

## EPILOGUE

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*The enormous growth in GIS over the past decade or so has left the industry in a buoyant state. To date GIS have been driven largely by technical considerations, although recently the importance of applying the technology has been widely demonstrated. As a consequence, the significance of geographical information science rather than geographical information systems has emerged. It is clear that in the early 1990s GIS have reached a level of maturity such that the 'GIS society' can properly be called a discipline in its own right. The basic principles on which GIS are predicated can be listed, at least in outline terms, and disciplinary trappings such as conferences, journals, textbooks and degree courses exist in abundance.*

*Future projections, based on current trends, suggest that the number of GIS systems installed will pass the 0.5 million mark before the end of this millennium. Substantial technical developments can also be anticipated, along with a diversification of applications and much-needed advances in understanding the introduction of GIS into organizations. Together, these should assist us in our corporate goal of describing, explaining and predicting Earth patterns and processes with a view to managing the environment, improving human welfare and sustaining our existence in general.*

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**INTRODUCTION**


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The GIS boom that began in the early 1980s is still accelerating. New vendors are entering the market with new and exciting products, education and training programmes are proliferating, the GIS software industry is reporting rapid growth rates, new textbooks and magazines are appearing, and GIS technology continues to find new applications and new acceptance.

The 1980s were years of unprecedented economic growth, both in Western economies generally and in GIS, and it is clear that the resources that were available to fund this growth in the 1980s will be much harder to find in the future. The 1980s also saw unprecedented changes in computing hardware with the development of personal computing and the workstation. What have we learnt so far – and particularly from the intensive activity in GIS that characterized the 1980s? Where do we stand in GIS research, and what are the important items in the research agenda that remain to be investigated before GIS can really

fulfil their promise? What are the prognoses for the future – where will GIS stand in the year 2000?

As we stated at the outset, our objective in this book has been to present a picture of the state of GIS thinking, and the condition of the GIS body politic. This epilogue reflects on that condition in four ways. The first section looks at GIS to date, and reflects on the short history of the field. The second looks at outstanding issues and the research agenda. The third looks into the crystal ball and presents a view of the condition of the field in the year 2000, based on current trends in the GIS market, and predictions about hardware and software. The final section considers the bigger picture, and looks at the social, economic, business and political context for GIS.

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**LOOKING BACK: THE STORY SO FAR**


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**The technological drive**

The roots of GIS go back well into the 1960s (Coppock and Rhind 1991 in this volume) and the

field owes a great amount to early efforts at that time by the Canadian federal government, IBM Canada and individuals such as Roger Tomlinson who developed the Canada Geographic Information System (Tomlinson 1989; Tomlinson, Calkins and Marble 1976). In fact the system made a remarkable number of technical breakthroughs, including the use of a scanner and raster/vector conversion; the separation of attributes and spatial data; representation of polygons by arcs; use of chain codes; and the use of Morton order for indexing. It was not, however, until the late 1970s that GIS really began the period of rapid growth that continues today. Several technological developments allowed this to happen (Goodchild 1991 in this volume). On the hardware side, 1980 saw the introduction of the super-mini, a multi-user system with virtual memory management for around \$200,000 and a useful platform for a stand-alone, turn-key GIS. On the software side, 1980 saw development of the first GIS to take advantage of a relational DBMS, providing enormous flexibility in the handling of relationships between spatial entities. Finally, 1980 saw the beginnings of the trend towards personal computing and the mass popularization of word processing and desktop publishing.

Today GIS incorporate a remarkably diverse set of interests. GIS applications range from resource management (Robinette 1991 in this volume), through urban infrastructure (Parrott and Stutz 1991 in this volume) to route finding (White 1991 in this volume), from political districting to forestry. GIS run on platforms from the PC to the large mainframe, including an enormous range of software architectures, from the simple, self-contained raster systems such as GRASS and IDRISI to the large database managers such as IBM's GFIS. Some vendors focus on a single platform, while others (notably ESRI) offer a single product over the full range of platforms and operating systems from DOS to VM/CMS. The GIS community includes an extraordinary range of disciplines, from archaeology and landscape ecology through forestry to civil engineering and computer science. Not surprisingly, there is as much variety in the definitions of the field (Maguire 1991 in this volume). GIS are variously described as spatial decision support systems; systems for input, storage, analysis and output of geographical data; or geographically referenced information

systems (to cite only three of the competing definitions).

Looking at the development of the field and its current condition raises curiosity about the glue that holds it all together. One major part of that glue is clearly the technology itself, and another is the widespread fascination with processing geographical data. Maps and graphics are interesting in their own right and a computer system that analyses and displays them is doubly interesting. There has been a steady and accelerating improvement over the past three decades in the cost and availability of graphical computing (see below), and this has had an undeniable impact on the growth of GIS. Peter Taylor, in an editorial in *Political Geography Quarterly*, characterized GIS as 'geography's own little bit of the "high-tech" revolution' (Taylor 1990: 212).

It would be grossly unfair to characterize GIS as a technology in search of applications, as this would largely ignore its enormous value to a wide range of its current users. While there may still be some doubt about the exact cost/benefit ratio, the old joke about dividing by zero is clearly inappropriate today in applications ranging from facilities management to forestry, at local and global scales. All the same, reference has been made at several points in this volume (e.g. Aangeenbrug 1991 in this volume; Openshaw 1991 in this volume) to a widely held sense that GIS have not yet found their full potential as tools for exploring and analysing the world, and for supporting human decisions. Instead, GIS seem too often limited to mapping, information management and simple inventory.

### The importance of science

The current range of GIS software and hardware products incorporates an impressive range of technological breakthroughs. Concepts such as the TIN (Weibel and Heller 1991 in this volume) and quadtree (Egenhofer and Herring 1991 in this volume) are the direct result of GIS research, and are only two among the many innovative ideas to have emerged over the past three decades. Any technologically-based field must be constantly supplied with new ideas if it is to thrive and needs to be supported by an active research and development community.

However, there is a strong feeling at the present time in the GIS community that the most important issues confronting the field are not necessarily technological. The GIS community seems to be converging not around a single, uniform software product (a standard GIS) or a single application, or around the technology itself, but around a set of generic issues that emerge from using the technology. Whatever the application or data processing solution, every user of GIS faces the same set of problems in dealing effectively with digital geographical data; these problems in turn form the agenda for discussion at GIS meetings – the true glue of the GIS community. Some of the more prominent are:

- *Data capture*: how to convert data from raw to digital form in an efficient, cost-effective manner.
- *Data modelling*: how to represent the infinite complexity of the real world in a discrete, digital machine (e.g. whether to use raster or vector, layers or objects and how to model complex objects).
- *Accuracy*: how to cope with the uncertainty present to varying degrees in all geographical data.
- *Volume*: how to deal with the fact that demands for geographical data will often exceed the space available for storage or the access time which is acceptable (e.g. designing data structures, indexes and algorithms to provide rapid access to large volumes of geographical data).
- *Analysis*: how to link GIS databases with advanced modelling capabilities.
- *User interfaces*: how to present the GIS database to the user in a friendly, comprehensible, readily used fashion.
- *Costs and benefits*: how to measure the benefits of GIS information and compare them to the costs.
- *Impact on organizations*: how to introduce GIS successfully into a complex organization.

All of these issues transcend the technology

itself and all of them in one way or another affect the technology's usefulness, whatever the application and whatever the platform. In recent years they have emerged in various guises as the basis of the research agenda of the National Center for Geographic Information and Analysis (NCGIA 1989), the Urban and Regional Information Systems Association (URISA: Craig 1989) and the UK Regional Research Laboratories (Masser 1990; Maguire 1990), as well as in independent assessments (Rhind 1988). Goodchild (1990) has argued that together they constitute a science of geographical information and that the future of the GIS community lies in recognizing a common interest in geographical information science rather than the technology of geographical information systems.

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

GIS have also affected the role of geographical information within organizations. They encourage the notion that geographical information is a commodity that flows through the organization, and that has a value determined by its accuracy, currency, accessibility, etc. In fact it may be the central commodity in some organizations such as forest resource management agencies. Collecting and updating geographical data need careful planning and budgeting if they are to be undertaken on a regular basis and are to be accessible to an organization's analysts and decision makers. Finally, if information *is* important, then it is rational to use different types of information as the

basis for the organization of departments and systems.

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

The case for GIS as the science of geographical information will probably be debated for many years to come. The complementary argument that GIS are a technological tool for the support of science is presently more widely accepted and is reflected in applications from archaeology to epidemiology. Geography provides a very powerful way of organizing and exploring data, but the map has lagged far behind the statistical table and graph because early generations of scientific computing tools made it so difficult to handle. GIS technology has finally provided the breakthrough, although it remains far from perfect. If we were to draw an analogy between GIS and the statistical software which began to emerge in the 1960s, then the current state of GIS development is probably equivalent to the state of the statistical packages around 1970. But GIS and statistics are ultimately very complementary sets of tools, both capable of supporting an enormous range of scientific enquiry.

To date, the major success of GIS has been in the capture and inventory of features of the Earth's surface, particularly as represented on maps, and in supporting simple queries. There has been much less success in making effective use of GIS capabilities for more sophisticated analysis and modelling (Maguire 1991 in this volume). It is hard to find examples of insights gained through the use of GIS, or discoveries made about the real world. GIS have not yet found widespread application in the solution of major social problems – disaster management, environmental quality, global issues or health. In part this comment is unfair, because such insights would be almost impossible to

document. In part the reason is commercial – the market for GIS as information management tools is currently far larger than that for spatial analysis so vendors have invested relatively little in developing and promoting analytical and modelling capabilities. Although current GIS technology is a major improvement on that of a decade ago, it is still difficult to collect, display and analyse data in geographical perspective. Finally, Couclelis (1989) has made the point that the current generation of GIS concentrate on a static view of space occupied by passive objects, offering little in support of a more humanistic view of dynamic interactions.

### GIS as a discipline

The current growth of GIS shows no signs of abating and will likely continue for some time into the 1990s. New magazines are appearing, and existing ones, such as *GISWorld* and *Mapping Awareness*, are growing and increasing their circulation. Conferences are numerous and successful, offering workshops on increasingly specialized topics and access to the latest vendor products. New software vendors are entering the market with exciting and innovative products. GIS are finding new applications and strengthening their penetration into existing markets. GIS courses are proliferating at universities and colleges, and are finding increasing interest from students anxious to acquire useful skills.

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

SPANS, Facility Mapping Systems' FMS/AC and Strategic Mapping's ATLAS\*GIS).

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

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

Despite this sense of growing diversity in the GIS community, there is evidence of convergence. The past few years have seen the emergence of

several series of conferences aimed at the full GIS community. In the United States, the annual GIS/LIS series sponsored by a consortium of five societies (AAG, ASPRS, ACSM, AM/FM and URISA) has grown quickly to over 3000 attendees (Morrison 1991 in this volume). In Canada, the Ottawa meetings in early March have been similarly successful. The lone textbook of 1986 by Burrough (*Principles of Geographical Information Systems for Land Resources Assessment*) has now been joined by several others (e.g. Aronoff (1989) *Geographic Information Systems: a management perspective*; Star and Estes (1990) *Geographic Information Systems: an introduction*) and many more are on the way. (See Maguire 1991 in this volume for a list of GIS textbooks.) New organizations have appeared and the Association for Geographic Information (AGI) in the United Kingdom seems to be a particularly successful example; and GIS technology now has its own journals. A large number of higher education institutions now offer Masters' courses and several even have undergraduate courses in GIS (e.g. Kingston and North East London Polytechnics in the United Kingdom).

All of these would be recognized in the sociology of science as symbols of an emerging scientific community – in short, a discipline. But unlike physics or biology, GIS have no fundamental problems to solve of the magnitude of the origins of the universe or the basis of life. One view holds that GIS are merely a tool, and that the GIS research community must wither away as the tool reaches perfection. Another, presented at some length above and amply illustrated in the chapters of this book, holds that there are fundamental issues in GIS – not so much in the tools any more as in the use of the tools. Alternatively, perhaps GIS are like statistics – a tool to most scientists, but a set of fundamental research problems to the parent discipline.

If GIS technology is a discipline, then it is clearly not 'owned' by any traditional one. Geography, cartography, surveying, photogrammetry and engineering have all been accused from time to time of trying to dominate GIS – but with little success as GIS are fundamentally an interdisciplinary field. Whether GIS develop the institutional structures of a discipline in its own right, like statistics, or remain an interdisciplinary consortium of interests like remote sensing remains to be seen.

## LOOKING AROUND: WHAT REMAINS TO BE DONE

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

If the future of GIS lies in specialization, then the key to success will be standards. Encouraging progress is being made in data exchange formats (e.g. USGS's SDTS, DMA's DIGEST and the UK NTF) and in standardizing terminology (DCDSTF 1988; Guptill 1991 in this volume). But terminology is notoriously difficult to standardize. For example, there is little indication to date that the proposed term for the common boundary between two polygons ('chain') will replace those in current usage ('arc', 'segment', 'edge', '1 cell', etc.). It is also difficult to standardize when the central concepts of GIS are so poorly articulated. Key terms such as 'raster' and 'vector', 'object' and 'layer' need to be standardized if we are to develop a well-defined set of data models. Standards are needed for data sources, particularly in describing quality, and for user interfaces. However, the diversity of the GIS community makes the development of standards difficult. For example, the needs of the US Bureau of the Census in a street network database are very different from those of the vehicle navigation industry, or the emergency response community, or the highway maintenance authorities.

Despite their importance, standards will do little to solve many of the more pressing problems of GIS. The field is only now beginning to come to grips with the issues of uncertainty and accuracy (Fisher 1991 in this volume; Chrisman 1991 in this volume) and, while recent research has led to significant advances in understanding how

uncertainty propagates through a GIS (Goodchild and Gopal 1989), it will be a long time before the accuracy requirements of GIS have significant impact on the process of geographical data collection and compilation. New and exciting concepts in data modelling, such as object orientation, are only now beginning to influence the field and much remains to be done in exploiting the ideas emerging from current research on user interfaces (Frank and Mark 1991 in this volume). If GIS research of the 1960s and 1970s was primarily directed at solving the technical problems of geographical data handling, allowing a significant industry to emerge in the 1980s, then the 1990s will be the decade in which the cycle reverses itself – when new concepts emerge from the application of the technology to affect conventional ways of thinking about geography. GIS are only now beginning to impact on the organizational structures of public agencies, the traditional providers of geographical data, conventions of map making, or the urban planning process.

Among the larger research issues still to be resolved are the following:

- How does GIS complement other technologies for handling geographical data, such as maps, atlases, text descriptions, or images? Should all of these be implemented in a digital environment, or can digital and analogue technologies complement each other?
- How will GIS, GPS and other novel technologies affect traditional methods of geographical data collection and compilation? Will the role of mapping agencies increase or diminish in the coming decades?
- How will the flexibility of digital geographical databases affect the role of geographical data in everyday life, which is now so closely geared to the paper map?
- How will the rigorous, objective perspective of GIS be adapted to the imprecise, subjective world of human reasoning and decision making? Will it be through the development of spatial decision support systems, knowledge-based or expert systems, or will the two paradigms find themselves incompatible?

Much also remains to be done in education and

training. Vendors and institutions have already responded to the critical shortage of staff by adding courses and programmes and the US NCGIA has developed and published a one-year course sequence (Goodchild and Kemp 1990). But GIS is still a novel field, and courses are often treated as add-ons to existing programmes, and rarely integrated into full curricula. There has been some discussion of integrated curriculum requirements in the literature (Nyerges and Chrisman 1989; Unwin and Dale 1990) and vendors are increasingly willing to offer more than simple training programmes. But GIS education remains an issue, intimately linked with the previous discussion of the nature of GIS as a discipline.

Much also remains to be done at the organizational and institutional level. The potential for sharing data between agencies remains unrealized in most countries because of traditional interdepartmental barriers. The development of standards is similarly impeded by a lack of coordination and leadership. The organizational structure of many public agencies continues to be dominated by the needs of traditional methods of map making and geographical data handling. In the new digital environment it is vital that the public agencies adopt a lead role in coordinating research and education programmes, in ensuring the health and vitality of the GIS industry, and in defining standards of data quality, data formats, etc. This is particularly important at a time when public sector funds for traditional map making are steadily diminishing.

In many areas the future of GIS will continue to be determined by developments in hardware – technological innovation will continue to influence GIS as long as new ideas continue to drive the computer industry. The cost per cycle will continue to drop in the next few years, as will the cost per megabyte of RAM. The 1990s will see the proliferation of 3-D technology, as high performance graphics adaptors become available for mass-produced workstations from vendors such as Silicon Graphics. The recent generation of workstations, typified by the IBM RS/6000, include 3-D adaptor options with display rates as high as one million 3-D vectors per second, with polyhedral rendering capabilities, in a platform running at 25–45 MIPS (Million Instructions Per Second). GIS will no longer be confined to the plane, and the DEM display capabilities of today will seem very

primitive in a few years. It will become possible to model and visualize subsurface conditions, and to analyse distributions over the surface of the earth without the distortions and interruptions produced by conventional map projections. In 3-D, the map metaphor is completely inadequate and the user interfaces for these systems will have to explore entirely new territory. How, for example, should a system allow the user to build knowledge of subsurface conditions from a variety of different types of evidence? In 2-D, this task of map compilation takes place on paper but in 3-D it can only take place in the abstract domain of the digital database. What tools does a user need to explore a model of the subsurface once it has been built? What icons should be provided in an appropriate user interface?

If GIS have been dominated thus far by the map, then fundamental changes now occurring in mapping will have significant effects in the coming decade. Low-cost GPS receivers are already available with higher accuracy than the base mapping available over most of North America (1 : 100 000, 1 : 24 000 in continental United States) and many areas of the rest of the world. GPS also provide a significantly cheaper method of primary data collection for many mapping activities. This system is already being used to map road and rail networks, and to track vehicle movements. At the same time the funds available to support large, public-sector mapping programmes are diminishing.

### **Current prospects for the future**

There seem to be two contrasting views of the prospects for GIS in the coming decade. The first is negative and the second positive, and it seems more likely that the second will prevail. However, there are actions that can be taken to strengthen the odds.

In the negative view, GIS will fragment and disappear, and by the end of the decade will be nothing but a memory. Geographers often draw a parallel between GIS and the introduction of quantitative methods to geography in the late 1960s (Taylor 1990), and comment on the lack of interest in quantification, at least in human geography, in the 1980s. On this view GIS will fragment because the system is too loose to hold together and because the glue is too weak and abstract. Users of IBM's GFIS, ESRI's ARC/INFO and Map/Info will cease

to see any reason to attend the same conferences. The consortium of five organizations responsible for the North American GIS/LIS conference series will break up and each will concentrate on its own agenda. GIS will be seen as the Edsel of EDP, too awkward, complex and expensive except in some specialized applications.

In the positive view, the GIS consortium will continue to converge. A constant supply of better tools seems assured, particularly in computing speed, software integration, network communication, graphics and storage capacity. The infrastructure of the GIS community will continue to improve, with better magazines, organizations, textbooks, meetings, and all of the symbols of an emerging speciality. Less assured but essential is a constant supply of new players in the industry, since the pattern has been that new players are the source of a disproportionate share of technological innovation. New players such as Prime/Wild with System/9, SmallWorld, or Strategic Mapping with ATLAS\*GIS bring new ideas to the industry.

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

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

- data models to handle 3-D and time dependence, and complex interactions between objects;
- support for complex analytical applications, including tracking of data lineage, tools for visual interaction with the stages in the analysis process, propagation of uncertainty;
- support for quality assurance and quality control (QA/QC) especially in GIS applications where litigation is a constant problem;
- support for multiple media – unstructured images, both digital and NTSC, text and sound;

- integration of GIS with the capabilities of GPS for data collection and compilation;
- tools for visualizing 3-D and time-dependent data;
- tools for data compilation, particularly in 3-D;
- improved techniques for conducting functional requirements studies, evaluating costs and benefits, benchmarking and other aspects of the GIS acquisition and project management process.

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

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### LOOKING FORWARD: GIS 2000

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All of the above is based upon our (considerable) collective experience in GIS and discussion with many colleagues. But it is also sensible to attempt to quantify some of our predictions: such forecasting is, for instance, central to all business planning and resource allocation. Inevitably, though, all such forecasts become less precise as the time period becomes more extended, but two basic techniques exist for predicting the future. The first is to project existing trends within the subject area and this is normally a sensible strategy in the short term, say for two years. The second is to analyse and understand what underlying changes are taking place in society or the environment as a whole, then to assess how long the effects of these will take to work through to individual sectors such as GIS. In this section, we attempt – briefly because of the paucity of the evidence – to use both methods in order to understand what is likely to happen to the future of GIS. In so doing, we avoid (wherever possible) technical and other details. It is all too



easy to write about the subject at the 'nuts and bolts' level of detail; indeed, that is where the great bulk of applications work thus far has been carried out and where most of the technical work seems to be directed. Moreover, dealing with detail is often immensely satisfying: the possibility of error is reduced to minute levels if the topic is reduced to the mechanical and the specific! But we need to deal with broad issues involving many intangibles; inevitably, then, we will get some of them wrong.

### Trend projections

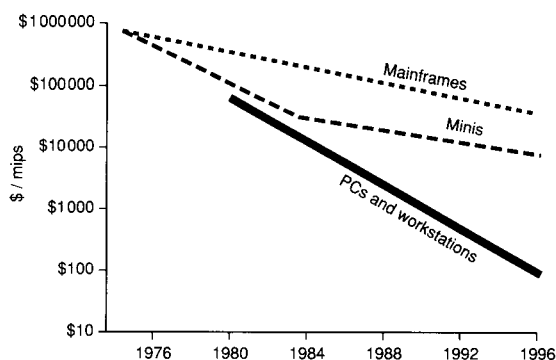
The simplest and probably the most reliable trend to project is that of hardware performance. Figure E.1, produced by the British consultants Price Waterhouse, shows the rapid diminution in cost of one measure of computer power – MIPS or million instructions per second. In practice, this is often a most misleading statistic, but its trend parallels that of most other measures of performance. Over the last 30 years, there has been about an order of magnitude decrease in cost of computing power every six years. What cost \$1 or £1 to compute with state-of-the-art equipment in 1990 cost about \$100 000 or £100 000 to compute when Tobler (1959) wrote his famous seminal paper on automated cartography. More recently, things have been changing even more rapidly. A simple way of describing the current growth in computer power is to consider a Digital Equipment Vax 11/780 of 1984 with 1 MIPS power; the growth in power for the same cost since then can be approximated by the expression:

$$\text{MIPS}_{\text{year}} = 2^{(\text{year}-1984)}$$

Hence, for 1991, MIPS = 128

Moreover, data storage with similar characteristics (such as direct access capabilities) has decreased in cost at similar rates. The bulk of computers has diminished as rapidly as has their reliability increased. The drawing speed and resolution of output displays has changed from the slow, coarse and relatively expensive storage cathode ray tubes of the 1970s to the million colour, 300 000+ vectors per second and modestly priced workstations of today (Goodchild 1991 in this volume). If this trend is spectacular, it shows no signs of conclusion: all the indications are that even

'traditional' computing engines may be made to go substantially faster and will become still cheaper. Moreover, it is evident that parallel processing (see, for instance, Dowers *et al.* 1990) will provide further increases in performance once the myriad of algorithmic and software problems have been resolved (Franklin 1991 in this volume). Finally, perhaps the most important development in hardware other than general-purpose computing engines is the rapid improvement in performance/cost ratio for Global Positioning Systems (or GPS); to be able to establish absolute position in three dimensions anywhere on the Earth's surface with an accuracy of metres, all achieved within a few seconds, is likely to revolutionize surveying practice, generate many more GIS-type applications and improve existing embryonic ones like vehicle navigation (see White 1991 in this volume).



**Fig. E.1** Hardware price performance trends. (Source: Price Waterhouse (1991).)

Costs of software can only be traced from the early 1980s since only then were the first commercial GIS available (Coppock and Rhind 1991 in this volume). Over that period, we have seen a decline in costs, accelerating as more and more systems arrive on the market. Thus the list price for a minicomputer version of ARC/INFO in 1983 was about \$100 000 (or about \$200 000 at 1990 prices); in 1990, a first copy for a 386-based computer of like performance (but with much more software functionality) was about \$10 000, with heavy discounts for multiple copies. In practice, such list prices are rarely paid; most vendors will discount to many classes of customers and some have given GIS software to organizations purchasing hardware; it is thus difficult to quantify

the trend precisely but dramatic price reductions and increase in quality of the product have occurred simultaneously. The extent to which this can go on is unknown, except in the mass market where GIS are sold for PCs and low cost workstations in a manner analogous to dBASE, Lotus 1-2-3, Excel or even word processing packages like Word and WordPerfect. If this occurs, we should expect to be able to buy fully functional GIS for about \$500 in the mid-1990s.

All of the market surveys carried out in Europe and North America at the time of writing this book paint a story of increasing use of GIS and related data sets. Unhappily, little comparable evidence is available for other areas of the world. The surveys show global sales of between \$500 million and \$4000 million per annum for GIS software, hardware, services and data, the sum varying with information source, with the definition of GIS adopted and with the base year taken (see Maguire 1991 in this volume). All surveys are unanimous that growth in the total expenditure by users is of the order of 20 to 30 per cent per annum. Some individual vendors such as ESRI report growths of income of over 40 per cent per annum. This and the ubiquitous nature of GIS applications has led organizations such as IBM to identify GIS as an area on which to concentrate (see Dangermond 1991 in this volume).

The immensely broad spectrum of what different individuals consider as a GIS complicates establishing a benchmark of the number of systems now in operation. Based, however, on sales of systems of known capabilities, there were not less than about 20 000 installations world-wide in 1990 with at least significant claims to being a GIS. In early to mid-1990, annual sales seemed to be running at about 6000 systems per annum, including PC products. The advent of new low price systems such as Atlas\*GIS later in that year made the forecasting of sales very much more difficult. Assuming, however, a 20 per cent per annum growth rate in GIS-related expenditure by users and a 40 per cent growth rate in the number of systems (because of the much faster growth in the number of small-machine than large-machine systems), the figures for sales and system numbers at different dates would be as indicated in Table E.1. It should be stressed that this is nothing more than projection of trends, assumed to be constant in proportional terms (i.e. exponential), from an uncertain base and over a time horizon during which the market will

certainly change both qualitatively and quantitatively. None the less, even if these trends only hold up for a short period, the implications are enormous.

**Table E.1** GIS trends 1990–2000

Year	1990	1993	1996	2000
Sales (\$million)	1000	1750	3000	6200
Number of systems ('000s)	20	55	150	580

It is also entirely possible that these figures may be achieved despite apparent saturation in certain markets and in particular areas. Thus, for instance, we might expect the market for GIS in utility organizations within developed countries to be saturated by the late 1990s but for growth of that market to expand in other currently less developed countries. In addition, all the current indications suggest that growth in use of systems for environmental, health and other purposes will more than compensate for any 'flattening off' in demand for systems within the 'early adopter' sectors. Overall, most GIS applications thus far have been at the inventory or monitoring level – computing taxes, routing vehicles and assessing the extent of change in the natural environment. This is really little more than transaction processing and periodic reporting on the overall level of some activity. Such functions are often critical: the very life of cities may break down if taxes are not collected, if assets are not managed properly and resources allocated effectively. But it is at least arguable that the use of GIS in modelling, in prediction and in supporting high-level decision makers, policy makers and politicians is as important as inventory tasks, if not more important, and that the former will come of age before the end of the millennium.

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#### **LOOKING TO THE WIDER SCENE: THE SOCIAL, ECONOMIC, BUSINESS AND POLITICAL CONTEXT TO THE YEAR 2000**

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Irrespective of the means employed, prediction of the future is highly error-prone, as the substantially unexpected collapse of Communism in the nations

of Eastern Europe in 1989 and the Gulf War of 1991 within six months of the Iraq invasion of Kuwait have demonstrated. In particular, trend projections never anticipate the broad patterns of change through history. While acknowledging the dangers involved, it is appropriate in this Epilogue to stand back and to examine the societal context in which GIS operates; from this, and an attempt to predict how this context will change, we can at least surmise how the use and form of GIS will be effected up to the end of the twentieth century.

We take the following societal changes at least to be likely:

- The 'internationalization' of national economies will continue to the extent that the economies of few, if any, countries will be unaffected by the state of global trade.
- There will be increasing levels of activity by multinational corporations and, as a proportion of the global market, a diminishing share will be held by national-only suppliers.
- Increasing levels of competition between states and between individual vendors will be the norm. Yet, despite free-trade agreements, multinational trading blocs such as the European Community will still attempt to foster indigenous developments and products.
- The acceptance and implementation of international standards will lead to increasing convergence of products, at least within individual market sectors.
- The need to maintain economic operations in a highly competitive market may ensure that only major vendors capable of financing new products, packaging and maintaining them and advertising appropriately will survive (except in niche markets). Set against this need for massive resources, of course, is the fact that small firms have thus far always been the source of innovation in the computing industry and that large firms not only become ossified but suffer the burden of having to support earlier systems in an upward-compatible manner. While the 'big and old' versus 'small and new' battle is unlikely always to be resolved one way, big and sclerotic firms will go out of business as well as those small ones unable to fund (by today's

standards) very well packaged and reliable products.

- Labour-intensive operations will increasingly be exported to areas of low labour costs.
- The level of global prosperity as a whole will continue to increase, but may continue to decrease in some areas such as Africa (see Taylor 1991 in this volume).
- Societies are going to become increasingly protective over the confidentiality of data relating to individuals.
- Individuals, corporations and governments are increasingly going to take the use of computerized databases for granted and, as a consequence, more are going to be created.
- Information in general (and geographical or spatial information in particular) is going to become more and more of a commodity in most parts of the world and be treated as a valuable resource – with obvious commercial consequences.

### The implications for GIS of societal changes

From all of the above, we can conjecture the following:

- We will see a convergence in general-purpose GIS, with most systems running under UNIX, and functionality (though not necessarily the ways of providing it) becoming more and more similar between different products. Interfaces will also come to share more common properties, whether through a standard spatial language (perhaps applied *post hoc*, via a universal dashboard which can be applied to any system – see Raper and Rhind 1990) or simply through use of similar menus, or because of the widespread use of the X-Windows Graphical User Interface (GUI).
- Notwithstanding such convergence, sector-specific products will probably appear. In part this will arise because the concept of an all-embracing GIS may well become impractical and in part because of market differentiation (see below).

- Vendors will attempt to differentiate their products in a number of ways. These will include: the efficiency of coding; the adaptation of their toolboxes to operate as 'self-contained and friendly' systems in important core markets such as the utilities; the production of spin-off products (such as ARCView); the transparent linkage of the GIS code with other functions such as modelling, accounting (e.g. spreadsheet), statistical and presentation graphics packages; the production of better training and documentation than their rivals; the production of 'national-specific' versions (see below); and through support of a variety of 'friendship' schemes such as user clubs.
- The market for GIS will attain the stage already reached by the Information Technology market as a whole so far as the world's biggest players – IBM and DEC – are concerned: the bulk of the market will lie outside the United States.
- Challenges to the US supremacy in software may well come from sources such as Japan and Europe.
- Political factors will ensure that software and system creation will need to be carried out in multiple locations. By analogy with car manufacturing in the 1980s, system creation will need, for instance, to be carried out by US and Japanese firms within Europe if they hope to be treated on equal terms with indigenous producers. Since there is a real possibility that the European Community by the year 2000 may include 20 countries and a population of nearly 500 million relatively affluent consumers (or almost twice that of the United States), this seems a matter of importance for all non-European-based vendors.
- Even ignoring the political case for local system creation, users will increasingly wish to see local customization in global products, such as the use of the local language – with all that implies for user interfaces, for the use of diacritical marks, etc.
- Digitizing, to accepted *de facto* standards, will be done wherever it is cheapest. Thus, manual digitizing contracts may well be carried out in China or elsewhere in South East Asia or in Eastern Europe. Mass digitizing may well die out in North America and Western Europe unless scanning and subsequent feature recognition and vectorization can be made routine and cheaper than the manual, 'off-shore' digitizing.
- In any event, the peak of the mass digitizing will be just past in the United States, and long past in the United Kingdom and several other countries by the year 2000. The topographic base maps and the utilities' networks will by then mostly be digitized (at least on all current projections). Thus the source of material for mass digitizing will increasingly come from areas outside that of the pioneers.
- This decline in mass digitizing will be accompanied by a growth in the routine use of direct position-fixing by use of GPS receivers. This may cause significant problems because the readings obtained may be more accurate than maps to which the data can be compared. Map revision by national mapping agencies will, therefore, be necessary though some of this may be achieved by use of 'rubber sheet' transformations using enough control points.
- GIS technology may well have disappeared as a 'free-standing' activity in many organizations as its functionality becomes encompassed by business-oriented systems, such as those for market analysis, and it becomes part of wider Management Information Systems.
- The data volume problem will have disappeared so far as certain applications are concerned, but will remain acute for others. In dealing with population and other censuses, for instance, storage technology is improving much faster than population growth! Given reasonable data compaction routines, it should be possible to hold about 30 items of information for every person in the United States or in Britain, France, Italy and Germany on a single CD-ROM disk whose current reproduction costs are about \$1 if produced in reasonable numbers. Even this storage capacity, however, falls into insignificance when contrasted with the need to hold the volumes of data produced from satellite imagery of the natural environment; global applications in particular seem likely to extend the range of hardware and software for decades to come.

- Much the greatest threat to widespread use of GIS comes from the data supply policies of those governments which require commercial returns to be made to the state for information already collected for the purposes of state administration. The ownership of data seems inevitably destined to become part of the competitive process and, as such, to affect the abilities of those in education in particular to carry out research and teaching relevant to the needs of the outside world except by forging intimate and individual links with data suppliers.
- Given all this and diminishing real costs of computing power, we expect to see a dramatic growth in 'value-added services'. These will include the use of GIS to combine data sets to meet the needs of specific customers, the use of skilled personnel in 'information literate' organizations to provide expert (and legally defensible) interpretations of geographical data sets for customer organizations and the provision of services for 'end-to-end' data compilation, analysis and interpretation when required.
- We suspect that the degree of concern over privacy and confidentiality of data will continue to be much greater for socio-economic data than for that pertaining to the natural environment (though emissions of pollution and like measures are obvious anomalies). In practice, GIS technology will have to grow much improved security facilities, but it also offers one major advantage: by offering the possibility of working at the area aggregate level and still permitting the linkage of different data sets, GIS can carry out analyses without infringing confidentiality restrictions on individual level data. The price to be paid for this is the set of problems which Openshaw (1991 in this volume) and others have described in this volume. Answers to analyses – at least using conventional statistical analysis tools – differ depending on what type and size of areal units are used. Clearly systems must be able to cope with such problems, or at least warn the unsuspecting users of the danger of data-induced artefacts.
- At the end of the day, the success of many

applications of GIS will depend for the foreseeable future upon the skills and professionalism of the individuals involved – irrespective of the success of expert systems. Indeed, because of the fuzzy nature of 'rules' currently followed in manually based analyses, the success of artificial intelligence (AI) in GIS may yet turn out to be small. It is essential, therefore, that GIS operators have access to proper training, carried out to certified standards, and to chartered status. In practice, the latter may most easily be achieved by adding GIS to the training of engineers, planners and surveyors, rather than creating a new chartered, professional institute. However it is done, something of this sort is essential if GIS is to become an accepted part of professional judgement and risk taking, and if insurance of new schemes is to be obtainable. Education and training in future, then, will have to concentrate as much upon setting and demonstrating standards as on the curriculum content.

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## CONCLUSIONS

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As we write this book, many already think of GIS as a mature discipline. Yet, as we have shown in the previous pages, there are still major shortcomings when GIS are used for certain purposes. Current research in progress will solve many of these yet, as the demands and range of users grow, presumably other problems will appear. While we expect many fundamental changes to occur in GIS – notably the decline of the 'map processing model' on which much early work and training were based – we are also clear that the best guide to the future is the recent past. We confidently expect, therefore:

- the further expansion of GIS concepts, tools and practice into a steadily widening range of roles;
- major technical developments and reductions in the price of hardware and software;
- the almost ubiquitous use of GIS in local and central government, in much business and in research and education;
- the rise of global applications and the

recognition that GIS are crucial components of Management Information Systems.

All of these developments will assist us greatly in achieving our corporate goal of describing, explaining and predicting the Earth's patterns and processes with a view to managing the environment and sustaining our existence.

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