1

Introduction

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Every day in different parts of the world people pose questions just like these:

Politician: 'What is the population of the Sedgefield parliamentary constituency?'

Farmer: 'What are the characteristics of the soils in the Lobley Plantation?'

Retailer: 'Where should I locate my next clothing outlet store?'

Gas engineer: 'Where should I dig up the road to gain access to the gas main?'

Health practitioner: 'How can my authority best respond to the needs of those single parent families with low income and poor housing?'

Climatologist: 'How has the hole in the ozone layer changed in the past 10 years?'

Geologist: 'Are there any trends in the pattern of earthquakes in Italy which could help predict future quakes?'

Planner: 'How has the distribution of urban and rural population changed between the past two censuses?'

Military commander: 'If I deploy my equipment and personnel here who will be able to see me and shoot at me?'

Home delivery service manager: 'What is the shortest route I can use to deliver all these refrigerators to the homes of new customers?'

City accountant: 'What is the total value of the land and property assets which the city has sold in the last 12 months?'

Forester: 'If a fire were to start here on a breezy day, in which direction would it spread and how much timber would be lost?'

Hydrologist: 'A large quantity of a pollutant has been introduced into this well: where will it spread and which customers will be affected?'

All of these questions and many more like them are concerned with geographical patterns and processes on the surface of the Earth. As practitioners of these fields know only too well, answering such questions requires access to geographical information which is characterised by its multidimensional nature (x,y,z coordinates and time), its large volume and high processing cost. To answer apparently simple geographical questions requires that data from several sources be integrated into a consistent form. The art, science, engineering, and technology associated with answering geographical questions is called Geographical Information Systems (GIS). GIS is a generic term denoting the use of computers to create and depict digital representations of the Earth's surface.

From humble beginnings in the 1960s, GIS has developed very rapidly into a major area of application and research, and into an important global business. In 1997 GIS was being taught in over 1500 universities and over 1000 schools, it had over 500 000 regular users (plus innumerable casual map users), and was a global business worth over US $12 billion. It has moved from being an esoteric academic field to being recognised as part of the information technology (IT) mainstream. Today GIS is a vibrant, active and rapidly expanding field which generates considerable public and private interest, debate, and speculation.

1 A BRIEF HISTORY OF GIS

The phenomenon – no other word seems quite as appropriate – now known as 'GIS' has many roots,

Table 1 Major GIS textbooks. Note only core text books are included here.

Antenucci J, Brown K, Croswell, Kevany M 1991 *Geographic information systems: a guide to the technology*. New York, Van Nostrand Reinhold
Aronoff S 1989 *Geographic information systems: a management perspective*. Ottawa, WDL Publications
Bernhardsen T 1992 *Geographic information systems*. Arendal, Norway, Viak IT and Norwegian Mapping Authority Cambridge (UK), GeoInformation International
Bonham-Carter G F 1994 *Geographic information systems for geoscientists: modeling with GIS*. New York, Pergamon Press
Burrough P A, McDonnell R A 1997 *Principles of geographical information systems*, 2nd edition. Oxford, Oxford University Press
Cassettari S 1993 *Introduction to integrated geo-information management*. London, Chapman and Hall
Chrisman N R 1997 *Exploring geographic information systems*. New York, John Wiley & Sons Inc.
Clarke K C 1997 *Getting started with geographic information systems* Englewood Cliffs, Prentice-Hall
Dale P F, McLaughlin J D 1989 *Land information management: an introduction*. Oxford, Oxford University Press
Davis B E 1996 *GIS: a visual approach*. Santa Fe, Onword Press
DeMers M N 1996 *Fundamentals of geographic information systems*. New York, John Wiley & Sons Inc.
Huxhold W E 1991 *An introduction to urban geographic information systems*. New York, Oxford University Press
Huxhold W E, Levinsohn A G 1995 *Managing geographic information system projects*. New York, Oxford University Press
Jones C 1997 *Geographical information systems and computer cartography*. Harlow, Longman
Laurini R, Thompson D 1992 *Fundamentals of spatial information systems*. London, Academic Press
Maguire D J, Goodchild M F, Rhind D W 1991 *Geographical information systems: principles and applications*. Harlow, Longman/New York, John Wiley & Sons Inc.
Martin D S 1996 *Geographic information systems: socioeconomic applications,* 2nd edition. London, Routledge
Peuquet D J, Marble D F 1990 *Introductory readings in geographic information systems*. London, Taylor and Francis
Star J L, Estes J E 1990 *Geographic information systems: an introduction*. Englewood Cliffs, Prentice-Hall
Worboys M F 1995 *GIS: a computing perspective*. London, Taylor and Francis

and it is impossible to do justice to all of them in a brief history. The first edition of this 'Big Book of GIS' (Maguire et al 1991) included a full chapter on GIS history; a book on the history of GIS edited by Foresman appeared early in 1998 (Foresman 1998) and many introductory texts include short histories (see Table 1). Rather than attempt to summarise, the emphasis here is on the diversity of GIS's roots, and on updating the story with a brief account of major events and trends since 1991 (when the first edition of this book appeared).

1.1 GIS as data analysis and display tools

The history of GIS is in many (but not all) ways the history of using digital computers to handle and analyse mapped data. Early computers were literally 'number crunchers', not handlers of the complex forms of information found on maps, and were designed to perform a task – the manipulation of numbers – that had no obvious applications in the world of map production and use. Thus it was many years after the development and deployment of the first electronic computers that uses for the new technology for handling maps began to emerge. It is now generally accepted that the British Colossus computer of the early 1940s, used to break the German Enigma codes, was probably the first electronic computer, although an electro-mechanical one had operated in Harvard a few years earlier. By the 1950s (Rhind 1998), Swedish meteorologists were producing weather maps with the aid of computers. Shortly afterwards, Terry Coppock was geographically analysing agricultural data by computer. At the end of the 1950s, he analysed about half a million records from the Agricultural Census using an early computer in London University. The programmes summarised the data records and classified them ready for mapping by hand. Though the potential value of computer mapping was clearly appreciated at the time, the limitations of machine performance and output devices rendered such automation impossible (Coppock 1962). His work may be the earliest substantive 'GIS-based research'. Working in Canada, Roger Tomlinson (see also section 7 below) is rightly credited with seeing the need for computers to perform certain simple but enormously labour-intensive tasks associated with the Canada Land Inventory in the mid 1960s, and with being the father of the Canada Geographic Information System (CGIS), itself widely acknowledged to be the first real GIS. Tomlinson saw that if a map could be represented in digital form, then it would be easy to make measurements of its basic elements, specifically the areas assigned to various classes of land use. At that time, normal practice involved laborious and tedious hand-measurement of area by counting dots on transparent overlays of known dot density. Tomlinson's cost–benefit analysis showed that computerisation would be cost effective, despite the enormous costs and primitive nature of the computers of the time.

It is, however, important to note that many other pioneers, often working alone, also played a very significant role: for instance, many of the same technical tools were also devised in Australia, while at Northwestern University in the USA, Duane Marble and colleagues became interested in using geographical information technologies to solve transportation and other urban problems.

1.2 GIS as map-making tools

A second and quite distinct history of GIS stems from the benefits of automating the map production process. Once information of any kind is in digital form, it is much easier to manipulate, copy, edit, and transmit. The primary GIS innovator in this context was David Bickmore: at his urging, Ray Boyle invented the 'free pencil' digitiser and, by 1964, Bickmore and Boyle had set up the Oxford system for high quality digital cartography (Rhind 1988). At that time, major mapping agencies – including the US and other military bodies – began the lengthy and often rocky process of automation. The complexity of the issues involved in doing this are confirmed by the fact that even today major map-producing agencies employ a sometimes awkward mix of manual and automated techniques (for a sense of some of the reasons behind this continuing difficulty, see Weibel and Dutton, Chapter 10). Widespread achievement of the benefits of automated cartography had to await the development of suitable mechanisms for input, display, and output of map data, but the necessary devices – map digitiser, interactive graphics display device and plotter, respectively – had become available at reasonable cost by the early to mid 1970s and from then onwards an increasing number of organisations set out to convert all their maps into computerised form.

1.3 Other roots of GIS

A third root of GIS lies in landscape architecture and environmentally sensitive planning. In the 1960s, a view of planning emerged that saw the world as composed of a set of largely independent layers, each representing some component of the environment, and thus some set of environmental concerns. These layers might include groundwater, natural vegetation, or soil. McHarg (1969; 1996) was the foremost proponent of this view, and his group at the University of Pennsylvania applied it in a long series of exemplary studies. Although the initial idea was strictly manual, the computerisation of these ideas in a layer-based raster GIS was a simple step, and many systems owe their origins to McHarg's simple model (e.g. Tomlin 1990).

GIS also has urban and demographic roots. Efforts to automate national population censuses go back to Hollerith and the very early days of office automation, and the mechanical card sorters that predate digital computing. A census is inherently geographical, requiring the tabulation and publication of statistics for a range of geographical units, with complex hierarchical relationships in space (see Martin, Chapter 6). The cost of these aggregations, and the notion that they could be performed automatically from a single representation at the most detailed level, had by the late 1960s driven the US Bureau of the Census to introduce the dual independent map encoding (DIME) system – a primitive GIS representation of the urban street network with simple topology. Interestingly, part of the rationale for the use of this approach to encoding – which initially contained no coordinates – was to permit automated checking of data consistency because the data collection process was spread over many offices. Many of these ideas were reapplied at even more detailed scales in cities in support of such urban functions as infrastructure maintenance, and the Urban and Regional Information Systems Association (URISA) was founded at about this time to foster further development.

Finally, GIS has roots in the stimulus provided by the development of remote sensing, again in the late 1960s and early 1970s, as a potentially cheap and ubiquitous source of Earth observations. While many of the techniques for processing images are highly specialised, more general GIS techniques become important in order to combine information from remote sensing with other information (Star et al 1997). Today, many GIS include extensive functionality for image processing, and all types of remote sensing are increasingly the data source of choice, particularly for detection of landscape change (see Barnsley, Chapter 32; Estes and Loveland, Chapter 48).

1.4 GIS as a coherent, multi-purpose 'thing'

If GIS has so many apparently independent roots, what brought them together, and why has the umbrella term 'GIS' become so widely accepted? First, there are obvious commonalties. For example, the representation of topology invented for the DIME system at the US Bureau of the Census is almost identical to that incorporated in CGIS and in Australian work; the methods of raster processing and storage used in remote sensing systems are almost identical conceptually to those used by systems that have implemented McHarg's multi-layer view of the world. Second, it was easy from the viewpoint of the software engineering paradigms of the 1970s and 1980s to integrate functions around common representations. Once a raster or vector data model had been established, functions that process that data model in different ways were easy to add – thus it was possible, for example, to build large-scale integrations of image processing functions around a common raster representation. By the end of the 1970s, the term 'GIS' had emerged in recognition both of common technical requirements and of the opportunity to build systems that could potentially satisfy all of these applications. It took rather longer for the 'raster GIS' of the McHarg and remote sensing roots to merge with the 'vector GIS' of the CGIS, mapping, urban, and census roots. Debates on whether one or the other was 'better' were commonplace in the 1970s and 1980s, with hybrids like the 'vaster' structure emerging. To some extent this remains a cleavage in GIS to this day, exacerbated by the many variants on the basic raster and vector options (see the various contributions on representational issues in the 'Space and time in GIS' Section of the Principles Part of this volume).

When the first edition of this book was assembled, between 1989 when the project started and 1991 when the book finally appeared, the prevailing view of GIS was this notion of large-scale software integration around a common data model. Since GIS made it possible to store many coverages, software development was seen as providing a large number of functions to operate on those layers, as well as basic housekeeping functions for input, storage, and output. Extending the data model, for example by adding an option to order layers as a temporal sequence, would allow even more functions to be added. Progress in GIS was for a time measured by such additions to the richness of its data models, and associated additions of functionality – all within a monolithic and often proprietary software environment.

This view began to crumble in the early 1990s. First, the demarcation that it implied between geographical and other types of data became less valid. It became possible, for example, to handle an image within a relational database environment or a statistical package; or to make a map from a simple spreadsheet. Second, while such monolithic and expensive packages optimised the overall use of available computer power, this did not necessarily mean that individual GIS operations were performed in the most efficient manner. Third, there was growing resistance in the marketplace to solutions that required all customers to acquire all functions, regardless of need. Finally, customers became increasingly frustrated with the direct and indirect costs of monolithic proprietary solutions.

As we discuss below, today's GIS is in the process of being reinvented. There is much less emphasis on 'system', with all that is implied in that term – a clearly demarcated, monolithic, probably proprietary solution. The 'open GIS' movement, most clearly seen in the Open GIS Consortium (but by no means restricted to it), is driven by a vision of GIS as a collection of interoperable modules, under common standards (Sondheim et al, Chapter 24). The growth of electronic communications networks and associated applications means that it is no longer necessary for the data, the software, and the user to be in the same place at the same time – in the late 1990s vision the activities associated with the term 'GIS' are increasingly distributed (Coleman, Chapter 22). In time these technical innovations are likely to be reflected in institutional changes, as the field moves further from its societal roots. The advent of powerful PCs has provided substantial GIS functionality, shrink-wrapped and relatively stable and easy to use, on the individual desktop. Perhaps most important of all, the advent of the World Wide Web (WWW) has facilitated the routinisation of database linkage (Pleuwe 1997). Since GIS software systems built by many different vendors and running on different hardware in different countries can now be linked routinely together and the data used in combination, the old concepts of GIS are totally dead. This is explored in much greater detail later in this chapter.

In 1980 the GIS collective was dominated by the disciplines that gave it its impetus – landscape architecture, urban and regional planning, geography, cartography, and remote sensing, among others. With the rapid growth of GIS in the 1980s came new alliances, notably with computer science and many of its sub-fields – computer graphics, computational geometry, and database theory. Interest in making GIS easier to use led to alliances with cognitive science and environmental psychology (see Mark, Chapter 7). Increasingly, GIS is seen as a specialised sub-field of information technology and information science, and there are links of growing importance with the library science community (see Adler and Larsgaard, Chapter 64). Perhaps as a result of all this, the large, national and general-purpose GIS conferences popular in the 1980s have begun to lose attendance. They are being replaced in popularity by regional and local general-purpose conferences and by vertical market ones (e.g. GIS appears in utility company conferences).

It is difficult to identify specific individual events in the past seven or so years that have been particularly significant in redirecting GIS. The founding of the Open GIS Consortium may be one, along with the events and trends in the wider information technology arena of 'open systems' that preceded it. Certain moves by GIS vendors – new products, changes of direction, adoption of standards – have also had trend-setting significance, as have various failures, demises, and terminations in the industry. The 1990s marked the final victory of commercial off-the-shelf (COTS) software over the public-sector software development efforts that had characterised earlier decades, and had persisted well into the 1990s in the case of GRASS. It marked very significant moves by major software vendors – Microsoft, Oracle, and Autodesk among them – to establish positions in the geographical information marketplace. It also saw moves by GIS vendors into the consumer software market – an alliance between Intergraph and Egghead, for example, and new consumer GIS products from ESRI (for more on consumer GIS, see Elshaw Thrall and Thrall, Chapter 23). Arguably, however, it is the advent of the WWW that has been the single most important development affecting GIS in the last 20 years.

2 DEFINITION AND CLASSIFICATION OF GIS

Geographical information is information about geography, that is, information tied to some specific set of locations on the Earth's surface (including the zones immediately adjacent to the surface, and thus the sub-surface, oceans, and atmosphere). 'Spatial' is often used synonymously with, or even in preference to, 'geographical' in this context, although in principle it might be taken to include information that is tied to frames other than the Earth's surface, such as the human body (as in medical imaging) or a building (as in architectural drawings). Because of this difficulty, the term 'geospatial' has become popular recently, notably in the context of the US National Spatial Data Infrastructure, the Canadian National Geospatial Infrastructure, and the UK National Geospatial Data Framework. In this book, the terms 'geographical' and 'geospatial' are used interchangeably.

2.1 GIS, GI, and maps

Goodchild (1992a; see also Peuquet, Chapter 8; Gatrell and Senior, Chapter 66) identifies two distinct primitive types of geographical information: field information, in which geography is conceived as a set of spatially continuous functions, each having a unique value everywhere in space; and information about discrete entities, where the world is conceived as populated by geometric objects that litter an otherwise empty space and are characterised by attributes, such that any point in space may lie in any number of discrete entities. The field/object dichotomy underlies many areas of GIS, including its data models, data quality, analysis, and modelling (e.g. Burrough and Frank 1996; see also Raper, Chapter 5; Martin, Chapter 6).

Over the years the vision of a GIS has shifted significantly, but has always included the notion of processing geographical information within an integrated environment. It has been argued that the environment need not be digital, and that the principles of GIS can certainly be taught outside the digital environment, but today's world is increasingly digital and GIS is now almost always associated with digital computing in one form or another. It has also been argued (e.g. Maguire 1991) that the definition of GIS should include much more than the digital environment – in this conception the people who interact with it are also part of the system. Finally, GIS has been defined by its objectives, as in Cowen's definition of a GIS as a spatial decision-support system (Cowen 1988).

Today, the term GIS tends to be applied whenever geographical information in digital form is manipulated, whatever the purpose of that manipulation. Thus using a computer to make a map is as likely to be described as 'GIS' as is using the same computer to analyse geographical information and to make future forecasts using complex models of geographical processes. At the same time, there are significant exceptions. The Earth images collected by remote-sensing satellites are geographical data, but the systems that process them are not likely to be called GIS as long as they remain specialised to this particular form of data – in such cases, 'GIS' tends to be reserved for systems that integrate remotely-sensed data with other types, or process data that have already been cleaned and transformed. Similarly, an atmospheric scientist or oceanographer will tend to associate 'GIS' with systems used more for multidisciplinary work and policy studies, and will use other software environments for modelling and analysis within the confines of his or her own discipline. In short, because GIS implies a generalised software environment that is exclusive to geographical information there is a tendency for it to be most strongly associated with multidisciplinary, integrative work and applications; in more narrowly-defined environments less general solutions may be adequate.

Moreover, there is a persistent – albeit unfortunate and misleading – tendency for 'GIS' to be associated with the digital representation of the kind of geographical information that has traditionally been shown on paper maps, rather than geographical information conceived more generally. While maps may appear to place few restrictions on their compilers and users, in reality they can be highly constrained in the ways they represent the Earth's surface. Traditionally (although with notable and celebrated exceptions) paper map information has typically been:

- static, favouring the representation of fixed aspects of the Earth's surface, because once made, a paper map cannot be changed;
- 2-dimensional, and unable to show many diverse attributes of 3-dimensional socioeconomic systems such as cities, or physical environments such as the subsurface, oceans, or atmosphere;
- flat, because the curved surface of the Earth must be projected in order for it to be shown on a sheet of paper – or a regular solid like a globe;
- apparently exact, because there have been few applications of cartographic techniques for showing uncertainty in mapped information;
- unconnected to other information that may be available about the same set of places, but cannot be shown on the same map (and possibly cannot even be physically stored in the same place).

Because of its roots in mapping in general, and traditional cartographic practice in particular, much of GIS practice and application has remained similarly shackled to these limitations, unable to move beyond the metaphor of the traditional paper map (but see the Epilogue for a prospective view).

Wright et al (1997) define several different interpretations of what it means, in today's parlance, to be 'doing GIS'. One interpretation might simply be the **application** of a particular class of software, having chosen it from among the classes available today by considering various pros and cons, in order to gain insight, learn more about the world, support some kind of **management** decision-making, etc. In a more general sense, 'doing GIS' might involve applying the **principles** of GIS, including its particular ways of representing the world, and thus operating within a 'GIS paradigm'. Or it might involve furthering GIS **technology** by developing new capabilities. Finally, GIS might provide the medium for studying one or more of the fundamental issues that arise in using digital information technology to examine the surface of the Earth. Wright et al argue that only in the last instance is one necessarily 'doing science' when 'doing GIS'.

This argument, and others related to it, has led to a search for new terms that encompass activities that are less dependent on the particular nature of today's software offerings. Goodchild (1992b) has argued that this can be done by decoding the familiar acronym as geographical information science (GISc), and this idea is reflected in the recent establishment in the USA of the University Consortium for Geographic Information Science (UCGIS), an organisation of the principal GIS research institutions (see *http://www.ucgis.org*). The term geomatics has also gained some popularity, particularly in Europe and Canada and in the surveying engineering and geodetic science communities (see for instance, *http://www.geocan.nrcan.gc.ca*). Geocomputation also has similar connotations, although here the modelling of process may be more important than the modelling of information per se. Forer and Unwin (Chapter 54) have suggested no fewer than three decodings of GIS: GISy for the systems, GISc for the science, and GISt when the focus is on studies of GIS, particularly in the context of society and its institutions.

2.2 Is spatial 'special'?

Ultimately, the continued existence of GIS relies on the belief that there is some value in dealing with geographical information as a special case – that there is 'something special about spatial' (unfortunately there seems to be no available English term to complete the more appropriate 'something . . . about geographical' – 'magical', 'fanatical' don't quite serve the purpose). In the past, the case was argued on several grounds, including:

- the nature of geographical queries, potentially combining topological, geometric, and attribute elements, all with some fuzziness embedded;
- the special data structures, indexing systems, and algorithms needed for efficient processing of geographical information;
- the multi-dimensional nature of geographical information (x,y,z,n. . .);
- the voluminous nature of much geographical information;
- the fundamental inability to create a perfect representation of the Earth's surface, forcing users of GIS to deal with problems of data quality, accuracy, and uncertainty;
- the isolated nature of traditional production arrangements for geographical data, including the existence of public sector mapping agencies in most countries;
- the need for special standards for geographical information;
- the combination of distinct legal and economic contexts of geographical information, including copyright laws, liability, privacy protection, freedom of information laws, and costs of acquisition, that vary markedly from one country to another.

Recently, however, much of this basis for demarcation has diminished, if not disappeared altogether. In today's software environments, the special structures needed for handling geographical data are largely invisible to the user. The size of a single remotely-sensed image from a sensor like Landsat no longer seems formidable when personal computers often include gigabytes of storage. And debates about the legal and economic contexts of GIS are increasingly embedded within much broader debates about information policy and practice in general. Moreover, several recent technical developments have reduced the need to maintain distinctions within today's computing environments. Open standards like Microsoft's Object Linking and Embedding/Component Object Model (OLE/COM) and Object Management Group's Common Object Request Broker Architecture (CORBA) allow information of different types to be passed between environments, suitably enclosed in 'wrappers' (interfaces) that describe the type to the host. Thus it is increasingly possible to hold geographical information within an environment designed for processing text – that is, a familiar word processor. In effect, these technologies decouple the handling of a container of information from the nature of its contents, treating all information as 'bags of bits'. Structured Query Language (SQL) and other query languages have been extended recently to handle the special cases of geographical information and geographical queries, and extensions like Oracle's SDO increasingly allow geographical information to be handled within the frameworks of mainstream database management systems.

2.3 Geographical Information is special

Unlike GIS software, geographical information *is* special in many ways, but some of the more fundamental of these have little to do with its manipulation in digital systems. Anselin (1989) has argued that 'spatial is special' in two crucial respects. The first is expressed in Tobler's famous 'First Law of Geography' (Tobler 1970): 'all things are related but nearby things are more related than distant things'. This property of spatial dependence, or at least autocorrelation, is endemic to geographical data, violates the principle of independence that underlies much of classical statistics, and is the basis on which any representation of the infinite complexity of the Earth's surface is even approximately possible.

Anselin's second special characteristic is spatial heterogeneity, the propensity of geographical data to 'drift' such that conditions at one place are not the same as conditions elsewhere. Statistically, this concept corresponds to non-stationarity, and is well-known in geostatistics (e.g. Isaaks and Srivastava 1989). Practically, it means that the results of any analysis are always dependent on how the boundaries of the study are drawn – whereas it is often (erroneously) assumed that a geographical study area is analogous to a sample in statistics, drawn from the set of all possible study areas by some random process, and thus that the choice of study area has minimal effect on the results. Many of the arguments that emerge from this point can be found in the fractal literature (e.g. Mandelbrot 1982). More recently, Fotheringham (1997), Getis and Ord (1992), and others have argued for a new approach to geographical analysis based on the need to determine the local characteristics of places, rather than universal generalities (see also Getis, Chapter 16).

To these two might be added a third, which is particularly apposite in the context of GIS. The idea of expressing geography as a series of layers suggests that each layer captures something unique to it; statistically, that each layer makes an independent contribution to the total picture of geographical variability. In practice, however, geographical layers are almost always highly (if variably) correlated. It is very difficult to imagine that two layers representing different aspects of the same geographical area would not somehow reveal that fact through similar patterns. For example, a map of rainfall and a map of population density would often clearly have *some* similarities: population could be dependent on agricultural production and thus rainfall (or irrigation!), or might tend to avoid steep slopes and high elevations where rainfall was also highest. Of course, these correlations are often indirect, with other controlling variables and cultural features and inertia playing important roles.

These special characteristics of geographical data are undoubtedly important, but often not unique. Dependence is also endemic in time series; non-stationarity occurs in many contexts. While there is every reason for users of GIS to be aware of the ecological fallacy (Robinson 1950) and the Modifiable Areal Unit Problem (Openshaw 1984) – and these themes are explored at greater length in the chapters on spatial analysis later in this volume (e.g. Openshaw and Alvanides, Chapter 18) – it is difficult to argue that they justify the demarcation of GIS from other types of software.

One final characteristic is worth discussion, because it appears to be of increasing significance as the information society moves to reliance on a world of distributed computing. Society's arrangements for production, storage, and use of information depend critically on how interest in that information is determined. In the case of detailed geographical information, interest tends to be highly localised – interest in a street map of Manchester is clearly of greater importance to users located in Manchester than it is to users in Paris. Traditionally, this has been reflected in the pattern of availability of that information in libraries, bookshops, etc. In a world in which information is distributed over a myriad of servers accessible through tools such as the Web it is of critical importance to know where a particular set of information can be found. That issue is resolved in the case of textual information through the existence of search engines, which use Web crawlers to find and catalogue text by key word. But no comparable mechanism yet exists for geographical information though embryonic Web-based geographical services already exist. In developing new geographical data search engines, the new world of distributed computing is likely to find new ways in which 'spatial is special'.

3 CURRENT TRENDS IN GIS

3.1 The evolving GIS environment

GIS is a young area of technological innovation and application. It is also a very rapidly changing one. Without doubt, developments in computer technology have been a major contributor to the rapid advances of GIS. Thus in exploring the world of GIS it is appropriate to begin by charting the main relevant technological advances of recent years and seeking to gauge their impact on GIS.

Perhaps the root cause of all technological advances, as far as GIS is concerned, is improvement in computer hardware. Twenty years ago Gordon Moore, co-founder of the microprocessor company Intel, suggested that computer hardware performance would double and price would halve every 18 months. In the intervening years this prediction, subsequently dubbed 'Moore's Law', has held true and it appears that for the foreseeable future hardware will continue to improve at this rate. In mid 1997, however, after many years of close adherence to Moore's Law, announcements by IBM and Intel predicted that the rate of growth of processor speed would be even faster in the next few years. IBM announced a technique to replace aluminium connections on microprocessors with copper (which has greater conductivity), and Intel announced 'flash' technology, which allows two or even more bits to be processed by each processor element instead of one.

As a result of these developments, not only have hardware systems become faster and cheaper, but their physical size has also decreased. Notebook and field portable computers, for example, are now very commonly used in GIS applications. Yet the full implications of improvements in computer processor speed have yet to be fully recognised in GIS applications. Perhaps inevitably, hardware bottlenecks do remain in today's computers, notably with respect to the internal communication bus and the speed of disk access. Some of the hardware performance increases have been soaked up by the development of ever more sophisticated graphical user interfaces (GUIs), while the emphasis in spatial analysis has been to use enhanced hardware performance to support visualisation and data exploration rather than data modelling as more traditionally conceived.

Only a few years ago, the engineering workstation with its UNIX operating system was the dominant platform for delivering GIS. Since then, there has been the shift towards the personal computer, the innovation of desktop computing, and the gradual domination of Microsoft (the Windows operating system) and Intel's microprocessors (the 'Wintel' combination). By 1997 the Wintel combination had become the system of choice for GIS applications on the desktop. For server machines and specialist applications, UNIX remains a credible and important alternative. But Windows has become so widely adopted in GIS applications because of its widespread use in general applications, its (comparative) ease of use, its ability to run both GIS and non-GIS applications, and its low cost. As a consequence, the major GIS software systems have a remarkably similar 'look and feel'.

As we saw in the opening paragraphs of this introduction, one of the fundamental characteristics of GIS applications has been their use of large and very large quantities of multi-dimensional data (i.e. *x*,*y*,*z* coordinates) and the need for multi-user access to spatially continuous databases. The early GIS software systems used binary flat files to store data and specialist data management routines for data organisation and access. Fairly quickly, with the rapid growth of relational database management system (RDBMS) technology, many software developers began to manage non-geometric data using RDBMS. Today, the issues of performance, multi-user access, and data compression have largely been resolved and it is the norm for GIS software systems to store both geometric and non-geometric data in an RDBMS. With the development of Object-Relational DBMS and their capability for extension so that they can manage complex data types, like spatial, these are expected quickly to become the standard.

Most early GIS were individual isolated islands of technology. Since then, the rise in importance of network technology has had a profound impact on GIS. The words of Scott McNealy, President of Sun Microsystems, 'the computer is the network, the network is the computer', clearly state the importance of networks. In the late 1980s there was a move to connect machines together using local area network technology. More recently, wide area network (WAN) technology has been of interest to users. None of these can really compare, however, to the growth in interest and rapid uptake of the Internet as network-based technology.

The Internet is the world's largest public network. It is a multi-faceted mosaic of computer servers supplying information upon request to multiple clients. The Internet is unified by common use of the Internet Protocol (IP). This communication standard allows heterogeneous hardware to communicate in a simple, but effective, fashion. The WWW is a popular application which operates over the Internet. The Web is a distributed collection of sites (servers) composed of multimedia documents. These are linked together using the hypertext transmission protocol (http) and are spatially referenced using a uniform resource locator (URL). Web use has increased at a truly incredible rate in recent years, establishing new standards for many types of GIS application. Those focusing on data publishing, simple display, and query have been most successfully implemented.

While the Internet is almost certainly the technological innovation that is exerting the greatest external influence upon GIS at the present time, its impacts are all the more far-reaching because of contemporaneous developments within GIS. Central to these developments has been the establishment of the Open GIS Consortium (OGC) in August 1994. This is an international consortium of more than 100 corporations, government agencies, and universities. The OGC has put considerable effort into the development of 'interoperable' software using OpenGIS (Open Geodata Interoperability Specification) to build links between different proprietary systems (Sondheim et al, Chapter 24). Allied with the development of the Internet, open object standards and object brokers have been used to support distributed computing. The CORBA and OLE/COM standards allow 'objects', or packages of digital information, to be passed freely between different software environments, and make the contents of objects understandable to systems. More recently, the Java language has provided a means for sending program modules over the Internet as well as data, allowing one system to send a process for another system to execute. Other fragments of programs known as 'applets', 'plug-ins' and 'add-ons' are now routinely distributed from one system to another. Each of these developments is contributing to a new Internet-based computing environment in which it is as common to distribute the ability to process as it is to distribute the subject of processing – that is, the data. This increasing fragmentation of programs is extending the GIS environment ever further beyond its self-contained, monolithic roots.

The combined effect of the application of these technologies is that GIS software is breaking up into reusable 'plug-and-play' modules, which can be assembled and used through the Internet. It is also leading to the development of packages of software modules and data for use as so-called 'desktop GIS' (Elshaw Thrall and Thrall, Chapter 23): some observers view this as a transitory phase on the way towards use of the Internet as the principal platform for GIS.

Each of these advances in technology has, of course, been designed to improve the ability to store, manage, manipulate, display, and query geographical data. Together they have also profoundly changed the way that computing is carried out, as the practice of a user interacting with a file server becomes supplemented by 'peer-to-peer' computing in which every user is potentially both a client and a server – both a source and a destination for computation.

3.2 Our digital world

There have also been a number of significant changes in the way data are used and disseminated which have additionally influenced GIS applications. Spatial referencing is by definition essential to any GIS application, yet application-specific thematic layers alone rarely create a readily-recognisable view of the world – as anyone who has been presented with a choropleth map of an unfamiliar area will testify. Important developments are taking place in the provision of digital 'framework data' for GIS (Rhind 1997b). Framework data provide information pertaining to the location of topographic and other key features in the natural, built, or cultural landscape, which may be used as a backcloth to application-specific thematic data. Since the first edition of this book, such data have been created by a number of national mapping, cadastral, and census agencies and these present officially sanctioned views of the surface of the Earth, to a range of emergent data standards (Salgé, Chapter 50). 'Unofficial' sources of framework data also exist in the form of classified high-resolution satellite images, obtained from the new generation of high-resolution remote sensing satellites or from the new radar sources (which are less limited by cloud).

Each of these sources of framework data has become increasingly commercialised during the 1990s – on the one hand, national mapping and census agencies in many parts of the world are developing commercial datasets in order to meet their cost recovery targets; while, on the other, the break up of the former Soviet Union and the launch of new commercial satellites has done much to multiply the number of sources of remote sensing imagery. The latter commercial developments have become of wider import to GIS given recent technical developments in softcopy photogrammetry and pattern recognition. These are leading to the widespread creation of new products such as digital orthophoto maps and elevation models (DEMs) at much lower cost than has previously been the case.

With the general proliferation of digital datasets it has become increasingly difficult for the GIS user to know what datasets exist, what quality they are, and how they might be obtained. Allied to the development of the Internet, an important current development is the creation of on-line metadata – data about data – services, a number of which are designed for use with geographical location as a primary search criterion. An interesting development in 1997 was the creation of comparatively low cost intelligent data products containing functionality and metadata which allow fast direct access by GIS software packages. More generally, the development of whole digital libraries of geographical information is becoming feasible, and there is growing interest in using the metaphor of libraries to support geographical information management and data sharing (Adler and Larsgaard, Chapter 64).

Just as it is becoming easier for GIS users to find out exactly which digital data exist, so it is also becoming easier for them to collect their own digital data. Although many of the bottlenecks of digitising data from old hardcopy sources remain, much new data are now collected using the global positioning system (GPS) technology that has developed rapidly during the 1990s (Lange and Gilbert, Chapter 33). Low cost hand-held or mounted GPS receivers are suitable for many (but by no means all) field data collection purposes, and record geographical location routinely to quite high levels of precision (40–100 metres for civilian 'selective availability' applications and 10–32 metres for military applications) by reference to the US NAVigation Satellite Timing And Ranging Global Positioning System (NAVSTAR GPS) or its Russian equivalent (GLONASS). Much higher resolutions are obtainable using differential GPS and post-processing. This technology has revolutionised data collection for a wide swath of applications, particularly as receivers have been developed which also permit input of aspatial attribute data during the data collection phase.

Even in 1991 it was clear that information in general and geographical information in particular were becoming both a tradable commodity and a strategic resource. Nowhere in GIS has this continuing trend become more apparent than in business applications of GIS, where a huge value added reseller (VAR) and consultancy industry has developed to service business client needs. The data for most business applications have hitherto largely been obtained by combining census variables into composite 'geodemographic' indicators, which experience has shown bear an identifiable correspondence with observed consumer behaviour. More recently, the proliferation of digital customer records, allied to the collection of data from new customer loyalty programmes, is leading to the creation of more and more 'lifestyles' databases. These are not as geographically comprehensive as conventional geodemographics, but are much more frequently updateable and contain data which might be judged more pertinent to prediction of customer behaviour than those from conventional censuses.

3.3 Scientiflc trends and research directions

Elsewhere in this book we will explore the broader scientific trends in GIS: the current emphasis on the big questions of geographic information science (GISc) over the small technical questions; the growth of interest in human cognition that should make GIS easier to use (Mark, Chapter 7); the shift in emphasis towards data modelling and ontological issues (Raper, Chapter 5; Martin, Chapter 6); and the development of new strong links to mainstream computer science (e.g. Worboys, Chapter 26; Oosterom, Chapter 27). These and many other interesting developments and research directions are discussed at length throughout the book, and particularly in the first two sections.

4 WHAT WAS WRONG LAST TIME

The message of all of this is that GIS continues to be a vibrant and fast-changing area of business, application development, and research. From its origins in the 1970s, through its rapid growth phase in the 1980s, GIS has rapidly expanded and matured into a general-purpose information technology that is capable of solving the widest range of problems in a geographical context. Although its disciplinary heart lies in academic geography (Couclelis, Chapter 2; Johnston, Chapter 3), its continued growth and vitality is much more broadly-based than this – GIS is at least as much grounded in people's enduring fascination with maps, and the ease of spatial expression and reasoning that maps allow, as in any particular disciplinary matrix.

The first edition of this book (Maguire et al 1991) attempted not just to set out the whole panoply of GIS circa 1991, but also to anticipate the directions in which its inherent dynamism would move it. If book sales and patterns of academic citations are anything to go by, the first edition certainly provided an accessible and comprehensive snapshot of the state of GIS at the time of its publication, but it is only now with the benefit of hindsight that we can identify the respects in which it failed to anticipate the direction and strength of change.

Perhaps the most glaring omission is the complete failure of the book to anticipate the growth of the Internet and the World Wide Web into a massive global computer. It follows that there was far too little discussion of the technologies required to support distributed databases, distributed processing, and above all distributed users, together with the emergent role of the Internet in supporting vast numbers of servers and clients.

Second, in retrospect, there is the sense throughout the book that the most important technical problems had all been solved and that the big remaining ones concerned GIS management and institutional usage. While there is undoubtedly truth in the latter, it is clear in hindsight that very big technical issues still remain, whilst in the related area of methodology the emergence of GISc and geocomputation suggests that spatial analytical elements may not have been afforded sufficient prominence last time.

Third, there was a sense in the first edition of a quest for the Holy Grail of an 'all-singing, not all-dancing' GIS which would permit the fullest range of analytical operations to be performed. Even from the brief discussion of current trends contained in the previous section, it should be clear that a strong counter-trend has been the break-up of GIS software into packaged components, and that data components are often of similar importance to analytical functions in such systems. The Internet has had the opposite effect in allowing software to converge across different domains, and as a result users have been able to assemble task-oriented systems at will and as needs dictate – particularly given that the drive towards interoperability has meant that component software modules need not all originate from a single source. Neither trend has fostered the development of a single integrated GIS software system. Indeed the emphasis upon the development of analytical functions proved to be a distraction from the under-played information management functions of GIS, development of which has subsequently been key to the wider dissemination and adoption of GIS.

Fourth, passages of the first edition are redolent of a rather more technocentric view of the world – a sentiment which also characterises most of the first generation of GIS textbooks. This sense of mechanistic manipulation has subsequently dissipated somewhat, with the advent of social critiques of GIS and the wider realisation that GIS can be as much an empowering technology as it is a technology of control. The reasons for this emphasis in the first edition probably lie in the then prohibitively high cost of GIS software systems (at a time prior to licensing deals for higher education and government usage, for example) and a fascination with the implications of plummeting costs of computation for analytical functionality rather than the far wider distribution of PC and networked computer technology. The technocentric view is epitomised by the amount of space devoted to the promise of artificial intelligence – a theme which requires surrender of power to the machine rather than encouraging user empowerment, and which subsequent experience suggests cannot deliver much of its early promise.

Finally, there is a recurring sense throughout the first edition that because 'spatial is special' the GIS industry would continue to comprise a set of isolated, proprietary, specialised vendors. Most of those have subsequently disappeared, although two of the early market leaders (ESRI and Intergraph) retain large market shares. The new entrants to the industry are the IT heavyweights Microsoft, Autodesk, and Oracle – as we will discuss further in the next section.

5 THE WORLD OF GIS

There are several encouraging signs that in recent years GIS has reached new levels of popularity, respectability and maturity, and here we will provide something of the flavour of the state of GIS in the late 1990s. It is impossible to be comprehensive in summarising the state of GIS. Quite apart from anything else, space – even in a book at large as this – does not permit it. Rather the approach we will take is to review some of the major strands of development and current interest.

A key sign of the maturity of any discipline or business area is the development of coordinating bodies and academic and professional societies. GIS now has these in abundance. In the USA, the best known include: ACSM (American Congress on Surveying and Mapping), the GIS speciality group of the AAG (Association of American Geographers), AM/FM (Automated Mapping and Facilities Management: also in Europe), ASPRS (American Society of Photogrammetry and Remote Sensing), UCGIS (University Consortium for Geographic

Information Science), and URISA (Urban and Regional Information Systems Association). In other parts of the world comparable organisations include: AGI (the UK Association for Geographic Information), EUROGI (the European GI organisation), AGILE (Association of Geographic Information Laboratories in Europe), CPGIS (Chinese Professionals in GIS), GISRUK (GIS Research – UK) and UDMS (the Urban Data Management Society in Europe). These and many other bodies regularly organise society meetings featuring conferences and exhibitions. Together with a parallel set of meetings organised by private companies and public agencies (notably under the auspices of the OGC, discussed in section 3.1 above), GIS events often feature several thousand participants and provide close interaction between vendors, users, consultants, and researchers.

OGC, through OpenGIS, has brought forward standards for the interoperability of GIS software. The initial standard is based on the straightforward exchange of simple features (points, lines, and polygons) between commercial systems. Comparable international standards bodies that are focusing effort on developing *de jure* standards for GIS include ISO (the International Standards Organisation) and CEN (Comité Européen de Normalisation: Salgé, Chapter 50). ISO is an international body with representatives in many countries and CEN is a European umbrella organisation. These and other organisations are seeking to standardise almost all aspects of GIS, from metadata to database interfaces. If these standards are complementary and are widely adopted then they should further stimulate the growth of GIS.

One of the interesting aspects of GIS is the close involvement of software vendors in the continued evolution. Two of the earliest and most successful vendors – Environmental Systems Research Institute Inc. (ESRI) and Intergraph Corporation – remain the GIS market leaders. However, the increasing use of GIS on the desktop has led to new market entrants such as Mapinfo Corporation, while the movement of GIS to the Web and the ever closer relationships between computer-aided design (CAD) and GIS software has brought firms like Autodesk and Bentley into the GIS market. At the same time, IBM Corporation, Informix Corporation and Oracle Corporation have extended their respective DBMS to incorporate spatial data. In late 1997 the value of the global software market was estimated to be worth between US$627 and $904 million, depending upon whether a narrow or broad definition of GIS was used, with ESRI and Intergraph having market shares of about 33 per cent each (using the narrow definition) or 20 per cent each (using the broad definition) (Crockett 1997). Each of the market leaders is diversifying into emergent market niches and data-related products. Smallworld Systems maintains a strong position in utilities. After a period of rationalisation (because of takeovers and bankruptcies) GIS has become dominated by just a handful of vendors. By 1997, the GIS software market was probably worth about $1 billion worldwide.

Overall, expenditures on GIS are much higher than simply those on software. The US Office of Management and Budget (OMB) found in 1993 that total expenditures on digital geographical information in Federal agencies amounted to over US$4 billion. Adding the effects of activities at the state and local levels, and the activities of the private sector and non-governmental organisations leads to estimates of between $10 billion and $14 billion for the total value of the digital geographical information industry in the USA, although this is almost certainly an underestimate. Precise estimates of the total number of GIS users are similarly difficult to ascertain. A conservative estimate is that there are about 100 000 highly technical or professional GIS users in the world. When the 500 000 desktop users and one million casual viewers are added, the total becomes about 1.6 million. This is well in excess of the 250 000 or so predicted by the editors of the first edition of this book (Maguire et al 1991). At the current rate of expansion there could be eight million GIS users worldwide by the year 2000.

Just as the number of users has grown, so has the interest and involvement of academics. Education in GIS began in the universities, but has spread over the years to include significant efforts in training colleges and vocational programs, secondary schools, and even elementary schools. These are largely complementary to the training programs offered by major GIS vendors. Recently there has been much interest in distance learning, to address what is perceived to be a lack of educational opportunities for professionals in mid-career, and the UNIGIS consortium now offers distance learning through a network of institutions in several countries. University-based research has been stimulated in many countries by major funding for centres. In the USA the National Center for Geographic Information and Analysis (NCGIA) was established in 1988, with funding from the National Science Foundation, as a consortium of three institutions. In the UK, the Regional Research Laboratories stimulated the development of a network of universities committed to GIS-based research, funded by the Economic and Social Research Council between 1987 and 1991. Similar national research programmes exist in Korea, the Netherlands, France, Japan, and many other countries. The University Consortium for Geographic Information Science (UCGIS) was established in the USA in 1995 as a network of major research universities, and now has nearly 50 members. The European Science Foundation's GISDATA program coordinated and stimulated GIS research in a network of European countries between 1993 and 1997.

6 GIS: PRINCIPLES, TECHNIQUES, MANAGEMENT, AND APPLICATIONS

Just about the only thing that has not changed about GIS during the 1990s is its inherent dynamism. It is seven years since the first edition of this 'Big Book of GIS' appeared, and the editors of this second edition find themselves dealing with a subject which has developed and expanded enormously – not least in the range of geographical realities that GIS used to represent and the wider range of media through which digital representations of that reality may be constructed. Since the first edition was published the scale and pace of human interactions with computers has accelerated, and the provision and use of digital geographical information has provided one means of navigating through a geographical reality that we understand to be ever more detailed and complex. What, in the face of these remarkable upheavals, are the prospects for recreating a GIS reference work that is as relevant in terms of content and coverage as its forebear?

It is perhaps best to begin with a view of what this book is not. First, in these two volumes we have not sought to revisit all of the principles expounded in the first edition, since much of this material has completed the transition from application-led research and practice to standard textbook material. Table 1 on page 2 lists some of the general GIS textbooks that are available. Even in a work of this length, it is impossible to cover everything in GIS from first principles, given the vast expansion of the field since the first edition. Second, neither is it possible to cover the entire range of GIS applications, and our aim here has been to review those applications from operational and strategic GIS practice which we judge to be of key importance in understanding the breadth of the field. Applications of GIS are truly legion and the detail of practice is as fast-changing as the field of GIS itself. For this reason, readers with particular application interests should instead consult any of the range of GIS journals and professional magazines, listed in Table 2, which contain periodic reports of the experience of a wide range of GIS applications – many of these are targeted at national or supranational markets, which adds further specificity to the experience that is reported. Third, it is not just an extended guide to the latest research in GIS by academics – various monographs (notably the GISDATA and Innovations in GIS series, and the books arising out of the NCGIA initiatives) exist to document these rapid developments and changes.

Table 2 Major GIS journals and magazines

(a) Journals

Cartography and Geographic Information Systems
Computers and Geosciences
Computers, Environment, and Urban Systems
Earth Observation Science
Geographical Analysis
Geoinformatica
International Journal of Geographical Information Science
Journal of the Urban and Regional Information Systems Association
Photogrammetric Engineering and Remote Sensing
Transactions in GIS

(b) Magazines

Geo Info Systems
GIM International: Geomatics Info Magazine
GIS Africa
GIS Asia Pacific
GIS Europe
GIS World
Mapping Awareness

Instead we have attempted to produce a work which is focused towards 'frontiers in GIS' and which discusses and explains the issues and practices important to everybody who comes into contact with GIS. Thus we have tried to summarise existing state-of-the-art knowledge and best practice, to explain recent developments, and to anticipate possible future ones. We have sought to cross-reference related themes and to provide pointers to other textbooks, research papers, and consultancy reports wherever appropriate. We hope that readers will find this new edition at least as comprehensive, readable and well-illustrated, and as thoroughly up-to-date as the first edition. In short, we have attempted to create a hybrid of relevant pedagogy and research and development, produced by the leading writers in the GIS field. The result looks very different to the first edition, but this is only fitting given the transformation of GIS itself over the last seven years.

In producing a second edition of what we hope will remain the definitive GIS reference book ('Big Book Two') we began essentially from scratch. At an early stage in our deliberations we recognised that we should separate our discussion of *technical issues* from underlying *principles* in order to reflect different interests among our readership. Due recognition of the wider *management* functions that GIS now has would require that a separate section be devoted to such issues. Finally, a new range of *applications* would be used in order to illustrate the ways in which theory, technique, and management map into a representative range of operational and strategic situations in practice. **Principles** and **Technical Issues** are discussed in the first volume of this set, and **Management Issues** and **Applications** in the second.

Of course it is not just the world of GIS that has changed so profoundly during the 1990s, but also those many aspects of the real world that GIS seeks to abstract and to model. At its simplest, if we recognise that the world is not the same as it was, then we should not be surprised if the ways in which we order it are not the same either. Science is also changing, as many of the old certainties are breaking down in response to the challenges of relativism. We thus begin the wholly rewritten **Principles** Part of this book with a review and reappraisal of the central role of GIS in structuring our geographical understanding of the world, including the arguments, debates, and dialogues that have developed since the first edition was published. New chapters also chart developments in the representation and visualisation of spatial phenomena. Data quality, error, and uncertainty are also given new and extended treatments, and an expanded group of contributions on spatial analysis present a contemporary view of the usefulness of GIS in analysing spatial distributions.

As we have seen, the technological setting to GIS has been transformed since the publication of the first edition – so our new **Technical Issues** Part traces the emergence of new technologies such as the development of networked and 'open' GIS and the introduction of GIS for the desktop. New techniques of spatial database management receive extensive attention, as does data capture through the latest remote sensing and GPS technologies. Finally in this section, a range of techniques for transforming and linking geographical data are discussed, notably in the context of terrain modelling, hydrographical analysis, and the creation of virtual GIS environments.

As GIS comes to play an important role in an ever-wider range of organisations, so management issues such as the choice between different commercial GIS, data availability and operational management become of importance to increasing numbers of people. These issues are addressed in the all-new **Management Issues** Part of the book. Information managers also need to be aware of legal liability issues in the provision and use of GIS, as well as data pricing and availability, and issues of privacy and confidentiality. This Part provides comprehensive introductions to these important emergent topics in GIS usage.

In many respects applications are the most important aspect of GIS since the only real point of working with GIS is to solve substantive real-world problems. Diverse though the range of GIS applications is, many nevertheless share common themes. In the **Applications** Part of this book we have selected a range of operational ('nitty gritty') and more strategic social and environmental applications. The former generally focus on practical issues such as cost effectiveness, service provision, system performance, competitive advantage, and database creation/access/use; while the latter are often more concerned with model sophistication, the social and environmental consequences of results, and the precision and accuracy of the findings.

In the Epilogue the editors draw some conclusions and indulge in some speculation as to what the future holds for GIS. We hope that readers will judge the end result to be an authoritative, comprehensive, and up-to-date statement of all that is relevant and interesting about GIS.

7 SOME INDEPENDENT VIEWS ON THE STATE, RELEVANCE, VALUE, OR FUTURE OF GIS

The act of producing a book, even one as large and diverse as this, is liable to force some degree of homogeneity on the contributions. Each author is honour-bound to report the latest trends or research findings in his or her field and assess these in a rational way; the editors need to ensure balance and provide cross-links between chapters. We considered this and agreed that a small number of iconoclastic, individual and personal views could add materially to the book. This would be especially true if they were written by individuals known to be incapable of being seduced by editorial or other blandishments and who had worked in the furnace at the centre of some major GIS developments.

As a consequence, we invited five contributions from well-known figures, with use of the first person to emphasise this personal viewpoint. Their brief was to write about the state, relevance, value, or future of GIS. We suggested that they might use 'major historical events', 'GIS in a societal context', 'future trends', 'how has GIS changed the way we live today?', 'a personal story about becoming involved in GIS' or 'what are the remaining challenges to GIS?' as the basis for their contributions, but no restrictions were placed on comments.

What follows represents some of the wider strands of thinking about GIS worldwide.

GIS as the national Majlis

by Sheik Ahmed Bin Hamad Al-Thani
Centre for Geographic Information Systems, Doha, Qatar

The Majlis, an informal village meeting to discuss community issues and resolve differences, is an ancient tradition known throughout the Middle East. Even as a child, I wondered at the ease with which this simple, open forum prompted inquiry, discussion, analysis, and resolution.

As a member of the Qatari government I faced, with others, the challenge of establishing methods of master planning and the redevelopment of our cities in a systematic way that would rectify the make-or-break construction projects of the past and provide a definitive guide for future development.

In the late 1980s I saw, by chance, my first demonstration of GIS. It was as if a beacon, or guiding light, was suddenly sighted and I realised that this technology was the key that would provide the framework for developing an information infrastructure for our entire country.

As with all computer-based technologies, compatibility was the central issue. If we were to implement a successful national GIS, standardisation would be critical. With the authority of the senior members of our government, I was able to establish a National GIS Steering Committee responsible for developing and maintaining national standards and the Centre for GIS which was tasked with implementing these standards. Today Qatar enjoys a unique, nationwide GIS in which all participating government agencies are connected by a high-speed optic fibre network. Each agency can access the data of all others but the responsibility for maintaining the data rests with the individual data custodians, the different agencies. As a result of all this, Qatar now has a GIS that will facilitate intragovernmental cooperation and coordination for many generations to come.

It is clear to me that, for successful implementation of a national GIS, those in the highest levels of government must understand the benefits of the technology and must actively support its implementation. GIS provides an easy method of standardising and sharing a wide variety of information amongst all levels of government. Like the Majlis, it fosters cooperation, interaction, analysis, and well-considered decisions, solving real problems in real time – from which a society can only benefit.

Technology changes everything

by John O'Callaghan
Cooperative Research Centre for Advanced Computational Systems,
The Australian National University, Canberra, Australia

I think the opportunities for GIS in the current age of 'convergence' are really exciting. We have now entered the age where the integration of computing, communications, and content is providing an information infrastructure which is fuelling the widespread use of GIS by government, industry, and the community.

GIS have built on the rapid advances in information technology and, since the 1960s, have exhibited typical stages of growth towards maturity: the experimentation with GIS technologies, the demonstration of GIS on practical applications, the consolidation of the geographical data infrastructure, and the realisation of benefits from operational GIS.

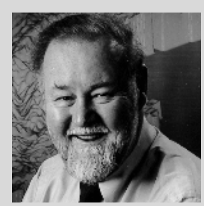
My own country – Australia – has been an early adopter of information technology and this, coupled with our coordinated approach to land ownership, our large geographical size and our dependence on natural resources, has resulted in Australia playing a leading role in the development and application of GIS.

Today, the most obvious demonstration of 'convergence' is the Internet, which is revolutionising the way we access data, interact with systems, and communicate with people. For GIS, the Internet is enabling the rapid deployment and widespread dissemination of geographical information services.

My group's research is now focused on enriching the user interfaces to these kinds of services: on-line navigation and analysis of large and distributed geographical databases; 3-dimensional modelling and visualisation of geographical data using 'immersive' display and haptic devices; and cooperative working on geographically-based simulations at several locations. We expect the results of this research to be adopted rapidly through the information infrastructure of the Internet and to contribute to the huge opportunities for GIS in this age of convergence.

How it all began and the importance of bright people

by Roger F Tomlinson
Tomlinson Associates, Ottawa, Ontario, Canada



The Canadian contribution to the development of GIS centres around the idea of using *computers to ask questions of maps*. This idea stemmed from the need for multiple map overlay and analysis facing Spartan Air Services, an Ottawa company working in Kenya in 1960. Later, in 1962, the approach was proposed by Spartan Air Services to the federal government of Canada, who adopted it for the Canada Land Inventory then planning to generate thousands of new maps to describe current and potential land use in Canada. This very successful federal-provincial programme funded the development of GIS in Canada for the next decade. From the basic idea came the concept that many maps in digital form could be linked across Canada to form a continent-wide map database to be permanently available for analysis, and further, that these digital maps could be linked intelligently to digital databases of statistics (particularly the Census of Canada) so that a wide range of spatial questions could be answered.

I directed the development of the Canada Geographic Information System from its conception until 1969. During that time over 40 people were involved in the

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work and there are many who deserve great credit. Lee Pratt was the young head of the Canada Land Inventory who, as a civil servant, took the entire risk of funding the new ideas. D R Thompson of IBM designed and built the first 48 x 48 cartographic scanner for primary map input. A R Boyle, then working for Dobbie McInnes (Electronics) Ltd in Scotland, designed and built the first 48 x 48 high precision free cursor digitising tables used to input point data. Guy Morton designed the continent-wide data structure incorporating a brilliant tessellation schema (the Morton Matrix) that allowed many maps to be handled by the tiny (in terms of speed and capacity) computers of the time. Don Lever was central to most of the logic of converting scanner data to topologically coded map format. It was the first use of the arc-node concept of line encoding incorporated in a GIS. Bruce Sparks and Peter Bédard made major contributions to the automatic map sheet edge match capability, which topologically matched polygons and contents seamlessly over a continent. Art Benjamin played a major part in designing the automatic topological map error recognition capability and in designing the links between map data and statistical data. Bob Kerneny developed the essential map data compaction methods using eight-directional codes originated by Galton and later called Freeman codes. Frank Jankaluk devised the reference coordinate system and made the calculations of error in calculation algorithms. Bob Whittaker designed the system for error correction and updating. Also incorporated in the system were map projection change, rubber sheet stretch, scale change, line smoothing and generalisation, automatic gap closing, area measurement, dissolve and merge, circle generation and new polygon generation, all operating in the topological domain.

The computer command language that recognised geographical analysis terms used to pose spatial questions, and that could be understood by a wide range of potential users, was a very important part of the system. Peter Kingston was responsible for the overall design of this data retrieval system and particularly for the efficient polygon-on-polygon overlay process. He also designed the command language, together with Ken Ward, Bruce Ferrier, Mike Doyle, John Sacker, Frank Jankaluk, Harry Knight, and Peter Hatfield.

Our most useful links to the academic world were through Waldo Tobler and Duane Marble in the USA, and Terry Coppock in the United Kingdom. In Canada the principal initiatives came from within private industry and government rather than academia. The links to work in the UK were through David Bickmore of the Oxford Cartographic System who, in the early 1960s, was responsible for many of the ideas for using computers to make maps. We disagreed on almost everything in the early days, but eventually our paths converged and we became firm friends.

The 1960s in Canada were exciting years, and I am happy to have been part of that excitement. While we all worked extremely hard, there was a spirit of adventure and the feeling that if you could imagine it you could make it. In those days, a few key individuals – many of them mentioned above – really counted. In the process I described, the first GIS was born and the field was named. We still call them the Champagne years.

GIS, politics, and technology

by Nancy Tosta
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In 1978, I tried to convince the Director of the California Department of Forestry that pixels were good for him and his agency. In those days, appointed and elected officials were highly suspicious of any form of geospatial technology. Their fears were justified. The price tags were huge and no one had proved that spending all those dollars to digitise data would pay off. I remember him asking why there were all those little squares on the map/image. Why didn't it look like the maps he usually used? How could the data be used? Now, writing in the early months of 1997, I would be hard pressed to find an elected official who does not know the meaning of GIS and who does not have a story to tell about how GIS was used to clarify or solve a problem. I knew that we had crossed a watershed in political acceptance of the technology in 1994 when President Clinton signed Executive Order 12906: 'Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure'. While labouring in the preparation of that order, I was astounded at the lack of questions from the White House and others about the technology. The assumption was that GIS was valuable and that data should be coordinated and shared to use the technology more effectively. Other nations have used Clinton's Order to generate political support for their GIS data efforts. The local elected officials I interact with today may not know about Federal Executive Orders, or exactly how much has been expended to develop their GIS, or what the software does, but they accept that the technology works. What more do we need to make a difference?

It's all about money, stupid!

by Joe Lobley
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Much rubbish has been talked about the special value of GIS. Even more rubbish has been heard about the essential contributions of academic research and the role of government in GIS. These two groups have made almost no contribution to the evolution of GIS to date nor will they greatly influence its future. Government talks a lot, produces lots of paper, and consumes our taxes. Other than spasmodic politically correct initiatives to 'modernise' itself, government is as moribund as ever it was (and will be). Academics are supposed to exist to question what is taken for granted but when did we ever see anything really critical or new come out of the geographers at least? Technically, it was probably in the mid 1960s. Since then we have spent loads of money on fancy research centres to little effect except airline revenues. Maybe some social geographers have hit something interesting in this ethics business but their posturing and soul-bearing seems a mite contrived to me (and has no real effect other than to cause more trees to be felled for their precious publications, read only by themselves).

No, the mainspring of everything important that has happened in GIS is business and the profit motive. Nothing of any significance started until the first commercial GIS became available. The growth in use of GIS has been fuelled by the decrease in cost of technology, driven in turn by commercial competition and salesmanship. Unlike most academics, some government data producers have a potentially important role simply because they hold valuable data assets. It's just a pity that they are typically complacent and act on geological timescales; the only way to jolt them out of all this is to contract out many of their activities. So far as access to software, hardware, and data are concerned – if people won't pay for software, data, and services, they don't really need them. If we pay for software and hardware from the commercial sector, why should we not pay for data from it – and why should government be involved at all?

The moral is obvious. Official history is created by those with the luxury of time to write and claim the credit. But the real achievers are those who have put their money on the line and built a business worldwide. I don't expect this situation to change much in future and I don't really care. But don't forget who really makes GIS happen!

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