72

Epilogue: seeking out the future

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We began this second edition of *Geographical Information Systems* with a description of the way the world of GIS has changed over the period since the production of the first edition. In this closing chapter, we take stock of some important current changes and anticipate their implications for the future development of GIS. Is it possible to make sense of the world of digital geographical information from the perspective of 1997, and to anticipate some of the trends that will emerge in the next ten years? The world seems much less certain, and change much more rapid, than seven years ago when the first edition was assembled; any attempt to forecast the future thus seems even more risky than it did then.

Nevertheless, here are some suggestions about what may become more prominent in the next few years as uses of geographical information and GIS technologies grow and diversify. Doubtless in ten years' time many of the chapters in this book will appear as little more than initial forays among the multitude of uses of GIS, while others may appear as detailed excursions up blind alleys – but, for the time being, we have tried to depict the comprehensive range of policies, institutional factors, technologies and applications which will interact with one another. Our hope is that the roots of future developments will at the very least be traceable to these themes.

There are some straightforward ways to anticipate the future. These include trend projection, use of Delphi-style forecasting, and brainstorming. Yet trend projection would not have identified many of the profound changes to the 'world of GIS' of the last few years that we identified in the Introduction (Longley et al, Chapter 1) – notably the innovation of the Internet and the World Wide Web. Thus we will rely here on reviewing the thoughts of others and their proposed actions to influence the future – particularly but not exclusively the work of academics who are paid to do research – as well as airing our own prejudices. Most unusually, we do not begin by discussing technology; whilst we do not doubt that it has played a vital role in controlling the nature and use of GIS until now and will continue to be a driver of events and actions in the future, there are now many other factors which influence its adoption. Our structure of this Epilogue is designed to reinforce our view that the interactions between multiple factors will become progressively more important in future.

1 THE PROFESSIONAL RESEARCHERS' PERSPECTIVE

If the past in any sense guides our understanding of the future, it follows that one obvious way to identify the changes that have taken place in GIS in the past ten years or so is to compare statements about the GIS research agenda. Research agendas present accessible statements of intent, and as such provide a broad indication of how future university-based research will develop. The by-gone research agenda provides us with measures of how GIS has developed as well as indications of the scale and pace of change. Several such agendas were published or publicised at about the time the first edition of this book was assembled (Craig 1989; Maguire 1990; NCGIA 1989; Rhind 1988), and they provide an interesting – and sometimes embarrassing – perspective on what people thought at the time were the pressing resolvable problems facing GIS research. Today's research agendas give some sense of how much things have changed in the past ten years, and what the face of GIS might look like in five, ten or even 15 years from now. Set out below are details of two major GIS research programmes which highlight debates and temporal trends within the US and European research communities: these also share a number of commonalties with trends in other parts of the world in their respective time periods.

1.1 The evolving views on the US research agenda

The early formal phase of the US GIS research agenda began with the creation of the National Center for Geographic Information and Analysis (NCGIA). Following a US National Science Foundation (NSF)-sponsored workshop in 1986, a five-part research agenda emerged which was subsequently developed (NCGIA 1989) and carried out by the consortium of three universities that won the NSF-funded NCGIA project (the University of California, Santa Barbara; the State University of New York at Buffalo; and the University of Maine).

The five-fold agenda addressed what were perceived at the time to be the main impediments to the greater use and effectiveness of GIS:

- spatial analysis and spatial statistics
- languages of spatial relations
- artificial intelligence and expert systems
- visualisation
- social, economic, and institutional impacts.

In hindsight, these five topics suggest several general concepts:

- There was a need to solve application-led problems of immediate practical necessity.
- GIS was regarded as a clearly demarcated software application running alone on a workstation, and included the software, hardware, and data.
- The system was seen as paramount: emphasis on artificial intelligence and expert systems indicated a willingness to believe that the system was firmly in control, and that the user might surrender even more control to it. Today, this argument seems to fly directly in the face of the view that computers empower people.
- Spatial is not only 'special' (Longley et al, Chapter 1), but is also rather isolated: very little of the detailed agenda addressed the links between GIS and other computer applications.

In June 1996, a new phase began when the new US University Consortium for Geographic Information Science (UCGIS) held its first annual assembly in Columbus, Ohio. The key requirement for membership of UCGIS is a strong commitment to GIS research. The organisation now comprises almost 50 major institutions. The UCGIS agenda was built from the bottom up, as an exercise in consensus-building within a broadly conceived (US) GIS research community that is much larger now than it was in 1987.

This agenda has ten components which have been described at length elsewhere (*http://www.ucgis.org*) and in a summary journal article (UCGIS 1996). Perhaps inevitably, given the international commonalties of view, almost all of them are discussed in greater detail in the chapters of this book. These components are set out below, together with the authors of chapters in this book who address the respective issue. The order in which they are presented below is not significant.

- spatial analysis (Anselin, Chapter 17; Church, Chapter 20; Fischer, Chapter 19; Getis, Chapter16; Openshaw and Alvanides, Chapter 18);
- uncertainty and data quality concerns (Beard and Buttenfield, Chapter 15; Fisher, Chapter 13; Heuvelink, Chapter 14; Veregin, Chapter 12);
- acquisition of new digital sources and their geographical integration (Barnsley, Chapter 32; Estes and Loveland, Chapter 48; Goodchild and Longley, Chapter 40; Lange and Gilbert, Chapter 33);
- cognition (Egenhofer and Kuhn, Chapter 28; Mark, Chapter 7);
- extensions to representation (Raper, Chapter 5; Martin, Chapter 6; Peuquet, Chapter 8);
- scale (Weibel and Dutton, Chapter 10; Hutchinson and Gallant, Chapter 9);
- interoperability (Coleman, Chapter 22; Sondheim et al, Chapter 24);
- distributed computing (Elshaw Thrall and Thrall, Chapter 23; Maguire, Chapter 25);
- (US) National Spatial Data Infrastructure (see the international perspectives of Rhind, Chapter 56; Salgé, Chapter 50; Smith and Rhind, Chapter 47);
- GIS and society (Curry, Chapter 55; Pickles, Chapter 4).

There are several elements of continuity with the original NCGIA agenda of seven years earlier – for example that between cognition and languages of spatial relations. Yet the following differences (at least in emphasis) are also apparent:

- the emphasis on spatial analysis has shifted towards: the complex interactions between system and methods of analysis; the need for analysis to enhance intuition; the need to develop techniques capable of dealing with very large volumes of data; and the value of exploration and hypothesis generation;
- the emphasis on systems has largely been replaced by a more general focus on data;
- there is now a deeper sense of the social context, in part attributable to the growing influence of GIS, and in part to the seriousness of the social issues it raises;
- the user is now clearly in charge, and earlier interest in technologies like artificial intelligence is largely missing. Like many other modern forms of computing, GIS is now seen as a technology capable of empowering the individual – like it or not, technologies like GIS enable everyone to feel they have become a specialist spatial analyst or cartographer, whatever their disciplinary background and training;
- spatial cognition is more clearly seen as one way of making the technology easier to use, and thus empowering the individual further;
- it is assumed that digital geographical information infrastructures (such as the US NSDI and the UK NGDF – see Rhind, Chapter 56) are now being firmly institutionalised in many countries.

This all suggests that the GIS research community is clearly responding in serious fashion to the social critiques of the early 1990s – even if some of those were manifestly excessive or ill-targeted (see Pickles, Chapter 4, for a review and perspective). Some element of response to market and user pressures is also evident.

A third element of the US research agenda is the Varenius project (scheduled for 1997–99). Unlike UCGIS, the research agenda of this NSF-funded project was devised in a strictly top-down fashion. The project agenda (*http://www.ncgia.ucsb.edu*) argues that geographic information science should be addressed in three strategic areas:

- **Cognitive models of geographical space**
  Human understanding of the geographical world is expressed in the form of instances of certain geographical concepts, ranging from the very simple and largely geometric – such as location, distance, or direction – to the complex and domain-specific – such as syncline (geology), esker (physical geography), or neighbourhood (human geography) – to the highly sophisticated and subjective, such as sense of place. Research into such concepts is motivated by the need to design systems that are more closely reflective of the way humans think about the world around them.
- **Computational implementations of geographical concepts**
  Communication in the information society is increasingly in digital form, and certain geographical concepts are clearly more easily expressed and structured in the digital environment than others. Much effort is being directed at extensions of GIS data models to include time, uncertainty, and other concepts of geographical space, but are there limits to how much of our understanding of the world around us can be expressed in the computer's 0s and 1s?
- **Geographies of the Information Society**
  Geographical information technologies have the potential to restructure much of human activity, by reducing the impact of distance, opening the possibility of virtual communities, and changing patterns of work, recreation, and education. A better understanding of these geographical impacts of information technologies is needed if humanity is to be able to anticipate and deal effectively with these changes.

The Varenius agenda is very different from that of NCGIA in 1988, and shows how far the field has come in its intellectual development. Instead of a series of practical problems to be addressed in the context of technology, it implies a well-defined field of science with its own structure and agenda.

1.2 The European researchers' perspective

Although it has many similarities to the US perspective – a tribute to the global interchange of ideas and collaborative working in GIS – the European research perspective has one particularly valuable aspect. This is that it is comprised of components fashioned within the 30 or so nations within greater Europe. To that extent, huge cultural diversity is overlaid on technological homogeneity. Fortunately, these national research agendas have been summarised and focused through the efforts of the European Science Foundation's GISDATA programme. The objectives of this programme were to:

- enhance existing national research efforts and promote collaborative ventures to overcome European-wide shortcomings in spatial data integration, database design, and social and environmental applications;
- increase awareness of the political, cultural, organisational, and technical and informational barriers to an increased utilisation and interoperability of GIS in Europe;
- promote the ethical use of integrated information systems, including GIS, which handle socioeconomic data by respecting the legal restrictions on data privacy at the national and European level;
- facilitate the development of appropriate methodologies for GIS research at the European level;
- produce outputs of high scientific value;
- build up a European network of researchers with particular emphasis on young researchers in the GIS field.

It will be evident that this is a somewhat more activist, less academic and more policy-oriented approach than the US NCGIA and Varenius project. It specifically sets out to improve, rather than investigate, the GIS world – especially that in Europe (see *http://www.shef.ac.uk/uni/academic/D-H/gis/gisdata.html*). A recurring theme has been that of geographical information availability, quality, provision, and access. Burrough et al (1997) set out a position statement for GI on behalf of this programme, derived from a series of pan-European meetings held over four years. They summarised the current status of a policy framework for Europe (see also Rhind, Chapter 56) and set out a typology of European GI activities. They identified four main uses of GI:

- in the mass market
- for operational functions
- for strategic functions
- for pure and applied research.

They argued that, to advance the use of GIS, different combinations of various actions were required in each of these four areas. These individual actions included enhancing access to data, creating a new framework for intellectual property rights, fostering different types of skills, improving metadata provision, raising awareness of business opportunities, clarification of the role of public services, and enhancing and defining privacy in a practical sense whilst the surveillance society continued to develop. Predictably – and properly – they proposed a series of actions which would enhance the use of GIS. The extent to which they create the future of GIS in Europe (and perhaps beyond) is of course dependent on the extent to which other players with influence or resources take up their recommendations.

2 THE DATA DOMAIN – PRIVATE SECTOR PERSPECTIVES ON THE FUTURE

To date, geographical data have been provided primarily as the producers believed appropriate. Thus far, only in a few countries have market forces driven producers to rethink completely their products to meet customer needs. As a consequence, the private sector is coming to play a larger role in data specification and provision, going far beyond in some cases merely rebadging and packaging data produced by government bodies. A key player is Microsoft, and Smyth (1997) has summarised his employer's view of the future data world. He argues that 'plug and play' geoinformation is essential and sketches out a vision of commerce in independent and interoperable purpose-built geographical data components. Smyth claims that Microsoft wants the following results and is working to achieve them:

- lots of accessible *geoinformation*;
- a high level of interoperability;
- many applications;
- low cost-per-use;
- high value to data owner;
- protection for data owner.

In contrast, what we currently have (Smyth argues) is:

- lots of *geodata*;
- little interoperability;
- restricted applications;
- high cost-per-use;
- low value to owner;
- data theft and misuse.

To achieve the desirable ends where geoinformation is widely used and its originators and third parties involved all benefit, Smyth sees two possible technology approaches. The first involves data format standardisation, viz:

- reworking of existing data;
- generic availability – no intellectual property interest or proprietary structure;
- acceptance that this will not work across different platforms.

Smyth (1997) argues that this is an untenable way to proceed and thus the second approach, data encapsulation, is essential. Encapsulation requires that information is accessible only through a software interface; that the information client sees only a logical view of the data; that the interface implementation is tailored to meet functionality and performance needs; and that data and interface are engineered and delivered as an integrated component (see also Hartman 1997).

Smyth goes on to argue that in future data architectures must support both *semantic* and *geometric* integration through shared models or meta-models with the 'reference frame' being supported by national mapping agencies (NMAs). Furthermore, the database entities must be based on human mental concepts – not on theme and coverage. The Microsoft vision involves semantic data linking based on named, classified entities in a particular relationship to their geographical context as well as the usual geometrical matching. Together, this would enable safe 'on-the-fly' data integration (i.e. the 'play' in 'plug-and-play'). A central requirement is agreement on how to define and name geographical entities which may split or aggregate in the course of GIS operations, and how to do this in a way acceptable to all. Smyth (1997) argues that this could best be done through setting up a protocol for defining universal geographical references.

Because Microsoft is so dominant in the software environment, these concepts may well change the way in which the GIS industry operates – assuming Microsoft uses its financial resources and market position to enforce these concepts as *de facto* standards. It is self-evident that this would have major implications for some GIS software vendors and for existing data providers.

Microsoft is not of course the only commercial player having a strong interest in data provision – though unlike Space Imaging, SPOT Image GDT, Etak, NavTech and some others, it does not seem to see itself as primarily a provider of information but rather as a supplier of tools. The various commercial players who (at the time of writing) are intending to launch high-resolution (3m to 1m) satellite imaging systems (Barnsley, Chapter 32; Estes and Loveland, Chapter 48) have recognised the need to supply products – differentiated to suit different markets – rather than raw data. The latter approach has failed spectacularly in previous attempts at commercialisation of remote sensing (see Rhind, Chapter 56; Harris 1997). Nevertheless, their investments represent a huge commercial gamble that a new set of markets can be fostered and that market share can be wrested from traditional suppliers – such as air photography firms. The third edition of 'Big Book' will describe the achievements and failures – whatever they are – of this intrepid venture!

3 THE POLITICAL DIMENSION: NATIONAL AND INTERNATIONAL COORDINATION AND DATA FACILITATION

It has become commonplace to argue that access, availability, pricing, and sharing of geographical data and information is a key determinant of how GIS is evolving (see Rhind, Chapter 56). In one sense this is all about how national policies are playing out as governments either look for additional revenues or become attracted to a Jeffersonian approach (i.e. information freely available to the citizen; Wood 1997).

Nowhere is the tension between cost recovery and 'free access' more evident than in the various national spatial data infrastructure (NSDI) schemes now springing up around the world. Whilst many of these share common terminologies and even apparently similar ends, the local situation is often highly affected by more local issues. Thus Soni Harsono, the Agrarian Minister of Indonesia, said at an international conference in Jakarta in October 1997 that:

'Today, information has become a strategic commodity. It has a high economic value. Although geoinformation is marketable, some of it cannot be sold or distributed, especially information related to national security . . . Because we are dealing with a national problem, there needs to be a Government policy . . .'

Given this international variability in the detail of NSDI-type activities, the terminological variations in use, and the many different agendas of those involved (see Figure 1), it is extremely difficult to predict their future evolution. In some respects the most fascinating of all is the Permanent Committee on GIS Infrastructure for Asia and the Pacific (see *http://www.permcom.apgis.gov.au*), the members of which are the directorates of the national mapping and survey organisations and equivalent organisations in the 55 countries of Asia and the Pacific. A distinguishing characteristic of this organisation is the emphasis its members place on United Nations (UN) involvement in bringing about regional coordination.

This involvement of UN bodies was also a characteristic of the early attempts to forge a global spatial data infrastructure (GSDI) in 1996 and 1997. The first tentative definitions of this – which was seen as a global summation of national infrastructures or frameworks – were attempted by Coleman and McLaughlin (1997) and Rhind (1997).

At the time of writing there is much activity devoted to the coordination of data creation, standards, and data sharing. Whilst there is a strong logic to this given the high fixed costs of creating and maintaining much geographical data, the trade-offs involved, and the role of the private sector render the future and the success of these initiatives unclear. If duplication is the essence of capitalism, are these schemes not inimical to some powerful private sector interests? How this will play out in future is not clear but we can safely assume much energy will be devoted to many well-intentioned additional attempts to harmonise and focus GI and GIS-related activities.

4 GIS TECHNOLOGY: HARDWARE, SOFTWARE, AND COMMUNICATIONS

Much has been made throughout this book about the pace of change in computing, which is now quite simply mind-bending. Batty and Longley (1996) report that, in terms of dollar value, more new factories were to begin manufacture of silicon chips in 1996 (90, costing over US$1 billion) than came on stream during the entire decade of the 1980s. The clear implication is that in tomorrow's digital world we will interact with computers not just much more often but also in many more different ways. Many of these interactions will relate to geographically referenced phenomena, but whether the systems will themselves be termed 'GIS' remains to be seen – for while GIS technology is becoming ever-more pervasive it is also becoming more invisible.

The current trend of hardware prices halving – also expressed as performance doubling – every 18 months, in accordance with the so-called Moore's Law (Longley et al, Chapter 1) seems set to continue or even accelerate for the foreseeable future.

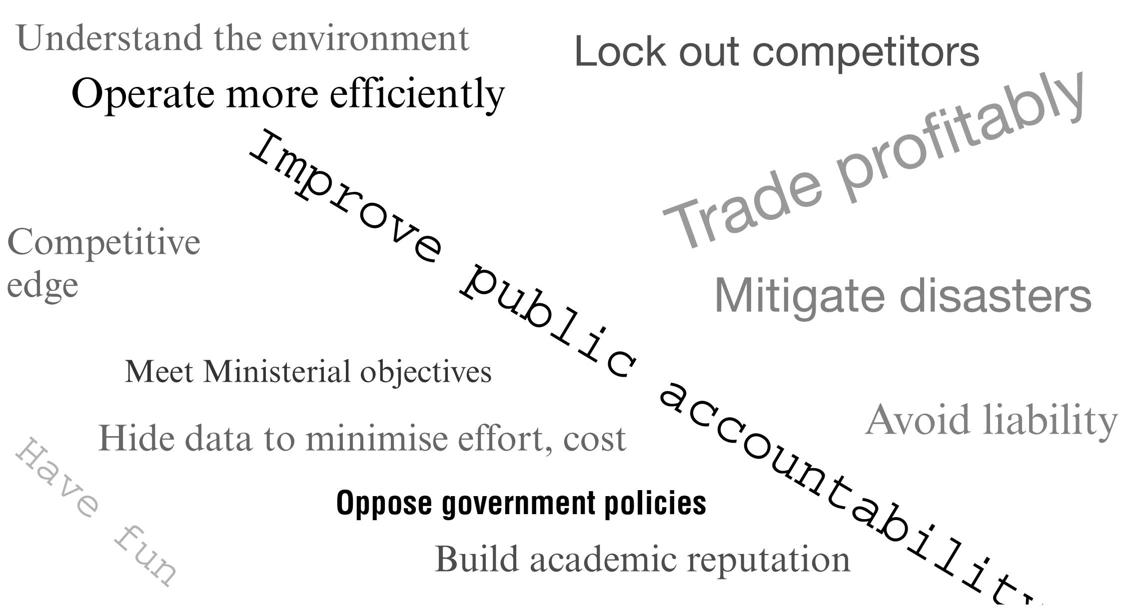

Fig 1. Some of the various agendas of the different players involved in NSDIs and the GSDI.

Doubtless not all this performance can expect to be directly reflected in end-user application performance – other hardware and network bottlenecks will remain, and new demands will arise out of larger databases, new software developments (e.g. verbal user interfaces), and more complex data models which are better able to represent the real world. As the cost of hardware falls, GIS software systems will change to exploit them. In 1997 the retail cost of memory is now US$4 per Mb and hard disks cost about $0.075 per Mb. As these become cheaper, software and data will increasingly become memory-resident and performance will be dramatically transformed – allowing real-time pan and zoom of large databases, for example. Machines will also become much smaller allowing direct field-based database entry. Indeed, as global positioning systems (GPS) become more widely deployed and the signals they receive more precise (assuming favourable US Federal legislation concerning NAVSTAR signals) data entry will change from digitising the known location of events and objects to simply obtaining a reading from a sensor indicating current location. Thus a utility, for example, will be able to use pole sensors to obtain direct positional and status information from any outside plant. This will usually be displayed in map form and be stored in a spatial DBMS, although other interfaces will be available to allow navigation by the visually impaired.

Clearly, this type of on-demand locational referencing constitutes a quite different paradigm for GIS. However, this information will in most cases still need to be displayed in some geographical context which, for the foreseeable future, will consist of legacy information and framework data originally collected by other means. We feel safe in predicting that the bulk of moving entities – whether they be cars, containers on trucks or ships, pallets, and even cargo goods themselves – will have embedded GPS receivers and transponders in a decade from now, with monitoring and diversion of position becoming a routine real-time function. Human ingenuity poses some scope for new forms of crime if real signals can be suppressed and false ones substituted. The falsifiability of unique identifiers and broadcast geographical coordinates offers important prospects for the military, as much as for crooks. Conversely, use of electronic tagging and GIS will provide a means of punishing criminals broadly in line with society's wishes, while avoiding some of the huge financial and social costs of imprisonment. Monitoring the movements of suspected wrong-doers by tapping cellphone signals raises a number of civil liberties issues.

The recent upheavals in information transfer and exchange arising out of the adoption of the Internet are equally profound and far-reaching. As we have indicated elsewhere, the rate of adoption of the Internet has been truly spectacular, without precedent in the history of communications – the fax took 22 years to accrue ten million users and the cell phone attained this level of usage in nine years, but between 1996 and 1997 the Internet achieved ten million users in just ten months (Lawrence 1997). A network-centric approach to GIS is already finding favour in GIS circles. Initially, users saw the value of sharing data and processing over local and wide area networks. Increasingly, however, many users are also interested in the Internet as a delivery mechanism and a new paradigm for implementing GIS applications. The Internet has found favour in GIS because of its ease of use (at least compared to previous technologies), its relatively low cost, its use of standards, and its widespread acceptance in many IT fields. The Internet has allowed many more people to access GIS databases through simple low-cost browsers. In the longer term, as desktop computing and Web-based computing converge, so GIS developers will further integrate GIS into the mainstream.

It is striking how much the economics of the software industry have changed since the first edition of this book was published. Then, the major software vendors like Intergraph were still generating the bulk of their considerable revenues from large-scale systems, often in use by the military and other parts of national governments. Each system was typically customised using expensive labour and installation costs could be over a million dollars. Since then, the spread of workstation then PC-based systems has decimated the cost per seat for GIS, with costs falling by between one and two orders of magnitude. Just when the vendors have adjusted to this new paradigm through increased volumes – which themselves require the software to be very different in nature, packaging, reliability, and usability to what was provided before – the advent of the Internet and the Web has reduced many non-software costs by another order of magnitude. Clearly this requires a quite different business model and one which is as yet unproven, although we foresee a return to server-based pricing models. Change is having fundamental effects on organisations which were created and staffed in one IT era but have been forced to change culture not once but twice within a decade. It is thus small wonder that many software vendors have gone bankrupt and there are now only a handful of major players and numerous tiny niche ones.

Taken together, the percolation of computing into more and more walks of life and the further development of networks for information exchange will set the context for reinvention and change in the domains and applications of GIS.

It is also interesting to speculate on changes in software. Today most GIS software vendors are already converging their development plans on the sort of common three-tier architecture shown in Figure 2. Within this architecture, applications are either clients or servers. Clients request data or processing services of servers, which perform the actual work. Clients and servers can communicate over local and wide area networks, as well as the Internet. End-users access enterprise geodata and geoprocessing services using familiar windows-based clients (e.g. thin Web browsers [Netscape Navigator or Microsoft Information Explorer] and Windows [Microsoft and X Windows] thick clients). These clients make requests to application servers, which encode the business logic of the organisation. Data, for use in applications or presentation to users, are managed by one or more data servers. Increasingly, organisations are recognising the many benefits of

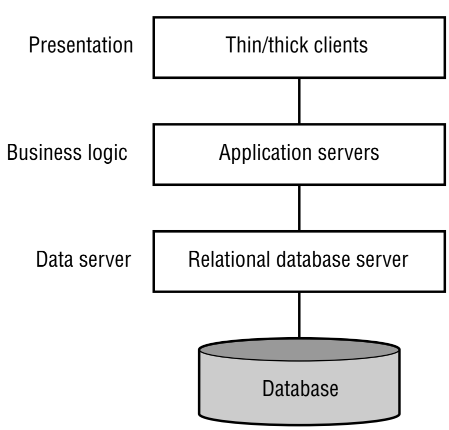

Fig 2. Classical three-tier, client/server architecture for building enterprise GIS solutions.

storing their spatial and non-spatial data together in a commercial off-the-shelf (COTS) DBMS.

As database management software vendors add functionality to their servers to handle the special characteristics of GIS data (e.g. long transactions, versioning, and extended multi-dimensional databases capable of dealing with geographical data which have variable length records), GIS vendors will switch to using COTS DBMS for managing geographical data. Thus the GIS software system of the future will begin to look and function increasingly like mainstream computer applications.

Currently there is a widespread trend, both within and without GIS, towards the development of modular re-usable software components. By creating software in this way vendors can write software once and use it many times in different applications. These software object components can also be assembled in different ways to create scaleable solutions. The most widely used component software standard is Microsoft's Object Linking and Embedding/Common Object Model (OLE/COM) and this has been widely implemented by many GIS vendors. Javasoft's Java Beans component standard has also generated some interest and is expected to gain wide acceptance, especially in the developing range of network applications. A further advantage of component-based GIS is that other non-GIS objects (e.g. personal schedulers, charting tools, and report writers) can also be easily combined by developers and end-users to create highly integrated, specific-purpose applications.

The vendors of GIS software systems will be well-prepared for changes following any freeing up of digital data supply arrangements since, allied with the move of GIS to the desktop, they are already supplementing their roles in software provision with the creation and supply of value-added data, business solutions, and consulting. We have remarked in the Introduction (Longley et al, Chapter 1) that recent years have seen rationalisation in the number of firms that make up the GIS industry, the development of strategic takeovers and alliances (Elshaw Thrall and Thrall, Chapter 23), and the entrance of new big players from elsewhere in the software industry. The convergence of software across all domains (CAD, GIS, image processing) will continue and basic GIS functions, like spatially referenced spreadsheets, will become ubiquitous. Software will both break up – into packages for the desktop which allow users to construct all kinds of tailor-made applications from individual software and data elements – and converge as the fruits of the OpenGIS initiative allow vendors to create specialised functions for their traditional software as well as pointers and handles to other software products. The vendor community will need to package graphics, data, areal units, spatial analysis methods and so on in whatever manner the user requires, yet in ways which are safe to use. This will be done using software drawn from a range of computer environments – and this will increasingly mean networks rather than desktops.

This will have fortuitous knock-on implications for the GIS research base in universities, in that researchers will be able to assemble software modules at will and hence develop highly customised solutions to spatial analytic problems using high-level languages. This approach will also characterise the sophisticated end of the business and service planning consultancy market (Birkin et al, Chapter 51), where it will be integral to the development of customised solutions to strategic and operational business applications.

GIS practitioners have rightly been criticised in the past for not acknowledging the influence of military and intelligence applications in driving the technology's development (Pickles, Chapter 4). Of course, GPS and GLONASS were developed initially for military purposes with military funds and, if anything, military interest in geographical information technologies has grown in recent years, with widespread acknowledgement of their role in the Gulf War. Today, the military community is recognising the strategic as well as the tactical value of geographical information, through the doctrine of 'information dominance'. Tomorrow's soldier will be equipped with an unprecedented array of information systems (including 'wearable GIS' for the battlefield), to support positioning, fighting at night, routing of vehicles over complex and unknown terrain, communication between the field and base, and between different groups in the field and in the air (Swann, Chapter 63). Substantial research and technical development (plus international collaborative agreements on data sharing between military and civilian bodies) will be needed to ensure that accurate, timely information is available; that the various systems interoperate effectively; and above all that users of data are fully aware of their quality and deficiencies (see the Principles Part, Section (b)).

While Neves and Câmara (Chapter 39) have described the current state of virtual reality, which immerses the user in environments created by the system, the development of precision agriculture described by Wilson (Chapter 70) is an instance of the inverse – the computer immersed in the real environment. Such 'ubiquitous computing' makes excellent sense for GIS, because it allows the system and reality to interact much more closely than is possible with desktop GIS, a technology that is essentially confined to the office. We are likely to see many developments in ubiquitous computing in the coming years, including various forms of miniaturisation of systems, right down to the 'wearable computer' integrated with personal clothing.

5 A CHANGING CONCEPTUAL RUBRIC

As we stated in the opening parts of the Introduction, much of our thinking to date (and particularly in applications of GIS) has remained grounded in the parallels between what can be achieved digitally with a database in analogy to what could be achieved earlier with a physical paper map – that is, the 'map metaphor'. The movement to multimedia, virtual reality, and temporal GIS signals that the widely quoted metaphor may finally have outlived its usefulness. In the Introduction we described the ways in which this map metaphor is fundamentally limiting, and the rapid innovation of a vast array of digital realities will necessitate the introduction of new and more appropriate representations.

Allied to this, the way that we conceptualise GIS – namely as a medium in which to carry out overlay analysis by analogy to manipulation of transparent maps – is already being supplemented with other conceptions of what digital representations of the Earth's surface entail. The concept of overlaying transparent hard copy maps will doubtless persist from the world of hard copy mapping into the digital world of the twenty-first century: it represents an efficient model for simplifying representation of the real world and a pragmatic means of data collection (e.g. planners capture and maintain land parcel data, engineers capture and maintain sewer lines, etc.). In the short term, this overlay model has also provided familiar landmarks and understanding at the beginning of the digital era. More generally and in the longer term, such legacies can also come to impose constraints on thinking, making it difficult to think 'outside the box' and to anticipate the eventual uses to which new technologies will be put.

In the early days of the twentieth century it was helpful to think of an automobile as a 'horseless carriage', but today people would never think of explaining the concept of an automobile by reference to a horse, except in a culture that was still dominated by horse transportation. Similarly, it is no longer helpful or convenient to describe a geographical database as a 'computer filled with maps' or as a 'digital map library chest'. Maps will always be with us (just like horses for particular courses), but will not always be the way we conceptualise and explain GIS.

Finally, developments in computing and the advent of a digital world – the two essential ingredients to geocomputation – have potentially profound implications for the pursuit of scientific enquiry. The toolbox of spatial analysis techniques assembled over the last 30 years has used mathematical and statistical rigour to pursue high theory in a way that is ordered, mathematically well-formulated, parsimonious, and comprehensive (Getis, Chapter 16). Yet, as Openshaw and Alvanides (Chapter 18) argue, geocomputation introduces a very different way of experimenting with the world in which the computer has become the new digital environment for analysis (Goodchild and Longley, Chapter 40). In geocomputation, computer representations are used to develop immediate solutions to spatial problems which may then be subjected to a range of sensitivity analyses. This amounts to a quite different way of exploring the world – a world in which knowledge is acquired by trial and error experiment, through learning by doing, rather than through accepting formal frameworks as given and then slotting different ideas into them for testing and refining. Geocomputational approaches demonstrably offer interesting new ways of approaching areal zoning and modifiable areal unit problems. Yet this relatively new paradigm has yet to generate much in the way of significant substantive conclusions. Moreover, in other important respects, geocomputation goes against the tide of current sentiment and perception of GIS as an empowering technology – in some of the emergent geocomputation literature there is the sense that analytical direction has been surrendered to the computer (Johnston, Chapter 3), lending the approach a similar resonance to technology-led areas such as artificial intelligence, which has rather fizzled since the first edition of this book was published. On balance, it is likely that geocomputation will stimulate spatial analysis in GIS, not least because of its tremendous data reduction potential, but it is unlikely to provide a panacea for spatial analysis.

6 EDUCATION AND PARTICIPATION

There is no doubt that the number of GIS users has increased significantly in the last few years. In part this is because GIS software systems have become easier to use. This arises out of a combination of standard user interfaces (Microsoft Windows), the development of domain-specific data models and applications, and better education in geographical concepts and techniques. At various points in this book we have commented that much of the increased power of computers has been soaked up in the creation of more intuitive and accessible, yet detailed and complex, graphical user interfaces (GUIs). Whilst a minority of existing GIS users will lament this diversion of computer power at the expense of, say, processing speed and analytical functionality (particularly if they have already mastered earlier, less intuitive GIS user interfaces), it is undeniable that this has fostered much wider adoption and usage of GIS technology. People find it easy to work with maps and pictures, and to explain things graphically – so it seems increasingly odd if a spatial technology like GIS is difficult to use. Much effort has already gone into the design of better user interfaces to GIS, yet much more will be needed if the technology is to be useful to wider communities of users, who will typically be less interested in advanced concepts and techniques than existing, more specialist, users.

If this can be done successfully, there would seem to be little to prevent GIS principles eventually being accessible to children in primary (elementary) school – and indeed there are many initiatives already underway to bring GIS to such schoolchildren. An important question for the next ten years of GIS development will be whether it is in fact possible to design a technology which is so easy to use, and so transparent to the user, that it can support a child of seven's exploration of the geographical world. Indeed, such developments could prove fundamental to the long term future strength and vitality of geography as a discipline, which has long been underrated in the USA and is presently facing a range of threats to its continued vitality elsewhere in the world.

'Think globally, act locally' have remained watchwords of the 1990s. In the GIS arena, it is clear that the geographical information technologies available in 1997 can already empower communities (both geographical and virtual) to collect and process their own geographical data (Shiffer, Chapter 52; and see, for example, the Friends of the Earth Wild Places GIS web site at *http://www.foe.co.uk:8070/SssiNavigator*). At the same time, the time-honoured arrangements of central data production are threatened by reductions in the resources made available by central governments (Goodchild and Longley, Chapter 40) – resulting either in a diminution of activity by the state, dramatic increases in efficiency, or the seeking of resources by the component bodies of government from their end-users. One extreme possibility is that new technologies, together with associated economics of geographical data production, will lead to a radical rearrangement in which both production and consumption of geographical data occur locally; at very least, the next ten years are likely to be exciting ones for geographical data production arrangements and institutions.

Looking to the global scale, it is clear that the development of metadata and metadata catalogues (Adler and Larsgaard, Chapter 64; Goodchild and Longley, Chapter 40), allied to the diffusion of Web usage, will allow ever more users to identify relevant datasets with characteristics salient to particular purposes, and to obtain the system instructions for handling them. As Adler and Larsgaard (Chapter 64) make clear, there are many examples of datasets that are not geographical, but nevertheless have well-defined 'footprints' on the Earth's surface – in other words, location is an important part of their metadata. Footprints can be a useful basis for searching for such datasets, although they raise many research issues which will need to be resolved first. In future, the geographical information technologies will include systems for managing such geographically referenced datasets as well as the more familiar geographical ones. Thus in future we may find ourselves searching for guidebooks to unfamiliar parts of the world using identical procedures – based on ranges of latitude and longitude – to those we are increasingly using to search for digital maps and remote sensing images. In the digital, connected world the old concept of the map library may be extended to cover access to items that we have not traditionally thought of as maps; but their well-defined geographical footprints allow us to use the same methods to search for them.

7 PUTTING IT ALL TOGETHER

All of the above suggests a number of changes to the 'world of GIS'. These are summarised in Table 1, which was created by McLaren (1997) but has been suitably extended.

In many parts of this book there has been a strong intimation that the day of GIS as we have known it – of readily-definable cores of software, data, expertise, and applications – is coming to an end, being progressively absorbed into other larger functions, IT systems, and science as a whole. In this scenario, research in GIS becomes unnecessary as the chameleon GIS application becomes an invisible part of the 'taken for granted world'. The decay of general-purpose GIS conferences in leading GIS countries might be taken as an indication of this transition – after all, we do not have conferences on wordprocessing, do we?

Yet many facets of GIS remain distinctive, and many see GIS as more akin to broad areas such as statistics or cartography than wordprocessing. Whatever, we do not doubt that GIS – defined generically to denote the use of computers to create and represent digital representations of the Earth's surface – will continue to prosper and mass market 'integrated with other applications' uses of it will proliferate. But equally we strongly suspect that these premonitions of the end of 'visible GIS' are premature. We expect there to be a third edition of this book!

These are exciting times indeed for GIS. At its heart, however, and despite all that has been said in the chapters of this book, GIS remains quite simply a means for exploring the world around us, that survives or falls against that simple goal. No amount of technological ingenuity can save a digital representation that is too inaccurate, too expensive, too cumbersome, or too opaque to reveal anything about the world that we did not already know. At its best, GIS allows schoolchildren to explore parts of the world they are curious about, market analysts to evaluate sites they would otherwise have to visit, farmers to make better decisions based on better knowledge of their own fields and of market conditions elsewhere, utility companies to see the facilities they have installed underground, and fulfils countless other practical and important needs. These activities continue to grow, giving humanity unprecedented ability to see its own environment in new and useful ways. Inevitably, they make our

Table 1 Factors supporting the GIS paradigm shift (expanded after McLaren 1997).

Current situation	Projected situation
Local client/server	Web-based client-server
Niche market	Mass market
Proprietary solution	Interoperability (Open GIS?)
Fragmented	Integrated
Expensive	Affordable
Annual data/software licenses	On demand data and software
Limited data	'Fire hose' of data
Single source of data	Competitive, multiple sources of data
Limited range of what is considered 'geographical data'	Much wider range of 'geographical data and information', with details accessible through digital libraries and/or data brokers
Information systems: few integrated GI-based services	Many GI-based services available from many providers (some of whom were originally software vendors)
Primitive models	Sophisticated, rich models
Single views of the GIS world	Multi-disciplinary
Highly skilled end-users	Casual, semi-skilled users
Many specialist applications, often discipline-based	Community-rooted applications as well as specialist, disciplinary ones
Office-based	Field- , home-, and office-based
Opaque graphical user interfaces, designed as extensions of the Mac desktop	Transparent communication interfaces based on sound research AND market acceptability
National or local coordination	International, national and local coordination (or anarchy?)
Highly varied pricing policies between different countries and application domains	More within-country variation in data pricing policies as private sector becomes more central to GI

environment more important to us, whether through increased concern for its health, through increased awareness of its forms and places and the processes that operate in it, or through more efficient use and better maintenance of its resources. Whatever the course of its technical future, it is the ability of GIS and related technologies to help us see our 'small blue planet' in better ways which render them important to us.

References

Batty M, Longley P 1996 Analytical GIS: the future. In Longley P, Batty M (eds) *Spatial analysis: modelling in a GIS environment*. Cambridge (UK), GeoInformation International: 345–52

Burrough P A, Craglia M, Masser I, Salgé F 1997 Geographic information: the European dimension. *GIS Data Newsletter* 8: 6–16. Strasbourg, European Science Foundation (see also *http://www.sheff.ac.uk/uni/academic/D-H/gis/gisdata.html*)

Coleman D J, McLaughlin J D 1997 Towards a global geospatial data infrastructure. *Proceedings GSDI Conference, University of North Carolina, Chapel Hill, 19–22 October*

Craig W J 1989 URISA's research agenda and the NCGIA. *Journal of the Urban and Regional Information Systems Association* 1: 7–16

Harris R 1997 *Earth observation data policy.* Chichester, John Wiley & Sons

Hartman R 1997 *Focus on GIS component software featuring ESRI MapObjects*. Santa Fe, Onword Press

Lawrence V V 1997 GIS in disguise: improving decision-making with geography. *Geographic information – exploiting the benefits: AGI 97 conference proceedings*. London, Blenheim/Association for Geographic Information: 3.2.1–3.2.5

Maguire D J 1990 A research plan for GIS in the 1990s. In Foster M J, Shand P (eds) *The Association for Geographic Information Yearbook 1990*. London, Taylor and Francis and Miles Arnold: 267–77

McLaren R 1997 Response in 'Question time for GIS – where are we going?' *Surveying World* 5, 6, 17. Hitchin, PV Publications

NCGIA 1989 The research plan of the National Center for Geographic Information and Analysis. *International Journal of Geographical Information Systems* 3: 117–36

Rhind D W 1988 A GIS research agenda. *International Journal of Geographical Information Systems* 2: 23–8

Rhind D W 1997c Implementing a global geospatial data infrastructure. *Proceedings, Global Spatial Data Infrastructure Conference, University of North Carolina, Chapel Hill, 19–22 October*

Smyth C S 1997 Plug-and-play geoinformation. *Proceedings, Global Spatial Data Infrastructure meeting, Chapel Hill, North Carolina, 19–22 October*

UCGIS 1996 Research priorities for geographic information science. *Cartography and Geographic Information Systems* 23: 115–127

Wood W B 1997 A Jeffersonian vision for mapping the world. *Issues in Science and Technology* XIV, 1. US National Academy of Sciences/University of Texas at Dallas