Geographic information systems

by M.F. Goodchild

I Definitions of GIS

Although reviews of cartography and geographic information systems (GIS) by Michael Blakemore have appeared in these pages for several years, this is the first exclusive review of GIS. Some initial clarification of the field would seem to be appropriate, particularly given the current widespread confusion over the nature of the field and its significance. In the same month that the President of the Association of American Geographers was able to see 'regional, cultural and historical geography . . . being swamped in the rush to GIS and similar easily justified but non-intellectual expertise' (Jordan, 1988), the Director of the Geography and Regional Science Program at the US National Science Foundation saw GIS provid[ing] geographers with ways of handling regional information:

> that they have sought for 2000 years. GIS are simultaneously the telescope, the microscope, the computer and the xerox machine of regional analysis and synthesis (Abler, 1988: 137).

Is this the latest in a series of shortlived technical bandwagons or the basis of a genuine paradigm shift?

Geographic information systems are integrated computer systems for the input, storage, analysis and output of spatially referenced data. They owe their origins to the development of the Canada Geographic Information System in the early 1960s, in the days of primitive mainframes and batch processing with punched cards, long before the emergence of cheap, interactive graphic workstations. Despite the technical limitations of the time, there was a clear recognition that certain types of map analysis and inventory, particularly overlay and measurement of area, can be done much more efficiently by computer than by hand, and this notion of automated map analysis remains a key justification for GIS today.

Although GIS has roots extending back nearly 30 years, the past three have seen an explosion of interest which has had enormous impact on geography, and to some extent on all disciplines which deal with spatial data. The reasons for this are complex and deserve enumeration. First, despite its origins in the analysis of land resource maps, GIS is in reality a conglomeration of interests. It brings together cartographers interested in the use of digital methods and their

extension beyond automated mapping to manipulation and analysis; surveyors and photogrammetrists similarly interested in extending the usefulness of digital products beyond simple hard copy maps; spatial analysts and geographers who see GIS as a route to larger, more comprehensive databases and better analytical techniques; and the remote sensing community with its desire to combine satellite data with other sources and to extend the range of possible analyses. To Burrough, geographic information systems 'are the result of linking parallel developments in many separate spatial data processing disciplines' (Burrough, 1986: 6).

Secondly, current interest in GIS is the direct result of the popularization of computing which occurred with the introduction of personal computers during the economic downturn of the early 1980s. GIS is to geography as high technology is to society generally; a symbol of the discipline's desire to be contemporary. At the same time steady increases in computing power and reductions in cost have meant that significant spatial data handling technology can be available to anyone able to afford a modest investment in hardware.

Finally, despite current enthusiasm, the rate of adoption of GIS concepts and techniques has been slow. Unlike many areas of electronic data processing, GIS does not automate an existing manual process, but instead offers to change the way geographers work in fundamental ways. In essence the field is technology driven, rather than application driven.

II The growth of interest in GIS

Many indicators suggest that interest in GIS has still not reached the midpoint of the growth curve. Major meetings in 1987–88 included Auto Carto 8 in Baltimore in March (the most recent in a series running since the mid-1970s and sponsored by the American Congress on Surveying and Mapping), GIS 87 organized by the American Society for Photogrammetry and Remote Sensing in San Francisco in October, IGIS 87 organized by the Association of American Geographers in Washington in November, the first meeting of the IGU Global Database Planning Project in the UK in May 1988, URISA 88 (Urban and Regional Information Systems Association) in Los Angeles in August, the Third International Symposium on Spatial Data Handling in Sydney in August 1988, a GIS Symposium convened by the US National Academy of Sciences, US Geological Survey and the Association of American State Geologists in Denver in September, and GIS/LIS 88, sponsored by ACSM, ASPRS, AAG and URISA in San Antonio in November 1988.

1987 saw the launch of the *International Journal of Geographical Information Systems*, the first journal devoted exclusively to the field:

> Relevant developments were either not being reported publicly or were appearing in a wide range of disciplinary journals not normally seen by many of those interested in GIS or in reports and conference proceedings of limited circulation (Coppock and Anderson, 1987: 5).

Many others have commented on the high proportion of the GIS literature which is 'fugitive' or 'grey' (Burrough, 1986: vii), perhaps reflecting the extent to which developments in this field have occurred outside academe, in government and industry.

The need for focus in this diffuse and many tentacled field is reflected in the setting up of Regional Research Laboratories in the UK in the past two years, and in parallel efforts by the US National Science Foundation to establish a National Center for Geographic Information and Analysis 'devoted to basic research on geographic analysis utilizing geographic information systems' (National Science Foundation, 1987). The solicitation for bids for the NCGIA saw its research programme as addressing the following 'general problems':

> Improved methods of spatial analysis and advances in spatial statistics;
> A general theory of spatial relationships and database structures;
> Artificial intelligence and expert systems relevant to the development of geographic information systems;
> Visualization research pertaining to the display and use of spatial data; and
> Social, economic and institutional issues arising from the use of GIS technology (NSF, 1987).

This statement remains the most succinct and comprehensive identification of a general research agenda for the field. The first point recognizes the importance of GIS to geographical analysis as a technology which can remove many of the impediments which currently prevent wider application of methods and models developed by quantitative geographers over the past three decades. The second stresses the importance of GIS as a formal model of spatial information and of the relationships among objects in space, a concern anticipated many years earlier by Nystuen (1968). The third emphasizes the complexity of many forms of spatial analysis and the need to harness the intense computing power of current systems to solve spatial problems (Couclelis, 1986); the same need has been recognized in automating the complex operations inherent in many aspects of map design.

Point four recognizes the importance of visualization in geography, and the signifcance of the map as a tool of spatial analysis. Computer systems provide new ways of displaying map information, and may be effective in overcoming display problems which have traditionally caused difficulty in cartography, including time dependence, uncertainty and fuzziness, flows and interactions, and the third dimension. Finally, the last point echoes Tomlinson (1988: 217) 'there are just as many problems, and possibly more, on the management side of implementing an information system as there are on the technical side'. The NCGIA will be the first BSF national centre with a significant social science component, and will offer the opportunity to study the ways in which human behaviour and human organizations can form impediments to the adoption of new digital technologies. Other key issues within the fifth point include legal responsibility for decisions made using GIS, and applications of copyright law to spatial data.

1987 saw the publication in the UK of one of the most significant reviews of spatial data handling in recent years, the Chorley Report, or more accurately the Report to the Secretary of State for the Environment of the Committee of Enquiry into the Handling of Geographic Information (Department of the Environment, 1987). Like the NSF it found enormous potential in the new technology, but impediments in the form of a lack of trained personnel, a need to coordinate diverse users and applications, and a lack of awareness of potential benefits.

III Progress on the research agenda

In this section we briefly review some of the more exciting research developments of the past year, using the NCGIA solicitation as a guide.

One of the recurrent themes of GIS research is the problem of error, as digital systems operate with a precision which is often far higher than the data. The data input to a GIS is a model or abstraction of reality, but this can easily be overlooked in analysis. For example, a forest stand will likely be shown on a map as a bounded area, and represented in the GIS as a polygon; it is easy for a GIS user to treat the polygon as homogeneous and ignore the variation which inevitably occurs in reality. Research continues to demonstrate the problem and to propose methods of measuring its severity (Chrisman, 1987; Walsh, Lightfoot and Butler, 1987).

The ultimate goal of research on GIS error must be the development of measures of uncertainty for GIS products, akin to the confidence limits of conventional statistics. These must be based on models of error which can be calibrated or parametrized for specific data sets, but there has been only limited progress in this direction. Goodchild and Dubuc (1987) proposed a model of error in thematic maps, but while it has uses in simulation the model will be difficult to calibrate because of the large number of parameters.

Several interesting directions have emerged in research in spatial analysis in the past year which are directly dependent on GIS techniques. Openshaw (1988) has described a new, computationally intensive approach to spatial interaction modelling in which the computer is seen as both a generator and tester of models. He argues that the reliance on deductive modelling which has emerged over the past two decades is inconsistent with our relatively poor understanding of reality and fails to make full use of the power of contemporary computing systems. Armstrong, Densham and Rushton (1986) have described the concept of a spatial decision support system, a GIS-based computer system designed to support a user in making spatial decisions in a complex environment. Besides applying a suite of standard models, the system might also allow the user to evaluate alternatives against a variety of criteria and to visualise the results of decisions in graphic or map form. The system could be packaged in a lap-top machine to be taken into the field as a means of extending the analyst's powers of direct observation.

The search for improved methods of digital representation of spatial information continues to occupy a substantial proportion of the GIS literature. The early raster and vector structures which relate directly to human experience have been eclipsed by the less intuitive hierarchical structures, including quadtrees. The efficiency of hierarchical structures has not yet been exhausted, as indicated by Mark's (1987a) work on their use in finding Thiessen networks. At the same time the TIN (triangulated irregular network) has emerged as the most efficient and effective approach to the representation of topographic surfaces. Algorithms based on TINs continue to appear (see for example Gold and Cormack, 1987).

Spatial data create enormous problems in the choice of efficient data structures because of the infinite richness of spatial relationships. The relational model continues as the most popular means of expressing those relationships in a database. However it is clearly impossible to model all relationships, so a typical implementation models only a small fraction, leaving others to be computed as necessary. It follows that there is no generally optimal structure, but instead that the nature of each application will determine the model to be used.

Not surprisingly, therefore, journals and conferences bring a steady stream of new papers on data models for GIS. In some areas the need for a complex feature type, composed of more primitive simple features, seems to be leading to a move away from the relational model towards a more hierarchical view (see for example, Herring, 1987; Charlwood, Moon and Tulip, 1987). This work is important for geographers because it concerns the search for an ideal model of the information on which any spatial analysis is based.

Another key development in this area concerns the importance of the cartographic model to GIS. Most systems derive their data from maps, and the map, with its points, lines and areas, continues to dominate the data models which most systems implement. Recent research has begun to show how limiting the map model is in many areas of GIS application. For example, in vehicle navigation the user can communicate much more effectively through navigational directions (turn left, go straight) than through a map display (Mark, 1987b). This has led to new interest in spatial cognition as the key to understanding how users think about spatial information.

The area of expert systems continues to stimulate GIS research. A knowledge-based GIS has been described by Smith *et al.* (1987), and work continues on the use of expert systems to automate cartographic design (Fisher and Mackaness, 1987).

Visualization is perhaps the most exciting area of research opportunity at the present time because of the potential offered by electronic display and the relative paucity of existing research. Much work remains to be done in adapting computer display technology to the types of data which cartography has traditionally found difficult, including uncertainty and time dependence.

Finally the fifth point on social and institutional concerns remains the most unexplored and in many ways the most important in the long term. Papers have begun to appear offering formal models of the GIS acquisition process (Goodchild and Rizzo, 1987; Goodchild, 1987) and describing formal benchmarks of vendor products. But issues of the adoption and impact of the new technology in traditional agencies, litigation and copyright, and organizational structures for efficient exploitation of GIS, remain on the research agenda for the future.

IV Concluding remarks

It is clear from a host of indicators that GIS is a major growth area of geography. Whether it will mature into a body of concept and theory or pass into the junkyard of discarded techniques remains to be seen, as the definitive work on the significance of GIS has yet to appear. In the meantime major investments in GIS are being made in the form of new faculty members and courses, and new research funding, not only in geography but in all land-related disciplines. We can only hope that both human and physical branches of geography will succeed in exploiting GIS to the fullest possible extent, and that the discipline will continue to play a prominent role in fundamental GIS research.

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Planning and applied geography

by Paul Knox

The further we are thrust into the post-Fordist uncertainties of flexible accumulation, 'disorganized' capitalism and postmodern planning (Harvey, 1987a; Lash and Urry, 1987), the clearer it becomes that we must not only reexamine the theoretical bases for our understanding of urban and regional change but also rethink some of the objectives and strategies of planning and applied geography (see Clarke and Wilson, 1987). The reexamination of theory is already vigorously under way, particularly in the pages of *Space and Society*, where Michael Dear has arranged – and contributed to – a lively debate that encompasses the need for locality studies versus the dangers of the empirical turn, the role of individuals versus structure, the postmodernism of reaction versus the postmodernism of resistance, and the deconstruction of, versus adherence to, marxism (Harvey, 1987b; N. Smith, 1987; Cooke, 1987a; 1988; Storper, 1987; Saunders and Williams, 1987a; Urry, 1987). Planners and applied geographers must be attentive to this debate. Specifically, given the economic, social and spatial restructuring associated with the transition to advanced/disorganized capitalism, the new international division of labour and the new international financial system (Storper, 1987b; Thrift, 1987b), what has been the role of policy and planning? What *could* be their role? And what *should* be their role?

In answer to the first question, Castells (1988) puts policies of 'technoeconomic restructuring' in a central role in forging the new models of economic, social and spatial organization that are being established. In this context, 'technoeconomic' policies cover a broad spectrum of both private and public sector activity. Of critical importance here are the policies associated with the new telecommunications technologies that underpin so many of the flexible strategies adopted by larger corporations (Cooke, 1987b; Piore and Sabel, 1984). The telecommunications industry has deployed regional telecommunications systems, long-distance fibre-optic cables, satellite teleports, microwave and 'smart' building technologies in a general climate of deregulation. The consequences can already be seen at every spatial scale, from the international 'electronic colonialism' arising from underdeveloped countries' dependence on US, European and Japanese telecommunications systems (McPhail, 1986), through the consolidation of major control