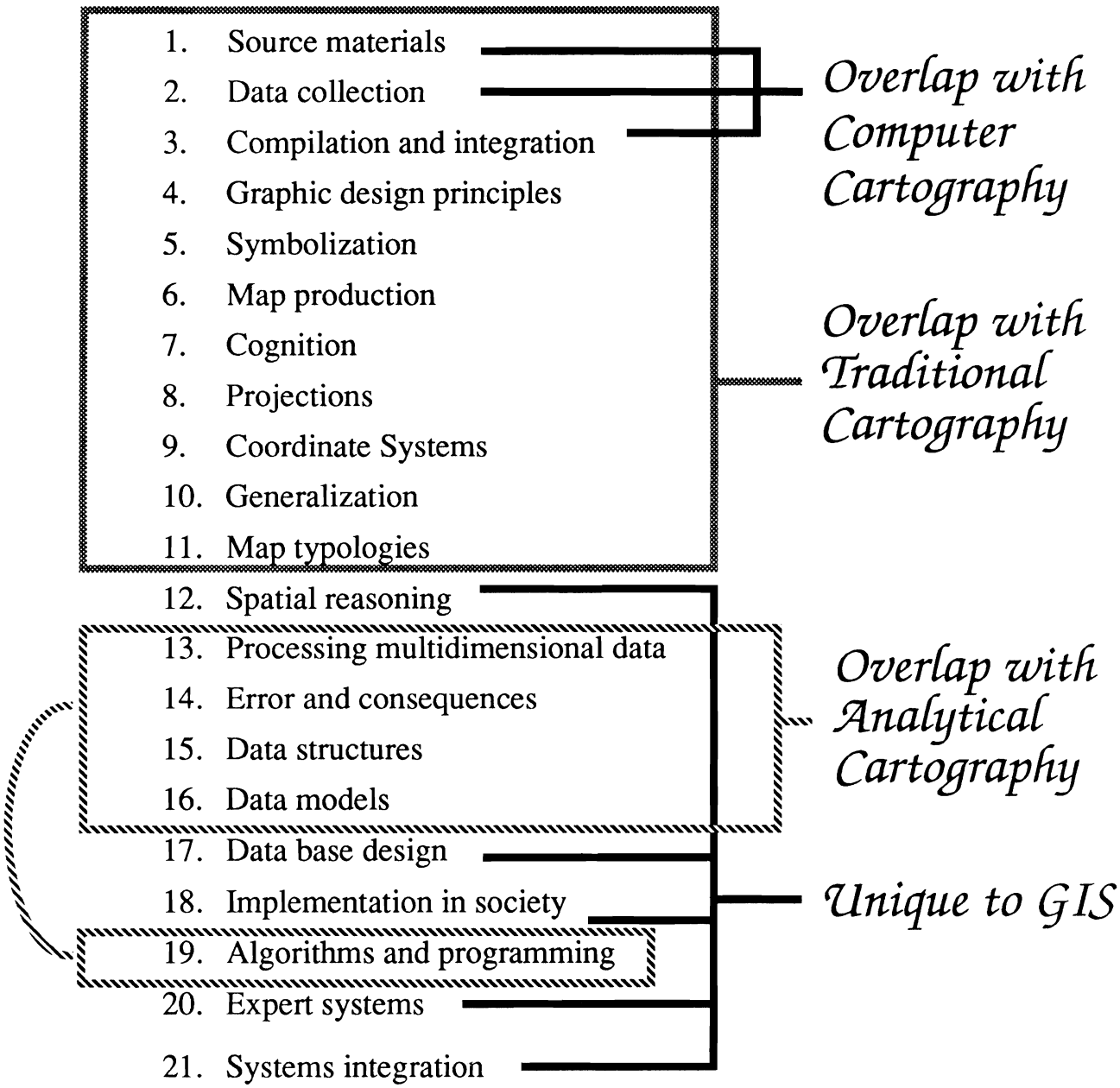

Figure 1

Overlap between Nyerges and Chrisman's Curriculum Topics and CaGIS Courses

cartographic education. From these efforts have come calls for integrated curricula, with joint attention to cartography, remote sensing, and GIS (Dahlberg and Jensen, 1986).

Nyerges and Chrisman devoted much of their paper to outlining the extent of the content of GIS curricula about which there is some agreement. Twenty-one topics were listed, and the University of Washington undergraduate and graduate course offerings were cross-tabulated in terms of depth of coverage of these topics. This focus on topics was chosen so as not to overlap with an instructor's desire to emphasize particular training or intellectual exercises within a class context. For example, a class in computer programming may choose to have students write their own versions of cartographic algorithms as a learning exercise, or alternatively can have a whole class participate in a software design and construction project, essentially as on-the-job training. The depths of content used were an exposure to a topic, principles behind the topic, mastery of tools to address the topic, and having students construct their own tools for the topic. In general, undergraduate classes sought to address the first two of these, and graduate classes the latter two. Nyerges and Chrisman also noted a substantial overlap between the curriculum topics of cartography and GIS, so much overlap, in fact, that the authors define a new speciality area within geography: CaGIS (Cartography and GIS). Such a speciality seems to have the support of the discipline of cartography at large, since the American Cartographic Association has recently changed the name of its journal from *The American Cartographer* to *Cartography and Geographic Information Systems*. With such an impending interdisciplinary merger in prospect, it is worth considering how extensive is the scope of the common body of content and what effect the merger will have on both disciplines.

THE OVERLAP BETWEEN CARTOGRAPHY AND GIS

Of the twenty-one topics listed by Nyerges and Chrisman, eleven overlap completely with cartography. These include map source materials, data collection, data compilation, graphics design principles, symbolization, map production, cognition, projections, coordinate systems, generalization, and map typology. Of these, the latter eight are normally found in a manual cartography class. Map sources, data collection, and compilation are most specific to computer cartography and GIS, since much map data are already in digital form and the process of geocoding cartographic data is beyond the scope of manual cartography. These topics, however, are very much a part of computer cartography, with lengthy textbook chapters devoted to them in both computer cartography (Clarke, 1990) and GIS (Burrough, 1986; Star and Estes, 1990).

Five of the topics have overlap with analytical cartography as defined by Tobler (1976). These include data conversion between dimensions (termed cartographic transformations elsewhere; Clarke, 1987; Tobler, 1979), cartographic error, data structures, data models, and algorithms and programming. With the exception of error, each of these fall into the scope of analytical cartography, forming entire textbook chapters in most cases (Clarke, 1990). The remaining five topics are indeed specific to GIS, and include spatial reasoning, data base design, implementation in society, knowledge-based constructs (expert systems), and systems integration, although some expert systems applications have been specific to cartography. The curriculum content of the overlap area between cartography and GIS is already well covered within the context of the traditional basic cartography class, in which such topics as map projections, design principles, map generalization, and coordinate systems have formed a substantial component for many years. In departments where the number of faculty is limited, and especially in those which are unable to compete in the GIS faculty hiring market, there is no need to duplicate whole sections of the existing curriculum. The material could, however, be separated from other aspects of cartography into a class that all geography students could use as a foundations or core class. Alternatively, GIS students could be required to take a sequence of classes in cartography, so that the mastery of the basic material of common interest could be assumed in the later GIS classes. Such a class could be entitled "Analytical Cartography.". As Nyerges and Chrisman noted, analytical cartography is the more important part of the cartography/GIS overlap. Before continuing, a working definition of analytical cartography is called for.

ANALYTICAL CARTOGRAPHY AND GIS

In 1976, Waldo Tobler published a paper in *The American Cartographer* outlining a course he had developed over the years entitled "Analytical Cartography." By publishing his course outline, Tobler provided a template for cartographic education that has been duplicated time and time again as the discipline of cartography has entered the computer age. Tobler's message was that the computer's impact on cartography would be not only to replace an existing set of map making tools and methodologies, but also to send cartography as a whole back to its mathematical and theoretical

roots. Cartographic education involves learning the specifics of a new technology of map-making, which Tobler called "computer cartography," pointing out its technological dependency by comparing it to pen-and-ink or scribing cartography. The theoretical and mathematical roots form the "analytical cartography" of the paper's title.

Tobler's contribution was to recognize the division between computer cartography and what he called analytical cartography. Analytical cartography covered advanced aspects of the discipline in a mathematical sense, studying the equations for map projections, learning the geometry behind representational methods, and understanding the principles of cartographic data processing. Analytical cartography also involved knowledge of principles in the related areas of image processing, photogrammetry, remote sensing, surveying, and geodesy. In this sense, Tobler included Nyerges and Chrisman's "systems integration" by suggesting that students be fully versed in the theory and methods of remote sensing, photogrammetry, surveying, and image processing.

In a later paper, Tobler presented a framework for unifying analytical cartography, putting its components into the context of map transformations. Cartographic transformations were classified as being classic cartographic transformations (i.e., transformations involving the locative aspects of the base map underlying an area of interest) or transformations of the substantive geographic data (or the "theme" aspect of a thematic map). Clarke (1990) expanded upon this theme, suggesting that cartographic transformations fall into four types: transformations from cartographic entity (a real-world object) to cartographic object (a digital representation of that entity); transformations from object to object, in the form of scale or data structure conversions; transformations of the map geometry; and the symbolization transformation.

In the Nyerges and Chrisman curriculum this transformational component is recognized only in the context of dimensional (point; line; area; volume) transformations and in the consideration of generalization. Within analytical cartography, the transformational approach forms a conceptual backbone for the entire curriculum, onto which other basic and advanced topics fit. Such a conceptual focus for the GIS curriculum is currently lacking, and GIS curricula could benefit from such an intellectual focus for the material. This focus should come not from the overlap, but from those areas unique to GIS.

TEACHING GIS

Academic geography has produced a varied response to the demand for GIS coursework, a demand driven by direct requests from students and GIS professionals. In the real world, few departments can afford the luxury of a designated GIS specialist. The teaching of GIS, therefore, like the teaching of geographic statistics and geographic computing, has fallen to geographers in cartography, economic geography, and location theory, and in some cases to physical geographers. Adding multi-semester sequences in GIS, therefore, is not a viable GIS teaching solution. This option is further complicated by the conflicting nature of the required GIS instruction. Two distinctive needs are obvious. First, GIS training is required. GIS tools are increasingly within the expense range of even the most stringent departmental budget. There is a need therefore for hands-on, laboratory-style instruction. Burns and Henderson (1989) describe this type of instruction as specialized, short-term, demanding concentrated student attention, using an intense delivery, practical, teaching performance skills, and seeking predominantly behavioral change in the students, that is allowing them access to the technical tools.

GIS curricula must go beyond simple training, however, to GIS education. Burns and Henderson (1989) characterized educational instruction as being general, long term, requiring dispersed and individualized attention, using a measured delivery, emphasizing theoretical concepts and knowledge skills, and requiring a synthesis of ideas. Educational teaching requires the delivery of materials by lecture, paper writing, research, and seminar discussion, while training uses mostly hands-on laboratory work and self-taught exercises prepared in advance and followed by each student. This distinction is not part of Nyerges and Chrisman's curriculum. To some extent, training must precede education. Teaching a class about theoretical aspects of GIS, data base design for example, before the students have used a GIS can only result in confusion. On the other hand, a laboratory exercise on a microcomputer, using an inexpensive GIS package, can seem like a meaningless rote learning process unless the theoretical concepts behind the exercise have already been presented. Ideally, both training and education should be integrated into the curriculum, an approach used successfully at the International Institute for Aerospace Survey and Earth Sciences, the ITC (Drummond et al., 1989).

GIS training and GIS education have widely different needs. Students seeking direct employment often want hands-on experience with a particular package, especially the more popular ones. Students who are geographers but not GIS specialists seek to be able to use the powerful capabilities

of GIS in their own research work, and to solve their own specific problems. Finally, GIS specialists want to go beyond simply being GIS users, and to understand the GIS to such an extent that they can build their own (hopefully better) systems.

Burns and Henderson (1989) in their discussion of the ESRI training program noted that "to properly learn about GIS we must first learn about geography and what it implies." This is an endorsement not simply of the separation and requirement of analytical cartography, but a call for the exposure of the potential GIS analyst to the traditions of geography. Of the traditions usually cited, the environmental tradition probably has most to gain in the use of GIS, in fact GIS provides the link between environmental understanding by academics and environmental decision making and policy.

CONCLUSIONS

This discussion has centered upon GIS's considerable overlap with existing elements of geography curricula. While Nyerges and Chrisman's approach to topical coverage and varying topical depth is meaningful and appropriate, few departments can afford the luxury of spreading GIS instruction between eleven undergraduate and graduate classes. First and foremost, to avoid duplication, GIS instruction should build upon two elements. These are, first, a course in analytical cartography, in which the topics of map projections, coordinate systems, map generalization, map typology, and the issues surrounding geocoding are covered at the introductory level; and second a mechanism by which the student is guaranteed an adequate general geographic training in the traditional sense. As more and more students are attracted to geography by GIS, the latter element will gain in importance. By acting to assure such a background, geographers can make the GIS analyst a "device-independent" specialist who can make contributions beyond the scope of the trained specialist.

Next, the material specific and unique to GIS theory, spatial reasoning, the influence of error, non-map data models, data base design, expert systems, the user interface, and issues related to systems integration and implementation in society must be taught. Students at ITC, mostly from lesser developed countries, are taught at the outset about the means and theory of actually implementing a GIS in its institutional setting as an initial part of the GIS curriculum (Drummond et al., 1989). All too often the GIS analyst finishes their training yet remains totally inept at dealing with GIS managers and day to day users. Most of this material can be taught in a single middle or advanced-level class, with microcomputer assignments used to stress theoretical issues rather than training. In addition, students should get experience with actual GIS training. Ideally, an internship arrangement with agencies involved in GIS use would be available for all students. In an atmosphere of high demand, perhaps this is a workable alternative.

Actual training on a system, however, should be on a non-credit basis, perhaps self-taught using videotapes, computer-aided instruction, or hypermedia. Alternatively, this self-instruction could be worked into the curriculum for other classes, such as environmental geography, cultural geography, or physical geography. Finally, students should get the interdisciplinary background which Tobler (1976) stressed as being so important for analytical cartography. Students should get at least exposure to the intellectual content of surveying, remote sensing, photogrammetry, statistics, image processing, and most important computer programming. If these classes are unavailable within the field of geography, students should be encouraged to seek them out in other departments. While such a combination may seem like a 120-credit B.A. in itself, such experience significantly enhances the problem-solving ability and employability of prospective GIS analysts.

Finally, analytical geography and cartography have a role to play in the pursuit of GIS research. Often those in the best position to teach GIS are the same people who conduct research aimed at improving GIS knowledge, design, and performance. With cartography so focal to GIS, analytical cartography should and does form the focal area for GIS research. In spite of the fluidity of the field, and the proliferation of journals and conferences, the AUTOCARTO proceedings remains as the primary forum for new ideas. If these conferences are the breeding ground for new GIS research, then historically it is cartography, analytical cartography at that, which has driven GIS to the all-encompassing, potentially revolutionary tool of geographic inquiry it represents today.

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