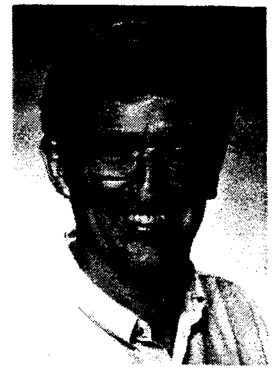
KEYNOTE SPEAKER
GEOGRAPHIC INFORMATION SYSTEMS -
WHAT HAVE WE LEARNED FROM THE 1980s?



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Introduction

The GIS boom that began in the early 1980s is still accelerating. New vendors are entering the market with new and exciting products, education and training programs are proliferating, the GIS software industry is reporting growth rates in excess of 40%, new textbooks and magazines are appearing, and GIS technology continues to find new applications and new acceptance. All the same, 1990 seems an appropriate time to reflect on where we have come, and where we are going. The 1980s were years of unprecedented economic growth, both in Western economies generally and in GIS, and it is clear that the resources that were available to fund this growth in the 1980s will be much harder to find in the new decade. The 1980s also saw unprecedented changes in computing hardware with the development of personal computing and the workstation. What have we learned from the 1980s, and how can we learn from retrospection as we enter the new decade? Where do we stand in GIS research, and what are the important items in the research agenda? What is the state if GIS education, and will it adapt to the demand for trained staff?

I would like to focus this presentation on four issues:

- Where are we now?
- Where are we going?
- Current deficiencies in GIS.
- Prospects for the future.

The emphasis in the paper will be on research and education, which are the primary objectives of the NCGIA. The Center was founded by the National Science Foundation in 1988 as a three-institution consortium of the University of California, Santa Barbara; the State University of New York at Buffalo; and the University of Maine. In research our primary goal is to address what we see as impediments to the successful adoption of GIS technology. These range from technical issues such as data models and data structures, through generic ones such as coping with uncertainty in data, to social problems such as the measurement of the benefits of GIS, and the impact of GIS on institutions. In education, our efforts are directed at increasing the supply of trained personnel in GIS, and the major focus to date has been the Core Curriculum Project, a set of teaching materials for a one-year university course sequence in GIS. More information about the Center can be obtained from the address above, or by contacting the Buffalo or Maine sites.

Where are we now?

The roots of GIS go back well into the 1960s, and we owe a great amount to the early Canadian efforts by the federal government, IBM Canada and others at that time to develop CGIS. In fact the system made a remarkable number of technical breakthroughs, including:

- the use of a scanner and raster/vector conversion
- the separation of attributes and spatial data
- representation of polygons by arcs
- chain code
- the use of Morton order for indexing.

But it wasn't until the late 1970s that GIS really began the period of rapid growth that continues today. Several developments allowed this to happen. On the hardware side, 1980 saw the introduction of the super-mini, a multi-user system with virtual memory management for around $200,000 and an ideal platform for a stand-alone, turnkey GIS. On the software side, 1980 saw the release of the first GIS to take advantage of a relational DBMS, providing enormous flexibility in the handling of relationships between spatial entities. Finally, 1980 saw the beginnings of the trend towards personal computing and the mass popularization of word processing and desktop publishing.

Ten years later, GIS is a large and growing industry. Estimates vary, but expenditures world-wide on GIS hardware, software and services are certainly in the billion-dollar range. But despite its growth, GIS is a remarkably diverse set of interests. Its applications range from resource management through urban infrastructure to emergency response, from political districting to forestry. It runs on platforms from the PC to the large mainframe. It includes an enormous range of software architectures, from the simple, self-contained raster systems such as GRASS and IDRISI to the large database managers such as IBM's

GFIS. Some vendors focus on a single platform, while others, notably ESRI, offer a single product over the full range from DOS to VM. The GIS community includes an extraordinary range of disciplines, from archaeology and landscape ecology through forestry to civil engineering and computer science. And there is as much variety in the definitions of the field. GIS is variously described as a spatial decision support system; a system for input, storage, analysis and output of geographic data; or a geographically referenced information system (to cite only three of the competing definitions). Finally there is LIS - is it the same as GIS, or is one a subset of the other, and if so, which?

But despite the diversity, there is evidence of convergence. The past few years have seen the emergence of several series of conferences aimed at the full GIS community. In the US, the annual GIS/LIS series sponsored by a consortium of five societies (AAG, ASPRS, ACSM, AM/FM and URISA) has grown quickly to over 3,000 attendees. In Canada, the Ottawa meetings in early March have been similarly successful. The lone textbook of 1986 by Peter Burrough (*Principles of GIS for Land Resources Assessment*, Oxford) has now been joined by several others (e.g. Aronoff's *GIS: A Management Perspective*, WDL, Ottawa; Star and Estes' *Introduction to GIS*, Prentice-Hall), and many more are on the way. New organizations have appeared, and the Association for Geographic Information (AGI) in the UK seems to be a particularly successful example. In many countries there have been efforts to develop national GIS policies, e.g. the UK's Chorley Report[1], and the US Department of the Interior's *Study of Land Information* (1989), although with mixed success. And new databases, such as the US Bureau of the Census's TIGER, have provided focus and impetus.

The GIS community seems to be converging not around a single, uniform software product (a standard GIS) or a single application, but around a set of generic issues that emerge from the technology[2]. Whatever the application or EDP solution, every user of GIS faces the same set of problems in dealing effectively with digital geographic data, and these problems in turn form the agenda for discussion at GIS meetings - the 'glue' of the GIS community. Some of the more prominent are:

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[1] Department of the Environment (1987). *Handling Geographic Information: Report of the Committee of Enquiry chaired by Lord Chorley*. HMSO, London.

[2] Digital Cartographic Data Standards Task Force (1988). The proposed standard for digital cartographic data. *The American Cartographer* **15(1)**.

- data capture - how to convert data from raw to digital form in an efficient, cost-effective manner;
- data modelling - how to represent the infinite complexity of the real world in a discrete, digital machine - whether to use raster or vector, layers or objects, how to model complex objects;
- accuracy - how to cope with the uncertainty present to varying degrees in all geographical data;
- volume - how to deal with the fact that demands for geographical data will often exceed the space available for storage;
- access - how to design data structures, indexes and algorithms to provide rapid access to large volumes of geographic data;
- analysis - how to link GIS databases with advanced modelling capabilities;
- user interfaces - how to present the GIS database to the user in a friendly, comprehensible, readily used fashion;
- costs and benefits - how to measure the benefits of GIS information and compare them to the costs;
- impact on organizations - how to introduce GIS successfully into a complex organization.

All of these issues transcend the technology itself, and all of them in one way or another affect the technology's usefulness, whatever the application and whatever the platform. In recent years they have emerged in various guises as the basis of the research agendas of the NCGIA[3], URISA[4] and the UK Regional Research Laboratories (Masser[5] and Maguire[6]).

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[3] NCGIA (1989). The research plan of the National Center for Geographic Information and Analysis. *International Journal of Geographical Information Systems* **3(2)**: 117-136.

[4] Craig, W.J. (1989). URISA's research agenda and the NCGIA. *Journal of the Urban and Regional Information Systems Association* **1(1)**: 7-16.

[5] Masser, I. (1990). The Regional Research Laboratory initiative: an update. *AGI Yearbook 1990*. Taylor and Francis, London: 259-263.

Once we begin to see the generic issues that underlie GIS, and transcend the particulars of its technology and its applications, then we can begin to understand how GIS can affect our view of the world. Traditionally, information about places on the earth's surface has been stored and transmitted in the form of maps, images, text and to some degree sound. The focus of early GIS was on the digital database as a store of maps - maps were the input, the output and the metaphor of GIS applications. But increasingly GIS is seen as a means of access not to maps but to the real world that those maps represent. The purpose of the database must be to inform the user accurately about the contents of the real world, not about the contents of a source document. A DEM, for example, should be assessed on its ability to return the elevation of any point on the earth's surface, not the position of an abstract contour line.

GIS has also affected the role of geographic information within an organization. It encourages the notion that geographic information is a commodity that flows through the organization, and that has a value determined by its accuracy, currency, accessibility etc. In fact it may be the central commodity in some organizations, for example forest resource management agencies. Geographic data needs careful planning and budgeting if it is to be collected and updated on a regular basis, and accessible to the organization's analysts and decision-makers. Finally, if information is important, then it is rational to use different types of information as the basis for the organization of departments and systems.

In summary, GIS in 1990 is a diverse collection of interests, software and hardware solutions, and applications. Two software products applied to the same problem (e.g. ESRI's ARC/INFO and IBM's GFIS applied to management of a utility company's facilities) would produce entirely different solutions; and the needs of forest resource management and school bus routing appear to have very little in common. But there is a growing sense that the issues that hold the GIS community together, and produce convergence rather than divergence, are the generic issues of dealing with geographic information - with representing it in a digital computer, and working effectively with it to produce answers to problems.

Where are we going?

First, the current growth of GIS shows no signs of abating and should continue for some

[6] Maguire, D.J. (1990). A research plan for GIS in the 1990s. *AGI Yearbook 1990.* Taylor and Francis, London: 267-277.

time into the 1990s. New magazines are appearing, and existing ones, such as *GIS World* and *Mapping Awareness*, are growing and increasing circulation. Conferences are numerous and successful, offering workshops on increasingly specialized topics and access to the latest vendor products. New software vendors are entering the market with exciting and innovative products. GIS is finding new applications and strengthening its penetration into existing markets. GIS courses are proliferating at universities and colleges, and are finding increasing interest from students anxious to acquire useful skills. Over 100 institutions participated in the testing phase of the NCGIA Core Curriculum Project, and over 250 have acquired the revised version of the materials to date.

On the other hand there are increasing signs of diversification, and this trend is likely to continue to strengthen in the next few years. GIS applications such as facilities management fall under the spatial information paradigm, whereas scientific and resource analysis applications fall under the spatial analysis paradigm. The former emphasizes the database and query aspects of GIS, whereas the latter tends to focus on modelling. The split is illustrated by the case of two Canadian companies - TYDAC and GeoVision - one marketing 'spatial analysis systems' with the very successful SPANS product, the other marketing 'geographic information systems'. Within the PC marketplace, there is increasing divergence between products aimed at GIS applications in resource management, facilities management, or market research (compare, for example, PAMAP, TYDAC's SPANS, Facility Mapping Systems' FMS/AC and Strategic Mapping's ATLAS*GIS).

This trend to diversification is appropriate and rational, as it matches software and platforms with different functions and applications. The complex modelling and analysis of resource management require a very different solution from intensive digitizing or the management of large facility inventories. In time, we can expect this trend to lead to more and more specialization within the GIS industry, as it becomes less and less possible to offer a single software solution for all platforms and all applications. One vendor may specialize in digitizing stations using PCs, another in database maintenance using large mainframes and terminals, another in spatial analysis using advanced personal workstations, and another in 3D applications.

There is an interesting analogy between the development of GIS and the history of communication. The written letter, an unstructured analog format, was first replaced by the highly structured digital telegraph, then by the unstructured analog telephone. Electronic mail, a highly structured digital format, is now in competition with relatively unstructured but digital FAX. Having spent the past three decades working to replace the unstructured, analog map with the digital GIS database, we are only now beginning to realize that there can be great value in combining other types of information, particularly unstructured images, text and even sound, with GIS. The multimedia GIS is already functioning in many highway maintenance organizations, where unstructured digital or NTSC images are linked with GPS-determined locations in a structured digital database, and multimedia GISs are also finding applications in resource management and marketing. In part this is a technical problem, as the software and hardware tools to manage multiple media have only recently become available, particularly in the Macintosh world. But it is also a conceptual problem, having to do with the role of the symbolic map in GIS thinking. If the GIS is a window on the world, then it makes sense to combine the view provided by its structured database with other media, whether digital or analog. We tend to see the structured GIS database as exclusive, and to know little about the relative value of other media.

In this and many areas the future of GIS will continue to be determined by developments in hardware. The cost per cycle will continue to drop in the next few years, as will the cost per megabyte of RAM. The 1990s will see the proliferation of 3D technology, as high performance graphics adapters become available for mass-produced workstations from vendors such as Silicon Graphics. The recent generation of workstations, typified by the IBM RS/6000, include 3D adapter options with display rates as high as 10^6 3D vectors per second, with polyhedral rendering capabilities, in a platform running at 25-45 MIPS. GIS will no longer be confined to the plane, and the DEM display capabilities of today will seem very primitive in a few years. It will become possible to model and visualize subsurface conditions, and to analyze distributions over the surface of the earth without the distortions and interruptions produced by conventional map projections. In 3D the map metaphor is completely inadequate, and the user interfaces for these systems will have to explore entirely new territory. How, for example, should a system allow the user to build knowledge of subsurface conditions from a variety of different types of evidence? In 2D this task of map compilation takes place on paper, but in 3D it can only take place in the abstract domain of the digital database. What tools does a user need to explore a model of the subsurface once it has been built? What icons should be provided in an appropriate user interface?

If GIS has been dominated by the map, then fundamental changes now occurring in mapping will have significant effects in the coming decade. Low-cost GPS receivers are already available with higher accuracy than the base mapping available over most of North America (1:100,000, 1:24,000 in the Continental US), and provide a significantly cheaper method of primary data collection for many mapping activities. GPS is already being used to map road and rail networks, and to track vehicle movements. At the same time the funds available to support large, public-sector mapping programs are diminishing. In this new environment it is vital that the public agencies adopt a lead role in coordinating research and education programs, in ensuring the health and vitality of the GIS industry, and in defining standards of data quality, data formats etc.

What is deficient?

It is becoming increasingly impossible for any one vendor to be all things to all GIS users - to offer one product on all platforms, under all operating systems, as a solution to all applications. One way to view specialization in the GIS industry is in terms of three measures: functionality, capacity, and accessibility. Ideally, a GIS should offer a wide range of forms of spatial analysis and manipulation on a large and accurate database, and provide responses immediately. In practice, these objectives conflict. Fast access to large databases is feasible only if the number of possible operations is severely limited, and systems that offer complex modelling and analysis often restrict capacity. In GIS there is no limit either to functionality or to capacity, since users will always find reasons for more.

If the future of GIS lies in specialization, then the key to success will be standards. Encouraging progress is being made in data exchange formats (e.g. USGS's SDTS, DMA's DIGEST), and in standardizing terminology (DCDSTF 1988). But terminology is notoriously difficult to standardize, and there is little indication to date that the proposed term for the common boundary between two polygons ('chain') will replace those in current usage ('arc', 'segment', 'edge' etc.). It is also difficult to standardize when the central concepts of GIS are so poorly articulated. Key terms such as 'raster' and 'vector', 'object' and 'layer' need to be standardized if we are to develop a well-defined set of data models. Standards are needed for data sources, particularly in describing quality, and for user interfaces. However the diversity of the GIS community makes the development of standards difficult. For example, the needs of the US Bureau of the Census in a street network database are very different from those of the vehicle navigation industry, or the emergency response community.

To date, the major success of GIS has been in capturing and inventorying the features of the earth's surface, particularly as represented on maps, and in supporting simple queries.

There has been much less success in making effective use of GIS's capabilities for more sophisticated analysis and modelling. It is hard to find examples of insights gained through the use of GIS, or discoveries made about the real world. GIS has not yet found widespread application in the solution of major social problems - disaster management, environmental quality, global issues or health. In part this comment is unfair, because such insights would be next to impossible to document. In part the reason is commercial - the market for GIS as an information management tool is far larger than that for spatial analysis, and vendors have invested relatively little in developing and promoting analytic and modelling capabilities. And although GIS is a major improvement, it is still difficult to collect, display and analyze data in geographical perspective. Finally, Couclelis[7] has made the point that the current generation of GIS concentrates on a static view of a space occupied by passive objects, and offers little in support of a more humanistic view of dynamic interactions.

Prospects for the future

In this last section I would like to offer two contrasting views of GIS in the 1990s. The first is negative and the second positive, and my guess is that the second will prevail. However there are actions we can take to strengthen the odds.

In the negative view, GIS will fragment and disappear, and by the end of the decade will be nothing but a memory. Geographers often draw a parallel between GIS and the introduction of quantitative methods to geography in the late 1960s, and comment on the lack of interest in quantification, at least in human geography, in the 1980s. GIS will fragment because it is too loose to hold together, and because the 'glue' is too weak and abstract. Users of IBM's GFIS, Intergraph's TIGRIS and Map/Info will cease to see any reason to attend the same conferences. The consortium of five organizations responsible for GIS/LIS will break up and each will concentrate on its own agenda. GIS will be seen as the Edsel of EDP, too awkward and expensive except in some specialized applications.

In the positive view, the GIS consortium will continue to converge. A constant supply of better tools seems assured, particularly in computing speed, software integration, network communication, graphics and storage capacity. The infrastructure of the GIS community will continue to improve, with better magazines, organizations, textbooks, meetings, and all

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[7] Couclelis, H. (1989). Geographically informed planning: requirements for a planning-relevant GIS. Presented to the North American meetings of the Regional Science Association, Santa Barbara, November.

of the symbols of an emerging specialty. Less assured is a constant supply of new players in the industry, since the pattern has been that new players are the source of a disproportionate share of technological innovation. New players bring new ideas to the industry, such as Prime/Wild with System/9, Small World, or ATLAS*GIS.

In the positive view, the public agencies will promote and develop standards for data exchange formats, structures, models, and data quality. Training and education programs will develop through cooperation between vendors and institutions, and lead to the emergence of a strong set of core concepts. Funds will be available through cooperative agreements to support the development of teaching facilities, and to ensure that these keep pace with developments in the technology.

The results of research currently under way will emerge in improved products. Of particular significance will be:

- data models to handle 3D and time dependence, and complex interactions between objects
- support for complex analytic applications, including tracking of data lineage, tools for visual interaction with the stages in the analysis process, propagation of uncertainty
- support for quality assurance and quality control (QA/QC) especially in GIS applications where litigation is a constant problem
- support for multiple media - unstructured images, both digital and NTSC, text and sound
- integration of GIS with the capabilities of GPS for data collection and compilation
- tools for visualizing 3D and time-dependent data
- tools for data compilation, particularly in 3D
- improved techniques for conducting functional requirements studies, evaluating costs and benefits, benchmarking and other aspects of the GIS acquisition and project management process.

Finally, the GIS community will converge around a common concern not only for the technology of GIS, but more importantly for the common issues that transcend the technology and pervade all of its applications. GIS can survive by constantly developing new and exciting capabilities, or by constantly finding new applications, but the really fundamental issues in GIS are those that are common to all users of geographic information - how to capture a complex and dynamic world in a digital database and provide access to it in a useful, accurate and cost-effective manner.

CHAIRMAN ZARZYCKI: Thank you very much, Mike, for that very stimulating speech.

Ladies and gentlemen, we will now break for coffee and an opportunity to see the exhibits which are set up in Rooms 105 and 106 down the hall. Please be back here at 11:00 sharp.

CHAIRMAN ZARZYCKI: Welcome back. The Chairman for the remainder of this morning's session is my boss, Ron Vrancart, the Executive Coordinator, Lands and Waters Group, Ministry of Natural Resources. A wide range of provincial activities fall within Ron's jurisdiction including but not limited to: the management of crown lands and waters, the disposition and acquisition of public lands, mineral aggregates and fuel mineral management, policy and financial assistance to conservation authorities, surveying, land-related geographical referencing, mapping, remote sensing and other high tech computer applications as well as matters relating to Indian Land Claim and Resource Issues.

Ron received his B.A. in 1965 from the University of Western Ontario where he majored in geography. He subsequently received a diploma in town and regional planning from the University of Toronto and his master's degree in town planning for the University of London.

Ron has been with the provincial government since 1969. His career has spanned a broad range of activities including a series of management and executive positions in the lands and waters and outdoor recreation programs. He was Director of the Niagara Escarpment Commission ... has lectured on urban planning as well as conservation and recreation planning ... been with management board ... and just prior to returning to MNR was Executive Director of the Planning and Administrative Division in Northern Development and Mines.