Municipal Affairs in opposing such a formula stated, "the use of a legislated formula would reduce our present flexibility to deal with individual situations. I believe it is preferable to deal with the issue of regional representation at the political level" (Grandmaitre, 1985).

ESCAPE FROM THE MUSKEG? POSSIBLE CHANGES UNDER THE NEW CONSTITUTION

If the US experience is a guide, electoral boundaries may eventually become an issue in Canadian courts. Moreover, recent judgments of the Supreme Court under Chief Justice Brian Dickson on issues involving the *Charter* might be described as "liberal" in the results they reach. Thus the current court may be willing to exercise its powers by moving into Justice Frankfurter's "political thicket."

How changes to Canada's electoral districts may emerge will depend upon the exact issues brought before the courts. It is unlikely that challenges will come at the federal level. The most glaring inequalities, such as the cases of Prince Edward Island and the Territories, are protected in Section 41(c) of the *Constitution Act, 1982* and Section 51 of the *Constitution Act (No. 1), 1975*, respectively. Moreover, these specific provisions in the act take precedence over the more general protections of the charter. Court challenges more likely will come at the provincial or municipal level. At present, electoral redistricting at these levels depends upon the sense of "fair play" of those in power, and possible reprisals by the electorate against a party practicing blatant gerrymandering. However, should an entrenched provincial or municipal government choose to create an electoral districting system as unrepresentative as that of the State of Queensland, then an action in the courts under Section 15 of the charter would be one way to mount a challenge. Clearly, the courts would more likely become involved in such a reapportionment issue if there were demonstrable inequalities that effectively disenfranchised a clearly defined interest group. In such circumstances, one can envision an action under the provisions of the new constitution to re-draw the boundaries of Canadian electoral districts at various levels.

Canada's new Constitution thus creates the possibility for defining electoral equality far more rigorously than at any previous stage in our history. As in the US case, many will regard this as a political muskeg out of which the courts should stay. We believe, in contrast, that this is a legitimate area for judicial action.

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FIVE ASSESSMENTS OF GEOGRAPHIC INFORMATION SYSTEM EDUCATION IN CANADA

The first four articles were presented in May, 1985 at Trois-Rivières during the annual CAG meeting in a session organized and chaired by Roger Tomlinson; the fifth article was presented in May, 1985 at a meeting of OICC. An article by Roger Tomlinson, "Geographic Information Systems — A New Frontier," appeared in *TOG* 1984 (5):31-36.

GEOGRAPHIC INFORMATION SYSTEMS IN UNDERGRADUATE GEOGRAPHY: A CONTEMPORARY DILEMMA

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INTRODUCTION

The past decade has seen the introduction of courses in Geographic Information Systems (GIS) and related topics in many undergraduate geography programs in Canada and elsewhere. A strong demand for junior faculty with specialization in these fields continues to exist. Only recently have undergraduate programs been developed which allow a student to concentrate in GIS as a specialty, although such programs have existed for some time at the graduate level. This article argues that the fundamental pedagogic issues of GIS have yet to be addressed, particularly in the context of undergraduate geography. The relational data model used explicitly or implicitly by many current systems represents a basic structuring of spatial data which can serve as the organizing principle for an intellectually sound approach to undergraduate techniques courses.

Anyone who happened to glance through the specialties listed in job advertisements in the AAG Newsletter during the winter of 1985 may have noted that GIS and the related fields of remote sensing and automated cartography are something of a growth industry in academic geography at the present time with demand quite clearly outstripping supply, at least as far as PhDs are concerned. Several departments already have, or are in the process of introducing, specialist programs at various levels, or have established specialist research units. Nevertheless we have little consensus on such issues as the appropriate content of a GIS course, on the role of GIS within the larger aims of undergraduate education in geography, or even on the meaning of the term; this is reflected in the almost complete absence of appropriate textbooks. Should GIS be given a place in the accepted philosophical underpinnings of the discipline, or is it merely another bag of tricks of no deep significance? The time seems to have come to discuss some of the deeper issues raised by this intense activity in our midst. The introductory part of the paper identifies three such issues, all of which are fundamental problems which must be addressed in clarifying the role of GIS in the curriculum.

The first is that the impetus for the introduction of GIS into the curriculum is quite clearly coming from outside the academic discipline. The tail, in other words, is in many respects wagging the dog. The term GIS was coined in a government agency (during the development of the Canada Geographic Information System in the early 1960s), and much of the basic research in the field in Canada and elsewhere has been carried out by the private sector, either for its own purposes or under contract to government. The record numbers of students who are enrolling in technique courses in geography programs are doing so not so much from a feeling that these courses are an integral part of the discipline as from the perception that they increase prospects for eventual employment in a tight labor market. And similarly although many curriculum committees may feel that GIS is by now a necessary part of a well-rounded geographer's educational experience, GIS fails to appear in any accepted paradigm of the subject. GIS should now become part of such a paradigm and become more precise as an element of the spatial analytic tradition if geography's claims to it are to have any substance at all.

The second issue which complicates any pedagogic discussion of GIS is its conventional role as an advanced technical specialty. As a field it has developed largely out of automated cartography, which in turn developed as a specialty within cartography. Similarly many of its specialists began as cartographers, progressing with the technology through automated mapping to GIS. GIS naturally tends to have been allocated a corresponding place in the curriculum as an advanced skill to be taken as an option by those who have already decided to specialize in cartography. But while we may logically view GIS in this way as another leaf on the tree, which courses should feed it and provide an adequate background?

GIS is a highly technical field, overlapping not only with computer graphics and image processing, but also with coordinate geometry and topology. As we note below, in order to cope successfully with the current conception of a generic GIS, some grounding in data structures is essential; similar arguments can be made about the necessity for prerequisites in other areas. Students with this sort of background are rarely found in a geography program.

Imagine for a moment a continuum with computer science at one end and geography at the other, with positions in between representing various mixtures of training in the two disciplines. Jobs which involve technical development in the GIS field, such as software engineering, clearly require a background toward the computer science end, whereas employment as a resource manager in an agency using a GIS suggests a training at the geography end of the spectrum. Given the prevalence of GIS's within resource management agencies at the present time, any geography program hoping to place its graduates in these agencies likely tries optimally to position its curriculum sufficiently far away from traditional geography and towards computer science in order to claim that its students have an adequate degree of technical understanding. Although we are seeing the emergence of joint degree programs between computer science and geography in some universities, in practice there are very severe constraints on the flexibility of most curricula to adapt to this sort of need. University undergraduate geography programs have traditionally tapped a population of students with below average technical and mathematical skills. Many in fact gravitate towards geography in high school because of a perhaps mistaken impression that by doing they can avoid mathematics, etc. To change this pattern in any significant way will require many years of consistent effort, and few indications exist that the public image of academic geography is strong or persistent enough to have such an effect. Similarly faculty resources have little flexibility. Graduate programs are unable to supply a sufficient number of faculty with GIS interests, particularly under the tight hiring constraints that affect many departments.

In effect, then, we are unable to produce substantial and rapid change in the backgrounds of students enrolling in GIS courses, in other words to change the supporting branches to suit the leaf. To move the leaf to another tree by allowing that computer science is the optimum basic training for resource managers in an era of GIS technology would be at best undesirable, and at worst disastrous. Another option exists, however: to make GIS a more fundamental part of the curriculum by changing its role in the model from a leaf to part of the stem. We will argue below that this is not only feasible, but appropriate and desirable given the current state of GIS thinking.

The third issue concerns the appropriate level and content for a course or program in GIS, especially the basic ambiguity of the field itself. We have, after all, no clearcut definition of what a GIS is, of what it is designed to do, or of how its use can be integrated into activities such as land use management or municipal planning, fields to which geographers make substantial contributions. From the perspective of an outsider, the field lacks many of the qualities which traditionally identify subdisciplines. It has a very limited literature. We have already noted the lack of text-books, although this may be due in part to the novelty of the field. In addition the literature that exists is largely fugitive, much of it being in government reports or volumes of proceedings rather than journals. There is no learned journal devoted exclusively to GIS, and much of the journal literature is to be found in periodicals at the edge of other disciplines. Important pieces have been published in cartographic journals such as *American Cartographer* and *Cartographica*, in theoretical geography (*Geographical Analysis*), and in geology (*Mathematical Geology*, *Computers and Geosciences*). Only one journal, *Geoprocessing*, limits itself to GIS and related topics. Again to the outsider, professional meetings in the GIS field often resemble trade shows more than conferences of learned societies. In short, we do not have a clear conception of the nature of the fundamental questions to be addressed by the field.

What, then, should be the content of a course or program in GIS? Undoubtedly fields of fundamental importance to anyone interested in GIS research or development include coordinate geometry, the mathematics of map projections, data structures and data models, algorithms and computational complexity, and perhaps most importantly of all, spatial statistics and spatial analysis. The principles of operation of graphics hardware and peripherals, and the design of software for graphics applications are less fundamental but equally important. Finally it would be hard to present oneself as an expert in GIS without some knowledge of the key players in the field at the present time, whether in hardware, software or personnel.

The content, in other words, must cover an enormous range from basic mathematics and computer science, to superficial but nevertheless important names and dates through to practical familiarity with the input requirements of major packages or the frustrations of polygon digitizing. Inevitably the realities of the backgrounds of geography students tend to lead to an emphasis on the more superficial at the expense of the more basic.

Although the concept of a GIS is by now more than twenty years old, only recently has any consensus begun to emerge on the nature of the generic concept. Early attempts at building systems were isolated and subject to the particular context of the sponsoring agency. Strong interest in GIS technology in resource management agencies, particularly in forestry, recently has allowed a number of private-sector vendors to establish a strong presence. The next sections of the paper address the nature of this emerging consensus.

GIS DEFINED

The concept of a Geographic Information System originated in the early 1960s as a means of adapting what were then very primitive computing capabilities to the analysis of map data. Although much conceptual overlap of the concepts has occurred since then, automated cartography was not part of the original conception, even as a useful byproduct. Instead the output of the system was primarily tabular in form, the major function being to measure and summarize geographical areas of specific characteristics. Cost benefit analysis was used to show that computerization would be substantially cheaper than the alternative of employing large numbers of clerical staff in the mind-numbing task of measuring areas from paper maps.

A GIS is best defined as a system which uses a spatial data base to provide answers to queries of a geographical nature. It is an information system (IS), like those used to support a variety of human activities from student records to airline reservations, to which various capabilities for spatial data manipulation and analysis have been added. It shares with the more general concept of an IS the characteristic that the structuring of the data base is not immediately apparent or important to the user. Since putting spatial data into a computer at great expense for the sole purpose of getting it out again would be pointless, a GIS must allow a variety of manipulations to be carried out, such as sorting, selective retrieval, calculation and spatial analysis and modelling. We also expect a full range of functions to allow input of data in map form, and cartographic output, although in many practical systems these cartographic functions are relatively crude.

Practical applications of the technology at present occur in two major areas, resource management and urban planning, with the former having the larger number of installed systems. As a minimum, a GIS must be capable of the input and editing of any type of geographic data, and output of tabular and map information products. Its use may be either for interactive query, or more likely, for the regular production of standard maps, reports and lists. In resource applications these might be regular updates to forest inventories, or in municipal applications updates to city sewer networks. Once the minimum capabilities have been achieved, it is relatively easy to add more and more sophisticated forms of spatial analysis to the system. This has been happening over the past decade as the initial barriers of functionality and cost were passed and systems began to be used for a wider and wider variety of purposes. A recent case in point has been the rapid development of network analysis functions for such applications as school planning in systems installed in municipal governments. We note below that by direct analogy, once the core GIS ideas have been established in a curriculum, more and more sophisticated spatial analytical techniques can be hung on the basic pedagogical framework.

Although the concept of a GIS has been established now for some twenty years, early developments were constrained by a number of factors. Many of the key technical problems were solved in the development of the Canada Geographic Information System in the early 1960s, but only national agencies could conceive of investments on a similar scale because of the high cost. A number of systems designed as lower cost alternatives in the 1960s and early 1970s failed to live up to expectations, and only in the late 1970s could hardware costs and software sophistication converge to produce a useful, cost-effective and adaptable system. An equally important but less tangible element in the recent growth of the GIS industry has been the convergence of thinking on the nature of the generic GIS.

THE GENERIC GIS

The simplest abstract structure for data is the flat file — a series of records each of which contains standard items of information on one member of a set of entities or objects with the information being presented in a consistent manner from one record to the next. Although few areas of application fall neatly into this model only in the past decade or so have data base management systems been designed which recognize this explicitly. Most applications have more than one type of entity or record, and each type of entity is associated with a different set of items of information. Furthermore, links or pointers probably exist between the records in one set and the records in another, or perhaps also within one set. An airline reservation system provides a familiar example of this sort of problem, or data model (Figure 1).

The associated attributes are different in each of the four types of record shown. For example the attributes of a passenger record include such things as name and telephone number, while an aircraft record includes type and registration. Some of the linkages are shown: a passenger record may point to one or more flights, and conversely a flight record points to a number of passenger records. To maintain this information in a flat file would require all relevant information on each flight, such as arrival and departure times, to be part of each passenger record: the use of pointers allows the two types to be kept separately as two flat files with associated linkages.

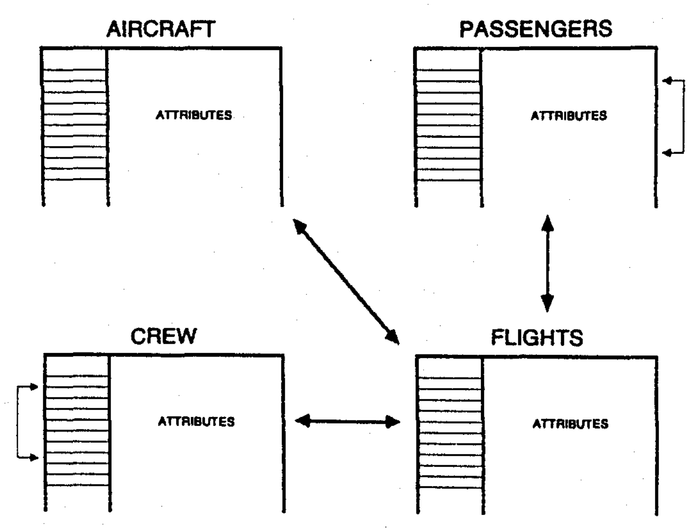

FIG. 1

"*The Operational Geographer/la géographie appliquée*, No. 8/1985"

The abstract model which has been used here to approximate the reality of airline reservation data is classified broadly as a relational data structure; a system designed to manipulate data of this type in an information system context is a relational data base management system (RDBMS). The spatial case shown in Figure 2 appears at first sight to be relatively simple and to fit within the same general framework.

The entities on a map fall naturally into one of three types, points, lines and areas, each of which may be associated with any number of attributes. The locational information presents a problem, because although a point can usually be located through the use of two coordinate attributes, lines and areas have variable amounts of locational information depending on their geometric complexity. Of more concern is the fact that the numbers of linkages between entities which exist because of their relative locations on the map are virtually limitless, and the linkages may themselves have attributes. In effect the map itself is a model of those linkages. Some of the possibilities are shown in Figure 3 in terms of the six pairwise combinations of the three types of entities. Moreover many types of spatial analysis create new types of entities or linkages from old ones. For example a flat file of points could produce a file of points could produce a file of point-point linkages with attributes of distance or spatial interaction, or a file of areas through the generation of Thiessen polygons, or a file of lines through the execution of a minimum spanning tree algorithm or some other network generation technique.

Many forms of spatial analysis require the ability to move freely from one type of spatial entity or linkage to another, a flexibility which has not traditionally been present in such tools as SPSS, SAS or BMD. The spatial interaction models used extensively in analyzing and predicting shopping behavior require simultaneous access to information on shopping trip destinations, usually points, origin zones (usually areas) and attributes of the links between points and areas. Anyone who has tried to use a standard package such as SPSS to calibrate a simple spatial interaction model will be familiar with the problems in dealing simultaneously with multiple entity types without the benefit of an RDBMS.

Despite the complications of spatial data, many of the operations which a GIS is called on to perform are nevertheless limited to flat files. The same simple file of points might be manipulated in much the same way as a passenger file for selective retrieval, to identify appropriate symbols for map output, or to calculate means or other statistics. All of these are conceptually simple operations which can be carried out on the point data alone. By contrast, the identification of the county in which each point lies, for example, requires a complex spatial analysis of the points in relation to the digital representation of a set of areas, or a point-on-polygon topological overlay. A polygon-on-polygon overlay might be used to identify all intersections between counties and some incompatible set of areas covering the same geographical region, such as watersheds. The operation performed on a given number of "red" counties and a given number of "blue" watersheds will produce a new set containing an unpredictable number of "purple" county-watershed combinations. In this case, two area files have generated a new area file, with associated attributes.

Current state-of-the-art GIS approach this abstract model fairly closely, but fall a little short of the theoretical ideal. The files of basic entities and the linkages between them are stored and manipulated without any explicit recognition of their special geographical nature, in many cases by using a standard RDBMS software product or a simplified imitation. Alongside the RDBMS are routines for performing those spatial operations which do not follow the model, either because they would not be relevant to non-spatial data or because they operate across several types of entities or linkages, or create new ones. For example a polygon-on-polygon overlay routine extracts two sets of areas from the RDBMS with their associated attributes, and returns a new set as a new file of area records. Any statistical analysis or retrieval operations on the new records, such as answering the query "Is there a record for Middlesex County and the Thames watershed?" (i.e., "Does the Thames watershed overlap Middlesex County?") could then be answered by a standard RDBMS selective retrieval

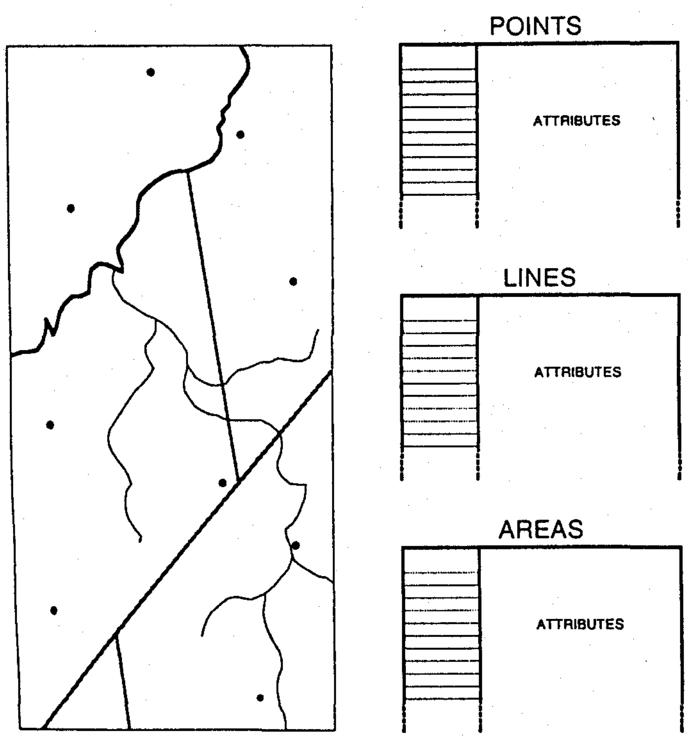

FIG. 2

ENTITY RELATIONSHIPS

Point - Point	Is nearest to . . . Interacts with . . . Is allocated to . . .
Line - Line	Joins . . . Is upstream of . .
Area - Area	Is adjacent to . . . Interacts with . . .
Point - Line	Is on . . . Is nearest to . . .
Point - Area	Is within . . . Is allocated to . .
Line - Area	Crosses . . . Borders . . .

FIG. 3

operation. The generic GIS thus can be viewed as a number of specialized spatial routines laid over a standard relational data base management system.

Figure 4 shows the types of operations which fall into the RDBMS and spatial categories respectively. The former set is fairly well defined, but the latter set is potentially very large, and only a limited number of the better-known techniques of spatial analysis and modelling have thus far been incorporated into vendor GIS. Certainly we are a long way from the point where spatial analyses can be conducted on spatial data in a GIS using multiple spatial entity types with the same ease as the major statistical packages currently allow in flat, non-spatial data sets. No major conceptual hurdles exist, however, in the way of achieving that end. Despite its somewhat unsatisfactory division of the world into two classes of operations, the model contains the necessary flexibility to handle any type of spatial entity or linkage between entities.

RDBMS Operations	Spatial Operations
Selective retrieval	Map input
Sorting	Map output
Calculation	Topological overlay
Statistical analysis	Distance and area calculation
Report output	Buffer zone creation
	Network analysis
	Location - allocation
	⋮

FIG. 4

THE GIS MODEL IN THE CURRICULUM

Although they readily found suitable applications in geography, the majority of the techniques which were introduced to the discipline during the quantitative revolution of the 1960s are fundamentally non-spatial. While the entities which are analyzed by such techniques as regression, analysis of variance, tests of means and a whole host of multivariate methods may have clearly defined locations, the latter can be shuffled and changed without in any way affecting the outcome. Only in a few cases, such as tests of spatial pattern, does location affect outcome. Only recently have the statistics of spatial pattern become a recognized and significant specialty within the field.

Another and perhaps more vivid illustration of this discordance between statistical tradition and geography is in the treatment of autocorrelation. Many statistical techniques assume the absence of spatial autocorrelation and are severely affected when it exists. Nevertheless, associated tests determine its presence or absence in a given data set. Yet for there to be no autocorrelation in a set of spatial data requires that all observations be statistically independent of each other. If geographers do indeed believe in what is often quoted as the first law of geography, then absence of spatial autocorrelation in a spatial data set should be an observation of great significance, not the assumed norm.

A grounding in statistics provides in essence a poor introduction to geographical analysis because statistical tradition is not overly compatible with the spatial analysis paradigm. Spatial data must too often be treated as the special case rather than as the archetype. For similar reasons, much common ground between traditional statistics and cartography is hard to find, and the two tend therefore to have been assigned separate, but often equal, positions in the curriculum. We have already seen, however, that both cartography and statistical analysis, and other forms of spatial analysis as well, follow very logically from the GIS model as branches of a consistent whole. The basic spatial entities — points, lines and areas—can be linked to each other to form higher entities such as point-point or area-area interactions, with statistical analysis limited to operations on sets of entities of the same class, but with many forms of spatial analysis operating across classes.

In summary, the theme of this paper has been that the teaching of GIS to undergraduate geographers raises serious pedagogic issues which are difficult to resolve as long as the field is treated as an advanced specialty. Conceptual thinking in the GIS field has advanced at the same time to the point where the generic design of a contemporary GIS is in effect a model or theory for spatial data. The model provides a satisfactory framework for the great variety of forms of analysis which have been derived for spatial data, and is much richer and more general than the traditional data model of statistics. Cartography can also be seen as part of the overall design, with the map as an image of the data model. It follows that GIS belongs at the root of the spatial analysis curriculum as an organizing principle from which both statistical methods and cartography can be derived.

GEOGRAPHIC INFORMATION SYSTEMS IN THE GEOGRAPHIC CURRICULUM

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INTRODUCTION

Over the last thirty years, geography has undergone a fundamental change from a largely descriptive to a conceptual discipline. The development of computing science and the adaption of the computer to geographic problems has influenced this change in the last twenty years. Geographic Information Systems (GIS) have developed to a point where we have to look at a more complete incorporation of this new approach into our discipline.

Geography has traditionally been better in adopting concepts and methods to its discipline than developing them on its own. It usually lags by considerable periods behind the disciplines that originate the concepts and methods. This explains why most geographers still use computers as not much more than fast calculating machines. The incorporation also creates internal struggles which are combined with perceptions about the "originators" which are usually based on outdated notions of their research domain. Thus, for example, economists would agree that historically their discipline was based largely on principles of utility maximization, a philosophical stand expanded decades ago.

A similar situation exists with computing science. Numerical analysis is the only sector that geographers usually know and computers are tightly coupled to the normative approach. The fact that computer scientists can handle intuitive and fuzzy notions easier within a logical organization than most other scientists is largely overlooked.