New Developments in Geographical Information Systems: Principles, Techniques, Management and Applications

P A LONGLEY, M F GOODCHILD, D J MAGUIRE, D W RHIND[1]

1 INTRODUCTION

We are delighted that the publisher of **Geographical Information Systems: Principles, Techniques, Management and Applications** (the 'Big Book' of GIS) has decided to publish this abridged edition of the original two-volume set. Since its publication in 1999, we believe that the title has become established as the premier reference compendium in its field, continuing a tradition begun with **Geographical Information Systems: Principles and Applications** in 1991. Both titles, we hope, are part of the history of GIS: as encyclopaedic reference works they have provided reliable reference points during the evolution of the subject; and as thoroughly cross-referenced essays, commissioned from leading authors, we think they still bear comparison with the best of all the encyclopaedias and handbooks that are now appearing in an increasingly crowded market place.

Our motivations for producing this abridged version are straightforward and simple. Following publication of this major work in 1999, we produced what we believe was an equally successful textbook, designed as an advanced introductory guide to GIS – the marketplace seemed to think this too, for that title, **Geographic Information Systems and Science,** sold over 25,000 copies in the three years following its publication. In the meantime, the 'Big Book' experienced a sustained level of sales to libraries and research organisations, and in 2004 a successful Chinese language version was published. We thought of the textbook (Longley, Goodchild, Maguire and Rhind 2001) as providing a primer to the fast-developing field of GIS, while the 'Big Book' would remain a key reference point that would reinforce its key concepts, techniques and management practices. Fundamental to our view of GIS is that principles and best practices are enduring, while the more ephemeral issues that pervade more techno-centric guides are not. Thus when the success of the textbook led the publisher to ask us for an expanded Second Edition (Longley, Goodchild, Maguire and Rhind 2005), we were keen to maintain a link with the research compendium that has been formative to our own understanding of GIS.

We were also keen that the book reach the widest possible audience – for example, individuals who would use the material to provide background information while undertaking courses in GIS education; those working in institutions that are new to GIS and might not have access to a copy of the original boxed set in their libraries; and small organisations for whom the pricing of the original work was prohibitive. We are very pleased that the publisher, John Wiley and Sons, Inc., was amenable to the view that their substantial initial investment in the second edition of 'Big Book' had been largely amortised, and that a low-cost abridged version could be published. We should add that we are grateful that similar magnanimity underlay their agreement to post those chapters of **Geographical Information Systems: Principles and Applications** (the first edition of the work: Maguire, Goodchild and Rhind 1991) on the Website of the textbook (www.wiley.com/go/longley), some years before free downloads became widespread. The economics of this project have nevertheless dictated that we reduce the number of chapters that are available in print form – although all of the contents of the original work are retained on the CD that is provided with the book.

1 Incorporating written suggestions of many of the contributors to the second 'Big Book' of GIS.

GIS is, without doubt, a fast-moving field, albeit one that is centred upon principles, techniques and management practices that are less transient than its software or its technology. We were guided by three criteria in selecting the chapters that would be retained in print form. Our first criterion was the relevance of the material that each retains. Much has happened since this work was first published in 1999, and it would be foolish to suggest that the practices of actually *doing* GIS have also not developed and changed in recent years. Because the use of GIS is now so pervasive, it is also the case that GIS is rarely thought of as a novel solution. For this reason, we have retained the original *Applications* part of the book in the CD-ROM only. Interested readers are invited to consult the Applications boxes in our textbook (Longley, Goodchild, Maguire and Rhind 2005) for recent case studies that we think exemplify particularly new or novel characteristics of real-world applications. Our second criterion concerned the balance of this abridged edition: we wished to retain material that was representative of all of the parts and sections in all of the remaining three parts (Principles, Techniques and Management) of the original. The third criterion was the degree to which the material directly reinforces that discussed in the second edition of *Geographic Information Systems and Science* – in order to reinforce our own view that the two works can be viewed as complementary. Thus the reader will find that nearly all of the chapters included in this abridged edition are cited in the *Guides to Further Reading* that are at the chapter ends in the Longley, Goodchild, Maguire and Rhind (2005) textbook.

In most all instances, we believe that the textbook enables the full benefits of this reference work to be unlocked. In the remainder of this extended update, however, we provide some additional observations that help to update the chapters in the original. These have been provided with the very significant assistance of the authors of many of the original chapters. We are very grateful, therefore, to the following for their inputs: Prue Adler, Luc Anselin, Richard Aspinall, Kate Beard, Yvan Bédard, Tor Bernhardsen, Antonio Câmara, Heather Campbell, David Coleman, Michael Curry, Peter Dale, Bill Davenhall, Ian Dowman, Sue Elshaw Thrall, Robert Fincham, Manfred Fischer, Peter Fisher, Pip Forer, Greg Forsyth, Art Getis, Steve Guptill, Gerard Heuvelink, Ron Johnston, Russ Johnson, Menno-Jan Kraak, Werner Kuhn, Art Lange, Mary Larsgaard, Robin McLaren, Dave MacDevette, Jeff Meyers, Helena Mitasova, Nancy Obermeyer, Peter van Oosterom, John Pickles, Mark Sondheim, David Swann, Grant Thrall, David Unwin, Nigel Walters, Rob Weibel and Mike Worboys.

2 PRINCIPLES (PART ONE)

(a) Space and time in GIS

A significant proportion of the opening part of the work focuses upon the disciplinary setting of GIS. It is interesting that most of the recent handbooks and encyclopaedias on GIS pay rather less attention to issues of spatial representation and the apparent central relevance of geography to them. Indeed, whilst some (e.g., Bossler et al 2002) are undoubtedly *about* GIS as an area of activity, they prefer to use the term 'geospatial' (implying a subset of the adjective 'spatial' applied specifically to the Earth's surface and near-surface) rather than 'geographical' – particularly when referring to technologies or generic techniques.

On balance, we think this is a pity – the term 'GIS' is distinctive, widely recognised in government and business, and suggests the clear and demonstrable link to *geographical information science* (GIScience) that underlies our own view of the development of the field. We suggest that the newer term, by contrast, which fails to confer any unequivocal advantages, is likely to confuse the uninitiated and seemingly presents applications as devoid of real-world scientific context. For us, the term 'geospatial' seems to imply a preoccupation with technology and low-order data concepts, rather than the higher levels of the chain of understanding (evidence, knowledge and wisdom) that we have discussed elsewhere (Longley, Goodchild, Maguire and Rhind 2005: Section 1.2). A new term may nevertheless be attractive to some, such as those developing instruments and technologies (e.g. GPS and remote sensing) associated with academic disciplines other than geography, and new business entrants to the field that may not have track records in GIS.

The rise of the term 'geospatial' also seems to convey to some a greater sense of 'hard science' and has sometimes gone un-noticed in the discipline of Geography. In some parts of the world (but notably not the United States), it seems to us that the discipline of Geography has developed a very complacent attitude to investment in its flagship specialism: GIS is widely recognised in high schools, is central to transferable geographical skills, is key to outreach to potential new recruits to the discipline and is crucial to justification of education funding as a part laboratory-based discipline. We observe that a decreasing real share of new student recruitment, a need to recruit skilled researchers from other disciplines, and a downturn in real share of research awards are seeming consequences of such neglect.

These are concerns with GIS as an applied problem-solving technology, and are thus not the central preoccupations of Helen Couclelis (Chapter 2: *Space, time, geography*) or Ron Johnston (Chapter 3: *Geography and GIS*). But these concerns nevertheless have ramifications for the practice of Geography and the vitality of the discipline. Today, the Geography taught in many quite respectable universities largely fails systematically to address the core organizing principles that are inherent to any widely recognized definition of the subject (see also the contribution of Pip Forer and David Unwin, Chapter 54: *Enabling progress in GIS and education*). Ron Johnston observes the periodic disciplinary rumblings about the inevitable ethical inconsistency of anything that can be measured, allied with assertions that quantitative measurement is either passé, no longer practiced, or relevant only to 'thin' preliminary description of geographical problems (e.g., Cloke et al 2004). Some traditional quantitative geographers have suggested that numbers are relevant to the vitality of the discipline, in ways that scarcely begin to capitalize on the potential and achievements of GIScience (Johnston et al 2003), while some external observers remain bemused at the failure of the discipline to agree on issues of content, coherence and relevance. Meanwhile, GIS practitioners continue to respond to interest within other disciplines and remain part of the GIS success story.

Six years on, it seems odd to recall the passions that were sparked by the early debates between social theorists and GIScientists, and that were so accurately recorded in the chapter by John Pickles (Chapter 4: *Arguments, debates and dialogues: the GIS–social theory debate and the concern for alternatives*). The dialog that began with the Friday Harbor meeting in 1993, and continued through Research Initiative 19 of the National Center for Geographic Information and Analysis (NCGIA) has continued, and today it would be inconceivable that a text in GIS written by a geographer would not address the social context and social impacts of the technology. As the author writes, referring to the well-known arguments presented by C.P. Snow in the 1950s about deep divisions in society between the technological orientation of the sciences on the one hand and the more reflective orientation of the humanities on the other (Snow 1961), 'the best of our students and young faculty members working in GIS and social theory are no longer...wrapped up in the 'Two Cultures' arguments and ways of thinking.'

Recently several significant new directions have emerged in the dialog. Most conspicuous of these, perhaps, is the growing interest in actor-network theory and the work of Bruno Latour, led by such GIScientists as Chrisman, Harvey, and Schuurman. It asks, in essence, how advances in GIScience can be understood in the context of the individuals who made them, their networks of interaction, and other aspects of their social setting. What, for example, can we learn from the particular circumstances surrounding Roger Tomlinson's proposal for a Canada Geographic Information System in the 1960s (Foresman 1998), or Ian McHarg's (1995) interest in modeling planning decisions through the overlay of transparent representations of different variables? Who were they talking with in that period, and what was the nature of their relationships with others?

Pickles also notes a third recent trend: '...the convergence of discussions about information and communication technologies, public-participation GIS (PPGIS), and broader writings about representational technologies. One branch of PPGIS has to do with issues of cost, access, open source, technical assistance, user-interface design, the Web, etc. These have moved along quickly, as [we] know. Another part of this, however, is the question of agency and voice – crudely put, who acts, who decides, who designs, and who inputs?' This second area seems to Pickles to be moving much more slowly, but the questions it asks seem more important, and he anticipates increasing interest in the years to come. Issues of public participation in GIS are addressed in detail by Craig et al (2002).

Several real breakthroughs have been achieved in the past six years in the area of map generalisation. Notable among them are the work of Bader and Barrault on the application of energy-minimisation techniques from engineering physics, and the careful analysis of feature shape employed in techniques developed for road generalisation at IGN. Progress has also been made in algorithms to control the generalisation process, by exploiting optimal selections and combinations from among the host of specialized techniques that have been developed by researchers over the past two decades. Ware et al (2003) used combinatorial optimisation techniques including simulated annealing and genetic algorithms, integrating several algorithms into a comprehensive process. In the AGENT project (http://agent.ign.fr), a multi-agent system was built that is even more flexible and basically allows integrating any generalisation algorithm into a comprehensive process using a constraint-based approach (Barrault et al 2001).

Author Robert Weibel writes: 'there is an increasing demand by map and data producers, in particular public mapping agencies, to be able to automate the production process of maps and databases more thoroughly, owing to new product requirements such as data or maps for navigation and for location-based services (LBS). In response to these requirements, the leading software manufacturers have improved their products considerably in recent years, both in terms of functionality and quality. For example, Laser-Scan, which has a tradition of concentrating on the mapping market, was a partner in the AGENT project. The agent-based prototype system of AGENT has since been turned into a commercial product called Clarity. Intergraph, another software vendor with a strong presence in the mapping market, offers its own generalisation software under the name DynaGen. Even ESRI, where mapping is but one of many markets, has added more generalisation-related functions into its system in recent years. Additionally, there are smaller vendors that offer their own solutions, such as Axes Systems with the Axpand software.'

Generalisation research is no longer restricted to automation of the production of paper maps, but is moving in new directions in response to new products, technologies, and demands. The extremely constrained screen area and resolution of hand-held devices, such as cellphones, is one such area, and others include automated generalisation of three-dimensional objects such as buildings, and the creation of the multi-resolution databases that are needed in vehicle guidance systems.

By 1999 it was abundantly clear that the Internet and Web were having a profound impact on many aspects of human activity. Over the past six years since the original publication of this book, several new directions have emerged in cartographic research and practice, driven in large part by the potential of these new communication technologies. As we also comment elsewhere in this review and update, dramatic reductions in the cost of software, and simultaneous increases in power, have enabled large numbers of non-experts to engage in map-making, and to make their products freely available to others. A specific design approach has emerged, motivated by the limited bandwidth of the Internet on the one hand, and by easy access to techniques of transparency, blinking and shading on the other. The Scalable Vector Graphics (SVG) format has been adopted widely in the cartographic community, leading to increasing facility of interaction and interoperability.

'In the GIScience community', writes author Menno-Jan Kraak (Chapter 11: *Visualising spatial distributions*), 'the abundance of geospatial data has created a new role for maps in exploratory environments where they are used to stimulate (visual) thinking about geospatial patterns, relationships and trends. The context where maps like this operate is the world of *geovisualisation* (Dykes et al 2004) which can be described as a loosely bounded domain that addresses the visual exploration, analysis, synthesis and presentation of geospatial data by integrating approaches from disciplines including cartography with those from scientific visualisation, image analysis, information visualisation, exploratory data analysis and GIScience.'

(b) Data quality

Interest in representation and ontologies is also relevant to the issues of data quality and uncertainty that are inherent in them. Shi et al (2002) provide perhaps the starkest statement of this problem when they claim that 'for many types of geographical data, there is no clear concept of *truth*, so that models that address the differences between measurement and truth are clearly inappropriate' (cited by Heuvelink 2003, 817). This invites consideration of semantics (termed *discord* in Peter Fisher's Chapter 13: *Models of uncertainty in spatial data*) and how discord arises through the social construction of information (also alluded to by John Pickles in his comments, above). Peter Fisher's contribution remains a very useful framework for thinking about uncertainty in GIS. However, the Shi et al (2002) volume now provides an additional valuable and wide-ranging update on spatial data quality issues of theory, method and application, and provides evidence that we now have a much fuller and more rounded view of the sources, operation and consequences of uncertainty in GIS. This volume also demonstrates the broadening of interest that has occurred in the topic over time, and illustrates how we have moved well beyond preoccupations with uncertainty propagated in map overlay operations and statistical models for representing positional uncertainty (discussed by Howard Veregin in Chapter 12: *Data quality parameters*). Today, there is a much more established interest in visualisation and communication of uncertainty, the pitfalls of decision-making under uncertainty, and the quest to develop error-sensitive GIS.

Within the statistical perspective, Gerard Heuvelink's treatment of uncertainty (Chapter 14: *Propagation of error in spatial modelling with GIS*) remains a holistic overview of the sources and operation of quantitative attribute errors that is of enduring importance. He identifies three respects in which the methodological discussion of Chapter 14 might be updated. First, he observes that Monte Carlo simulation is very much taking over from the Taylor series approximation method and other more analytically based methods for uncertainty propagation analyses. Algorithms for stochastic simulation of spatial phenomena, he argues, have become much richer over recent years – particularly with regard to problems involving categorical spatial data and the stochastic simulation of objects. Second, and related to this, he notes progress in problems of uncertainty involving categorical spatial attributes (e.g. Kyriakidis and Duncan 2001). He observes that problems of uncertainty with categorical attributes are more difficult than their continuous-attribute counterparts. Third, he sees progress in handling error propagation arising out of positional uncertainty, as discussed by Shi et al (2002).

More generally, the recent literature provides some evidence that spatial uncertainty analysis is enjoying greater real-world professional application. However, it is the case today that uncertainty analysis remains the preserve of the GIS specialist, and that it remains a labour-intensive task. Time will tell whether uncertainty analysis and risk analysis will become more standard elements in spatial analysis.

Kate Beard and Barbara Buttenfield's contribution (Chapter 15: *Detecting and evaluating errors by graphical methods*) remains an important early graphical evaluation of uncertainty (or more specifically, errors). In 1999 it seemed that further advances in the detection and evaluation of errors by graphical methods depended on further refinement of error models. Since then, new methods and models have been developed, and a general trend is evident away from summary-level measurements, such as root-mean-square error (RMSE), toward local statistics that reflect non-stationarity. They concur with Gerard Heuvelink that greater quality assessment is now supported through use of Monte Carlo simulations to generate multiple realisations of error processes. Author Kate Beard writes 'These improvements have raised new challenges for graphic display. Finer detail in spatial variation can be more difficult to communicate and the side-by-side and sequenced graphic displays originally proposed for quality depiction are less able to support user perception and association of fine spatial variations in quality with the data distribution. With simulations the visualisation challenge is to convey effectively the uncertainty represented by large sets of possible realisations.'

Progress has been made in the development of techniques linked to specific error types and assessment contexts, and such work has become more central to the visual analysis of spatial distributions discussed in Section 1(a) above. For example, Menno-Jan Kraak (Chapter 11: *Visualising spatial distributions*) has recently described a visualisation tool for fuzzy attribute classification that uses a collection of multiple and dynamically linked visual displays including images, parallel coordinate plots, and a 3D feature space plot that users can interact with to explore the classification process. Rather than simply viewing static displays of error, this approach creates an environment for interactive exploration that potentially leads to a better understanding of uncertainty.

Gerard Heuvelink, Kate Beard and Barbara Buttenfield share a frustration that little of this research has found its way into the commercial GIS packages and into mainstream use. The need for quality assessment has if anything grown in the past few years with the explosion of Web applications and the growing availability of spatial data. While the majority of the spatial data distributed over the Web now have metadata associated with them, quality descriptions are not as complete or as useful as they might be for prospective users. Work by

Devillers et al (2002) and Bédard et al (2004) makes some progress on this front. Their work targets data-quality exploration in an interactive environment associated with a SOLAP (spatial on-line analytic processing) architecture that allows users to isolate and explore individual data-quality variables or to view data-quality metadata at several different aggregation levels from an individual data value, to object classes, to an entire data set.

(c) Spatial analysis

Spatial analysis is very much the engine that drives research applications of GIS. In technological terms, the chapters in this section assimilate many of the implications of the ongoing improvements in computer memory and processing speed, and these developments have continued to impact profoundly upon the field of GIS. The chapter by Stan Openshaw and Seraphim Alvanides (Chapter 18: *Applying geocomputation to the analysis of spatial distributions*) exemplifies an approach to spatial analysis that continues to develop using the increased power of computing: although widely applicable analytical solutions to the modifiable areal unit problem remain as elusive as ever, the geocomputational approach to zone design provides an example of the use of research techniques in spatial analysis in applied problem solving – for example, the 2001 UK Census zones were designed around some of the principles set out in Chapter 18.

The contributions to this section of the book also variously flag a number of longstanding issues about the ways in which we carry out our scientific investigations and seek to improve the kind of findings that we are able to generate. The linkage of these issues to those of spatial, temporal and cognitive representation, and to visualisation (all discussed in Section 1(a) of this book) has strengthened in recent years. This is largely because improvements in computation have facilitated greater disaggregation and a greater focus upon individuals and micro-scale events and occurrences, alongside improved representation of temporal dynamics and, in socio-economic applications, more realistic simulation of spatial behaviour.

Developments in digital data infrastructures have also fuelled interest in spatial analysis techniques that perform well using large numbers of georeferenced observations. Data-mining techniques (Miller and Han 2001) in the geocomputational paradigm provide the most obvious examples. Tremendous progress has been made in the past six years in the development and dissemination of readily accessible tools for advanced forms of spatial analysis. Luc Anselin's (Chapter 17: *Interactive techniques and exploratory spatial data analysis*) GeoDa consolidates and extends the available set of tools for exploratory spatial data analysis, local statistics and spatial regression. It has been developed through the Center for Spatially Integrated Social Science (www.csiss.org) and has been downloaded over 4,000 times. At the same time, ESRI's ArcGIS 9.0 has greatly expanded the set of tools available either as extensions or as parts of the core of this popular GIS; GeoVISTA Studio from Pennsylvania State University has become a powerful collection of open-source tools with an emphasis on visualisation (www.geovistastudio.psu.edu); and Serge Rey's STARS (Space-Time Analysis of Regional Systems; stars-py.sourceforge.net) adds another open-source package focused on statistical techniques to this rapidly growing collection.

Historically, GIS has provided a medium within which spatial analysis techniques, that often predate the innovation of GIS by decades, could be rehabilitated for real-world problem solving in data-rich environments. The pace of development is evident in the increasing recognition of the importance of space in academic disciplines outside Geography. As this rehabilitation nears its completion, the techniques that are most used are those that deliver the most in real-world applications. Thus while some of the techniques reviewed by Art Getis (Chapter 16: *Spatial statistics*) and Manfred Fischer (Chapter 19: *Spatial analysis: retrospect and prospect*) have withered in usage, others – notably Bayesian and non-parametric statistics, have become much more widely used. It is also important to note that the software environment of GIS is also leading to the development of new spatial analysis methods – geographically weighted regression (Fotheringham et al 2002) being perhaps the best example. This is an example of a technique that allows the unique characteristics of localities to be examined within what is ultimately a global statistical generalisation – this kind of statistical sensitivity to context is also illustrated by locally sensitive measures of spatial autocorrelation, such as the Ord and Getis O statistic (Ord and Getis 2001).

Finally, it is also clear that practical problems of extending theory in applied contexts and accommodating ethical concerns are becoming increasingly important: problems of ownership of data, copyright, and the limits posed by changing conceptions of ownership are changing the way we are able to share and communicate spatial information, and require ever more of spatial analysts in relation to privacy issues (see Michael Curry, Chapter 55: *Rethinking privacy in a geocoded world*).

3 TECHNIQUES (PART TWO)

(a) GIS architecture issues

As suggested above, the original edition of this book postdated the innovation of the Internet, but far-reaching changes in peer-to-peer networking (David Coleman, Chapter 22: *GIS in networked environments*) have occurred in recent years. The notion of using peer-to-peer technology and standards to access distributed spatial data holdings began attracting the attention of the GIS community in late 2000. In suggesting the scale of change that has occurred since this book was first published, David Coleman cites OECD statistics that suggest the number of Internet subscribers worldwide has more than tripled to over 300 million since 1999, and the number of those subscribers with broadband connections has increased to over 100 million over the same period. He points out that the sharing of digital data (whether as downloaded music, movies, images, games, software or geographical data) through peer-to-peer networks continues to increase at an unprecedented rate: the number of people logged on simultaneously to popular file-sharing networks approached 10 million in April 2004, a rise of 30% from the same period a year earlier.

GIS interoperability (Mark Sondheim, Kenn Gardels and Kurt Buehler, Chapter 24: *GIS interoperability*) is key to driving such data exchange. Using Open Geospatial Consortium (OGC; www.opengeospatial.org), U.S. Federal Geographic Data Committee (FGDC; www.fdgc.gov) and ISO specifications along with IT industry standards (e.g. SOAP/XML, .Net and Java), emerging Web mapping services based upon common standards are enabling users not only to access geospatial data from different servers around the world, but also to determine their fitness for a particular application, conflate (not just register) them to a common base, and then communicate the results to others. Geoportals (Maguire and Longley 2005) such as Geospatial One Stop (www.geodata.govv: see also Section 4(a) below) have become important ways of facilitating access to data (see also David Rhind, Chapter 56: *National and international geospatial data policies*). Much of this progress has been driven by developments in the wider information technology arena, and their adaptation to the special needs of GIS. For example, the success of XML (eXtensible Markup Language) has led to the development of GML (Geography Markup Language) as a GIS data transfer format; and several of the leading database management systems have added spatial capabilities, in the form of IBM DB2 Spatial Extender and Oracle Spatial, for example.

Author Mark Sondheim writes 'The Open Geospatial Consortium and related ISO (International Standards Organisation) activities have been increasingly successful in developing specifications highly relevant to GIS interoperability. The most popular of these is certainly the Web Map Service; however, Web Feature Service, Web Coverage Service, Location Based Services, Web Coordinate Transformation Service, Web Registry Service (as a profile of the OGC Catalogue Service) and others are beginning to be implemented as well. Of course GML is a key development of the OGC and integral to some of these services. It is of note that both commercial and open-source versions of some of these services are now available. This bodes well for their broader acceptance.'

An important area of GIS that we did not anticipate in 1999 is the convergence of networked GIS with communications and positioning technologies in *location-based services*. Today, GIS data and software are increasingly accessed remotely, allowing the user to move away from the desktop and hence to apply GIS anywhere – as 'distributed GIS'. Limited GIS services are already available in common mobile devices such as cell phones, and are increasingly being installed in vehicles. In the future it is clear that GIS will become both more mobile and ubiquitous, and will be based around distributed data, distributed users and distributed software (Longley, Goodchild, Maguire and Rhind 2005: 241-59). Author David Coleman notes that the number of cell phone users worldwide has almost quadrupled since this book was published in 1999;

and that many of these cell phones contain tiny Global Positioning System (GPS) receivers that allow service providers to know the location of the caller in the event of an emergency or (with user consent) to monitor his or her activity patterns. In a similar way, sensor webs are being created, composed of intelligent digital devices that exchange many kinds of information with people and other machines around them. These are creating new types of networks which will ultimately provide important sources of input to GIS and Web-mapping systems.

Distributed GIS offers enormous advantages, in reducing duplication of effort, allowing users to take advantage of remotely located data and services through simple devices, and providing ways of combining information gathered through the senses with information provided from digital sources. However, progress on a number of fronts is difficult because of complications resulting from the difficulties of interacting with devices in field settings, limitations placed on communication bandwidth and reliability, and limitations inherent in battery technology. Thus for the foreseeable future, we are likely to continue to associate GIS with the desktop, where rapid developments in software (Elshaw Thrall and Thrall, Chapter 23: *Desktop GIS software*) remain central to the development of the field.

Sue Elshaw Thrall and Grant Thrall reflect that the compounded effect of developments in desktop software has led to a bifurcation in GIS. On the one hand, specialised GIS software continues to add spatial analysis applications while, on the other, many core functions are no longer recognised as GIS *per se*. With respect to the latter, they point out that end mass-market GIS users are only rarely aware that they are using high-technology geography. Thus interactive street displays and route finders are standard fixtures in up-market automobiles; camping stores sell GPS-enabled wristwatch-like devices that use GPS and digital terrain maps for off-road route finding; joggers use similar devices as high-tech alternatives to the pedometer; and Internet mapping has become ubiquitous, through services such as mapquest.com and yell.com. Perhaps most impressive of all, Microsoft's MapPoint finds routes, calculates drive times, and interfaces with both GPS devices and standard Excel software, thereby becoming much more than geographically enabled spreadsheets. MapPoint is not yet presented as a serious contender to challenge mainstream GIS functionality: but if and when the general public becomes familiar with and expects GIS functionality, MapPoint will be there to seamlessly deliver to and interface with Microsoft Office applications.

An update of core GIS software offerings and the ways in which they may be customised (David Maguire, Chapter 25: *GIS customisation*) is provided by Longley, Goodchild, Maguire and Rhind (2005: 157-75). Proprietary geographically enabled programming languages have been replaced with integration of GIS functionality within standard programming languages such as Microsoft's Visual Basic, Visual C++, C# and Java. These development tools have assisted deployment of GIS via wireless interfaces to a range of hand-held devices, and as such have contributed to the development of location-based services. A major new development in this arena is the adoption of distributed architectures (such the .Net and Java frameworks) for implementing enterprise systems. Web services and service-oriented architectures (SOA) are the underlying technologies that sew together legacy and new systems.

A final point is that GIS software and data products are sensitive to the end uses to which they are put. Recent years have seen increasing usage of GIS in the areas of business and business geography (Thrall and Campins 2004). It is sometimes the case that such users use different spatial terminology (e.g. 'trade areas') and are reluctant to become acquainted with the established terminology of GIS. Thus GIS market development has entailed repackaging of standard offerings into business-specific application packages, such as ESRI's Business Analyst, that use novel user interfaces to guide the user through solving a business problem, rather than requiring mastery of a list of GIS functional logic.

(b) Spatial databases

Relational database technology (Mike Worboys, Chapter 26: *Relational databases and beyond*) remains and looks set to continue to be at the heart of geographical data management and analysis for the foreseeable future. Author Mike Worboys reflects that object-oriented database management systems (DBMS) have not turned out to be replacements for relational systems. Instead, he sees that the most popular model, and that implemented by the large database players, has been to incorporate object-oriented concepts in extended relational database systems. The challenges set out in Mike Worboys' chapter still remain: constraint databases remain an elusive route towards incorporating more expressive power; and the dynamic nature of the world is still not addressed by the current round of database technology (e.g. see Worboys 2005). Elsewhere more progress has been in evidence: geosensor data management suggests clear and important goals for the future of database science in the context of real-time data management; the linkage between agent-based computational models and database technology provides interesting possibilities for the management and analysis of dynamic spatial data; and event-oriented models are becoming important for the development of our ability to represent and reason about dynamic geographical phenomena.

Most of the current generation of DBMSs in commercial systems (e.g. Oracle, Informix, DB2, etc.) and open source software (e.g. PostgreSQL, MySQL) support geographical data to some degree. This represents a significant improvement on the situation when Peter van Oosterom (Chapter 27: *Spatial access methods*) prepared his contribution, although the spatial indexing methods that are supported remain limited to variants of simple grids, R-trees and quadtrees. He notes that there remain challenges to using these methods to manage a greater range of topological structures, such as linear networks and TINs, which have been responded to in part by Oracle's, LaserScan's and ESRI's commercial systems. He sees a growing areas of interest in creating methods to support 3D data within GIS and geo-DBMSs: this entails implementation of appropriate data types (e.g. polyhedra), operators (e.g. for computing volume and intersection), 3D spatial access methods and complex 3D structures (polyhedral partitions of 3D space, TINs, etc.). He also notes that progress towards the development of multi-scale spatial storage and access methods has been very limited.

The past six years have seen rapid development and adoption of the database design environments described by Yvan Bédard (Chapter 29: *Principles of spatial database analysis and design*). Modelling techniques are now generally accepted in the development of geographic databases for GIS, LBS and other position-aware applications, and several GIS products now include modelling tools. Over the past six years, UML has clearly established itself as a standard and is nowadays used on a regular basis by the GIS industry, academia and standardisation bodies like the ISO/TC-211 and OGC. A good example of this evolution is the thousands of downloads of the spatially extended UML CASE tool 'Perceptory' and its use in over 40 countries – a major increase in usage rates since the late 1990s. In the meantime, very flexible approaches to system design have emerged in reaction to the highly disciplined approaches typically represented by RUP (Rational Unified Process). These light but robust approaches, stemming from the philosophy of Extreme Programming, are described by the umbrella terms 'Agile Development' and 'Agile Modelling'. Yvan Bédard observes that numerous books describing these new approaches have appeared in the past six years, including books specifically focused upon agile database techniques. Books comparing 'heavy methods' with 'light methods' have also appeared in order to appraise users of their relative merits.

New sources and types of data may generate the need for new access methods. In particular, Peter van Oosterom identifies the need to support a basic 'point cloud' data structure, in order to manage the massive amounts of point cloud data that are now collected by laser scanning (or multi-beam sonar), and for which traditional (raster and vector) data structure access methods are not very effective.

Human interaction with GIS (Max Egenhofer and Werner Kuhn, Chapter 28: *Interacting with GIS*) is also changing in detail, if not in its fundamental nature. Author Werner Kuhn identifies a number of developments in current thinking about user interface issues. First, he observes that the user interface of many applications is now a Web browser, or at least is being accessed through one. This has generally improved the possibility of transferring knowledge from one application to another (and thereby the usability of both). Second, Web interfaces have also led to an increased emphasis on the use of remote services in preference to locally installed functions. This has had the effect of vastly simplifying the functionality of GIS. Third, the range of devices and their user interfaces has broadened: some of the most challenging user-interface problems are now those of small, mobile devices such as cellphones (see the discussion of location-based services in Section 2(a) above). Fourth (and also echoing David Coleman's comments in Section 2(a) above), user interaction is increasingly becoming implicit, as more and more information about users becomes available through sensors, including the determination of user location. Fifth, 'clickable' maps and other forms of dynamic user interaction are now commonplace. And sixth, interactive visualisation of 3D and 4D data remains generally awkward and confined to research prototypes.

(c) Technical aspects of GIS data collection

There have been significant developments in the image data available for use in GIS, subsequent to the publication of Ian Dowman's chapter (Chapter 31: *Encoding and validating data from maps and images*). He observes that not only has photogrammetry moved into the digital age, but a number of new and important satellite sensors have come into service (e.g. see Donnay et al 2001). Digital photogrammetric workstations were available at the time that this book was originally published, but these have now become standard for photogrammetric map production in most developed countries. In very recent years digital airborne cameras have reached the market and are already making an impact by cutting out film processing and extending the range of conditions under which photography can be obtained. Ian Dowman notes that airborne LiDAR and interferometric synthetic aperture radar (SAR) are now used for directly generating digital elevation models (DEMs) and have allowed dense networks of accurate elevation points to be obtained for applications such as 3D city models and flood prediction and management. High-resolution optical sensors on satellites, with pixel sizes of 0.6m, are now available, thus extending the accuracy of images available from space (cf. Mike Barnsley, Chapter 32: *Digital remotely-sensed data and their characteristics* and Chapter 48: Jack Estes and Tom Loveland: *Characteristics, sources, and management of remotely-sensed data*). More DEMs are now available using data from space sensors, the most notable being a near-global DEM at 90m spacing and 10m vertical accuracy from the Shuttle Radar Topography Mission (SRTM); these data are freely available over the Internet.

While there have been a number of technical improvements in Global Positioning System equipment, the basic technology fundamentally remains the same (Art Lange and Chuck Gilbert, Chapter 33: *Using GPS for GIS data capture*). Art Lange observes that there are now more and better sources of differential correction such as the Federal Aviation Administration's Wide Area Augmentation System (WAAS) and its counterpart in Europe and Japan. Virtual Reference Station (VRS) networks are another new source of differential correction being implemented across Europe and more recently in select areas within the United States. The appeal of VRS technology is easy to understand: a mobile GIS user equipped with a standard mapping-grade GPS unit connected to a cell phone with data transfer capability can routinely collect location data with sub-meter accuracy – without assistance from a dedicated receiver used as a base station. More importantly, differential correction is constant within the VRS network area. There is no degradation of correction accuracy as the user moves away from the differential signal source.

Art Lange anticipates that within the next few years, a new generation of GPS satellites will be launched with improved access to the L2 Civilian (L2C) signal (the 'second frequency'). This will lead to improved measurement accuracy by removing some of the errors associated with atmospheric GPS signal distortion. The general trend of GPS receivers for GIS applications has been to provide greater accuracy and more user-friendly features at a generally lower cost. The widespread availability of consumer-grade GPS receivers with built-in large map data bases has changed the way many non-GIS professionals depend upon, and are affected by, the accuracy of the coordinates in GIS databases. GIS software for processing field-collected data has continued to evolve – for example, the GPS extensions to ArcGIS and ArcPad, which make the process of transferring field-collected GPS/GIS data to the user's database a seamless operation.

While GPS-enabled devices have opened the door for location-based technologies, the emergence of Wi-Fi-based systems promises to bring the same location-tracking services indoors to hospitals, warehouses and large industrial complexes. Creating what has been sometimes called 'the Internet of Things' or 'indoor GIS', these systems are being used to track moveable assets, such as machines, merchandise, animals, and even people carrying or wearing a new generation of tiny RFID (Radio Frequency Identification) tags which will store important attribute information about the object or wearer of the tag.

Here once again, the potential of these systems also highlights the important growing debate over what constitutes 'appropriate' access to personal data and a person's current location (see Chapter 55, Michael Curry: *Rethinking privacy in a geocoded world*).

(d) Data transformation and linkage

Spatial interpolation continues to be a vitally important part of GIS functionality, and the set of tools has matured significantly over the past six years. Increasingly, spatial interpolation services are being offered remotely over the Web, as the field of scientific computing moves to a more integrated view of how standard operations are packaged and made available.

The most dramatic recent development has been the increase in the size of the datasets that require spatial interpolation or approximation. New mapping technologies, such as LiDAR, real-time kinematic GPS, and automated sensors have made data acquisition orders of magnitude more efficient. However, data processing and analysis often lags behind data acquisition – for example, millions of georeferenced points can be measured by LiDAR within a single hour but it takes much longer to produce a bare-Earth digital elevation model. The properties of data produced by automated technologies also require smoothing of noise and, as a result, spatial approximation rather than exact interpolation has become increasingly important.

While the principles of the most commonly used methods (Kriging, splines, inverse distance weighting, nearest neighbour, triangulated irregular network) remain the same, their implementation has become more robust and better adapted to data heterogeneity, noise and large datasets. Research into model-based interpolation continues and is being used for specialised applications (meteorology, topography, groundwater). A fully automated methodology that would select the most appropriate method and optimise its parameters for a given dataset and application is still not available. However, the tools that help to select a suitable method (geostatistical analysis, visualisation, etc.) have improved significantly. Nevertheless, writes author Helena Mitasova, 'spatial interpolation and approximation remain a challenging task for many GIS users that requires a solid understanding of available methods and modelled phenomena.'

Author Antonio Câmara sees four main trends underlying the integration of GIS and virtual environments over the past six years. First, the promise of immersive systems largely failed to deliver, and the field remains dominated by non-immersive desktop solutions. These benefit from the development of an extension to VRML (Virtual Reality Markup Language) known as GeoVRML, which provides the capability to browse multi-resolution, tiled data that are streamed over the Web (Reddy et al 1999, 2001). Second, interoperability efforts, such as those promoted by the Open GeoSpatial Consortium (www.opengeospatial.org), are also facilitating the integration of GIS with virtual environments. SRI International is in the implementation phase of an OGC Web Map Service (WMS) capable of generating GeoVRML output.

Third, improved representations of virtual terrains have become possible thanks to new techniques of detail management and multi-resolution modeling of geographical data. The work of Losasso and Hoppe (2004) and Cignoni et al (2003) on interactive rendering of large-sized textured terrain surfaces is worth mentioning. Finally, mobility is a new trend in GIS due to the emergence of the wireless Internet and the availability of communication-enabled mobile devices. Romao et al (2003) discuss the promise of location-based augmented reality services, where three-dimensional synthetic images from databases are superimposed on real images in mobile devices.

Many of the issues of emerging data infrastructures, provision and access that are raised by Mike Goodchild and Paul Longley (Chapter 40: *The future of GIS and spatial analysis*) are becoming still more significant with the gradual maturation of advanced information economies. They observe that this is particularly apparent in the socio-economic realm, where small-area geodemographic measures of social and economic conditions are becoming key to GIS-based models of resource allocation. Current research in geodemographics illustrates the interdependences between classification method, variable selection and data source when devising classifications that work in the real world. They reiterate the point already made several times above that, in measurement terms, more data are collected about more aspects of our individual lifestyles than at any point in the past, through routine interactions between humans and machines. They see enlightened approaches to public and academic data access (e.g. through geoportals: Maguire and Longley 2005) as key to making wide dissemination of socio-economic data a reality, and making possible an open debate about the remit and potential of social measurement at neighbourhood scales. Geodemographic systems based on framework socio-economic data can be successfully 'fused' to census sources to provide richer depictions of lifestyles – yet lifestyles data sources are usually not scientific in collection and require reconsideration of the practices of science in the ways identified in Chapter 40. If this can be successfully undertaken, the toolkit of spatial analysis in GIS now makes it easier than ever before to match diverse data sources and accommodate the uncertainties created by scale and aggregation effects.

4 MANAGEMENT (PART THREE)

As in most other things, the GIS world of 2005 is a rather different place to that of 1999 when the original version of this book was published. Before we discuss what has changed in the world of GIS, we first rehearse (very briefly) the external factors which impact on our subject matter and which differ from those of 1999.

(a) The changing context

One factor is common to the drivers for change noted in the Principles and Techniques section. The continuing evolution of information technology has been rapid. This has had some direct effects and many indirect ones. The growth of storage capacity – typically around 20GB in 1999 and around 100GB now – exemplifies the more/smaller/faster trend which enables software functionality and applications that were hitherto impossible to become commonplace. The most obvious change is in regard to location-based services (LBS) which have penetrated both consumer cellphone and industrial and military tracking markets. The dramatic growth in broadband uptake and Internet bandwidth has also fuelled the interest in such geographic Web services.

Aside from the technology, the most obvious change of GIS drivers is that governments and their leaders have changed. Nowhere has this been more important than in the USA, the largest individual 'engine' of GIS. The replacement of Clinton and Gore by Bush and Cheney resulted in a loss of overt support for GIS based on the former administration's seemingly altruistic approach – this was the underpinning of the 1994 Presidential Executive Order which triggered the US National Spatial Data Infrastructure. Yet federal government support in the USA has not died: rather it has been transformed into something driven by the two imperatives of getting more efficient government and Homeland Security issues (see below). Like many other governments, the US federal one has launched an e-government initiative to enhance efficiency and service to the citizens, with one of the initial batch of projects being a GIS metadata service: the Geospatial One Stop initiative (see Section 3(a) above and Box 20.6 in Longley, Goodchild, Maguire and Rhind 2005) builds upon much of the work described by Guptill (Chapter 49: *Metadata and data catalogues*). Underpinning the present situation is that metadata standards have continued to evolve as they have made their way through the various national and international standards bodies. While this has helped in the syntax and coding of metadata, the underlying content has remained pretty much intact. As more diverse user groups have reviewed the metadata standards they have added elements of value to their specialty. As a general result, the number of possible data elements has grown quite considerably. The major difficulty was, and continues to be, that very few parties are willing to fully populate both the 'mandatory' and 'optional' fields. Mandatory fields are usually reduced to the equivalent of 'title, author, date' and are usually populated. Since many other fields are optional and left unfilled, any third party data user is left unaware as to the value of the data and its fitness for particular uses. The only way out of this problem is if GIS software becomes a lot smarter and automatically encodes more fields of metadata.

The number of catalogues has continued to grow but there is as yet no good catalogue of catalogues. Thus much surfing is still required to discover what is needed (or if it exists). The user interfaces for the catalogues are also different, creating a learning curve for novice users. Private sector sites have emerged which point to their products and the products of their partners. Some of the products are repackaged government data sets. This can cause some user confusion.

More generally, whilst the formal policies of national governments described in Rhind (Chapter 56: *National and international geospatial data policies*) have not changed dramatically, some blurring has occurred at the edges, some potentially important international agreements have been launched (see Longley, Goodchild, Maguire and Rhind 2005, Chapter 20) and the advent of commercial suppliers has rendered the practical import of some policies much more limited: government matters less in GIS than it did. Perhaps because of this, the nature of the National Map is evolving rather differently in many countries (see, for instance, Longley, Goodchild, Maguire and Rhind 2005, Section 19.3) – most dramatically between the USA and the UK.

The 'new world order' has transformed many aspects of our world since 1999 and impacted on GIS. The growth of terrorism, notably manifested in the events of 9/11 in the USA but replicated in many ways in other countries as far afield as Colombia, India and Russia, has triggered a renewed focus on 'homeland security' and military campaigns such as those in Afghanistan and Iraq. Immediately after 9/11 there was a flurry of activity in removing GI from Websites so as to minimise aid to terrorists; after various studies it was concluded that this was not really necessary (see Baker et al 2004). But, more generally, GIS is clearly relevant to homeland security issues. We can think of five stages in any major disaster, natural or man-made. They are:

- Risk assessment
- Preparedness
- Mitigation
- Response
- Recovery

It is now widely accepted that each of these inherently involves use of geographic information and GIS. Equally, some parts of all of these stages involve human judgement, understanding of the characteristics of other organisations as well as of data and a clear understanding of what needs to be done for the greater good – and a strong code of ethics. The consequences for those in GIS of terrorism acts and of natural disasters alike (like the South East Asia tsunami disaster of December 2004) has been a further impetus to the development of hardware and software, including sensing platforms ranging from aircraft a few centimetres across to commercial satellite imaging (supplied to the military, the 'anchor customers') with resolutions as great as 60cm (and getting still finer – 40cm is predicted by 2007).

But the consequences of the changed geopolitical situation are not all those of Homeland Security. The addition of a further 10 countries to the European Union, now an entity with 450 million people, creates a formidably large trading bloc and one which is determined to become a major player in high technology and its uses; GIS is part of this, the European Union proposing far-reaching plans for a new GI directive.

In one sense a 'counterbalance' to terrorism and homeland security is the use of GIS to support humanitarian efforts arising both from natural and human causes. Both in-field hand-held mobile GIS and office-based systems have been used to great effect during such crises – the former to collect data about safety, infrastructure damage, disease, for example, and the latter to plan missions such as food drops, and temporary hospital locations, as well as to brief executives and members of the press. Rapid access to current data can help save lives and reduce human suffering.

It is not only military concerns and homeland security issues that have become global. Global science has come of age. Concerns with 'big issues', such as climate change and global warming and dimming, have become widespread. Models of past and projected changes to our habitat have typically used GIS: the geographical manifestations of any changes have become highly charged political issues. And natural disasters – such as the South East Asia tsunami but also many others – have forced a need for much-improved monitoring and early warning tools in which GIS has a key role to play.

(b) The results

Over the past few years we have seen a maturing recognition of the potential of GIS in its original heartland (North America, some parts of Western Europe and Australasia) but also in the emerging economies of Asia, Europe and Latin America. We have estimated (Longley, Goodchild, Maguire and Rhind 2005) that the likely number of active GIS professional users must be well over two million people world-wide. At least double that number of individuals will have had some direct experience of GIS and perhaps an order of magnitude more people (i.e. well over 10 million) will have heard about it (e.g. through such events as GIS Day). Yet more will – sometimes unknowingly – have used elementary GIS capabilities in passive Web services such as local mapping. We estimated that, in 2004, the total global expenditure caused by the use of GIS could not be less that $20 to $25 billion annually; the sum is not precisely knowable and is partly dependent on how we define GIS – but it is large and continuing to grow every year. One indicator of this growth is the numbers attending software conferences: that hosted by ESRI has seen numbers grow from a start of 23 attendees in 1982 to 12,000+ in 2004. Even if we take our highest estimate (10 million globally) of those having had some experience of GIS, this still means that only one person in 600 on Earth falls in this category. Clearly there is still a long way to go! Part of this growth has come about by a spread of the same type of applications worldwide and part from innovative applications. Section 5 describes how these have expanded and diversified.

The GIS industry has also become more mature. This is manifested in various ways. There is now widespread international agreement on the use of standards of various kinds, on mainstream functionality and even the terminology used – with one exception (see below). The growth of the commercial elements in GIS – software, system integration, consultancy, data provision, etc. – has become global and has led to some consolidation. The US hegemony is being challenged: for example, the data and services company Tele-Atlas of the Netherlands purchased its equivalent, GDT of the USA.

In becoming more mature, the industry has become more commercial. We now know much more about the business of selling data and services based upon sound economic principles (see for instance, Box 19.10 in Longley, Goodchild, Maguire and Rhind 2005 or Shapiro and Varian 1999). We have already identified the ease with which global monitoring by commercial satellite and data-serving organisations is carried out. To an extent, GIS has become democratised: mapping is now produced more frequently by individuals via the Web than by national mapping organisations and the underlying service is funded by advertising – a dramatic change to the situation of a few years ago. The early work described by Shiffer (Chapter 52: *Managing public discourse: towards the augmentation of GIS with multimedia*) has become much more commonplace and public participation in GIS (PPGIS) has blossomed with the fall of GIS software costs and the spread of GIS skills (see Box 20.2 in Longley, Goodchild, Maguire and Rhind 2005).

Although business applications of GIS have not developed at the rate anticipated when this book was first published (see the comments of Sue Elshaw Thrall and Grant Thrall in Section 3 above), there have nevertheless been three sustained developments in the area described by Mark Birkin, Graham Clarke and Martin Clarke in the book (Chapter 51: *GIS for business and service planning*). First, businesses have continued to create ever-increasing volumes of data about their operations, customer behaviour, and competitive environment (e.g. through loyalty cards, lifestyle data, stock control systems, etc). Many of these data are spatially referenced with respect to the points of delivery and of consumption. However, Mark Birkin, Graham Clarke and Martin Clarke suggest that there 'is as yet little evidence that retail and service businesses are able to determine key actions based on this information, for example in the optimisation of product mix or network configuration.' In their view, off-the-shelf GIS packages offer appropriate components for operations such as like spatial interaction modelling, but still lack the flexibility and sophistication required to support business decision-making, especially at the strategic level. Second, some of the increasing interest in spatial decision support systems (e.g. Geertman and Stillwell, 2002) has been directed at business applications, though this area of activity remains small relative to environment and physical planning applications. Third, there has been interest in new modelling techniques such as intelligent agents and cellular automata (see Longley and Batty 2003). Here again, however, the emphasis has not been upon the tactical or strategic needs of business, or upon activity patterns and spatial behaviour, but rather has addressed more general problems of urban form and structure. There has, however, been an upsurge in interest in the use of geodemographics (a tool traditionally focused upon business applications) to issues of efficiency and effectiveness of *public* service delivery, and these are addressed in the update on Tony Yeh's contribution (Chapter 62: *Urban planning and GIS*) in Section 5(a) below.

In general, the capabilities of GIS to profile entire populations of a country (or beyond), grouping those millions of individuals on the basis of their inferred (e.g. purchasing) characteristics, has created commercially valuable knowledge. But this has a downside. The black forebodings about the capacity of the technology to destroy privacy expressed by Michael Curry (Chapter 55: *Rethinking privacy in a geocoded world*) have more than come to pass. Knowing where people are at any moment clearly has some benefits – e.g. if someone is being attacked and calls for help, the emergency can be targeted effectively in real time. But combining this with a detailed or inferred knowledge of a variety of the victim's characteristics – and potentially producing a cradle-to-grave narrative of an individual's life poses real challenges for the sort of society we wish to be. Curry has gone so far as to suggest that the impact of homeland security and the developments in locational technology mean that we have returned in some senses to the 1960s and 1970s. He argues that whilst in the 1980s and 1990s it was widely believed that business was the most significant threat to individuals' rights to privacy and autonomy, the more significant threat now appears to arise from government.

If the technology and practical experience of designing, selecting and using GIS has come some way since 1999, the legal aspects remain complex. The law touches everything. During a career in GIS, we may have to deal with several manifestations of the law. These could include copyright and other intellectual property rights (IPR), data protection laws, public access issues enabled (e.g.) through Freedom of Information Acts (FOIA), and legal liability issues. But since laws of various sorts have several roles – to regulate and incentivise the behavior of citizens and to help resolve disputes and protect the individual citizen – almost all aspects of the operations of organizations and individuals are steered or constrained by them. One complication in areas such as GIS is that the law is always doomed to trail behind the development of new technology; laws only get enacted after (sometimes long after) a technology appears. All those using GIS need to be aware that, whilst commerce is global, law – for the most part – is not. In essence, there is a geography of the law, the legal framework varying from country to country. The creation, maintenance and dissemination of 'official' (government-produced) geographic information are strongly influenced by national laws and practice. The best recent overall summary of this is Cho (2005).

The management of GIS has also come some way: chapters by Bernhardsen (Chapter 41: *Choosing a GIS*), by Obermeyer (Chapter 42: *Measuring the benefits and costs of a GIS*) and Sugarbaker (Chapter 43: *Managing an operational GIS*) still contain much of value. But since 1999 much focus has been put on 'interoperability' and the concept of spatial data infrastructures (SDI). These two topics have given a new dimension to the process of choosing a GIS. They are technically based on the development of standards created by ISO and OGC, such as the geography markup language (GML) and the Web map service (WMS). These technical developments are discussed in Section 3(a) above. The driving force is the user's requirements for access to data, and thus to increase the social benefit of data collected with only minor increase in the costs. Any organisation producing georeferenced data, and which is in the process of choosing a GIS, should now choose a system not only on the basis of their internal user requirements, but should seek to integrate their own new system in the regional or national spatial data infrastructure. Our understanding of how to assess costs and projected benefits of systems has also improved considerably (see Thomas and Ospina 2004 and Tomlinson 2003). There are, for instance, far more examples of real-world benefit-cost analyses for GIS implementations than there were in 1999; good examples include the 'best-GIS' ESPRIT-ESSI Project n.21.580 at http://www.gisig.it/best-gis/Guides/chapter9/nine.htm or that written by Darlene Wilcox at http://www.geoplace.com/gw/2000/0200/0200wlcx.asp.

Given the much-enhanced commercial interest in GIS and GI, it is no great surprise to find that university departments outside the traditional ones of geography and surveying are now beginning to teach and research in our subject area. The highest-ranked business school world-wide on many occasions in the past decade has been the Wharton School of the University of Pennsylvania. It now has a senior member of staff working in GIS and this trend is being followed elsewhere.

All this begs the question of what is needed and what is changing in GIS education. In truth, we know relatively little about the backgrounds of many people who are active GIS practitioners since some at least seem to have become 'accidental geographers', drawn into GIS by the need to carry out spatial operations in their own, original, field of endeavour. What they felt they needed is therefore less than crystal-clear. Traditionally, however, much education in GIS has really been training, especially in how to use a particular set of software tools (see Forer and Unwin's Chapter 54: *Enabling progress in GIS and education*). Forer has argued that we 'may be producing a range of people who have a simple tool for simple problems, and aren't impatient with the tool or aware of its multiple limitations'. Unwin, on the other hand, has claimed that four developments have occurred since 1999 in GIS and education:

- The development of several Web-based distance learning courses. This, he argues, says more about universities' needs to expand their market in general than it does about GIS;
- A near universal concentration on GIScience as opposed to GISystems, though training remains a thriving industry;
- Greatly increased teaching of GIScience in contexts other than academic geography. Mainly this seems to be in applications areas such as archaeology and environmental science and management rather than computer science.
- A divergence in trajectories between the US and UK. In the US, geography has done well out of embracing GIScience, which has been the spearhead of a very substantial revival in the discipline's fortunes throughout education. This is not so in the UK where, despite the best efforts of many people, it has not been greatly used in an 'embedded' mode, to teach about other parts of the discipline (see also the comments on Ron Johnston's Chapter 3: *Geography and GIS*, in Section 2(a) above).

Given all this and since the world of applications has spread ever-wider, surely the old approaches are no longer appropriate and new core competences are needed? To maximise the utility of GIS, we see the need for education offerings in GIS and GI-related areas to extend beyond the ambit of commercial firms and universities. We see the need for some GIS education to be much more sophisticated in relation to critical theory and its application to understand the downsides as well as the upsides of GIS and to help understand how it is changing some aspects of society. We therefore conjecture the need for GIS education now to include:

- Entrepreneurial skill development and leadership
- The principles of geographical science
- Understanding of and familiarity with GIS technologies
- Understanding of organisations
- Finance, investment criteria and risk management
- Human resources policies and practice and ethics relating to use of GIS
- Legal constraints to local operations
- Cultural differences between disciplines
- Awareness of international differences in culture, legal practice and policy priorities
- Formal management training, including staff development, team working using GIS, and presentational and analytic skills
- Attempts to embed GIS and GIScience in the mainstream of the academic discipline of geography as well as other disciplines

Clearly not all courses and learning needs to include all of this material and some of it is not best learned from courses. Some elements will be particularly relevant to those engaged (as all professionals should be) in continuing professional development. The introduction of local legal, cultural and application-related elements to GIS courses – as well as buttressing the global technical, business and management issues – will be to the benefit of GIS practitioners, the discipline and business (used in a wide sense) alike.

One characteristic which has become ever more commonplace is the role of GIS partnerships. These now operate at all levels, ranging from the very local (e.g. where lobby groups share resources and pool skills to produce maps to illustrate threats), to the continental (like the Permanent GIS Committee comprising 55 countries in Asia) to the global. They also range from the informal through to those defined via international treaty obligations, with commercial partnerships being somewhere in the middle. The most common manifestation of these partnerships is a national spatial data infrastructure: some 39 countries are now said to have one though what really is happening on the ground is somewhat variable. How partnerships are best made to work in an era of Homeland Security, where safeguarding access to information is seen by some as crucial, is not immediately clear.

5 APPLICATIONS (PART FOUR)

In the Introduction to the Applications section in the book we classified GIS applications as traditional, developing and new. Traditional applications include military, government, education, utilities and also natural resources. In the last six years these traditional areas have continued to prosper and still constitute the lion's share of GIS application activity and revenue. The US National Geospatial-Intelligence Agency (NGA) continues to be the largest single spender on GIS in the world. The developing applications of the mid-1990s involved general business uses such as banking and financial services, transportation logistics, real estate and market analysis. Consistent with Sue Elshaw Thrall and Grant Thrall's comments in Section 3 above, we observe that in the ensuing years these applications have not made the progress we had expected. In part this is a manifestation of the downturn in the US economy in the early 2000s (its stock market has yet to regain its all time high of early 2000), but other contributory factors include commercial company inertia, an inability for GIS vendors and consultants to simplify the technology, and a poor presentation of the business case. Nonetheless, there are notable showcase examples of GIS in business, such as home delivery of electrical goods at Sears in the USA, reinsurance risk modelling by PartnerRe in Europe and, at a more local scale, direct marketing to banking customers by Arrowhead Credit Union, California (Thomas and Ospina 2004). Back in 1999 we hypothesized that small office/home office (SOHO) and personal or consumer applications would represent the next wave of new GIS applications. While we were incorrect in our SOHO prediction we were on target with our suggestion about personal/consumer applications. There has been rapid growth in interest in location-based services. Some things that we did not foresee in 1999 included growth in interest in homeland security, in geoportals and in spatial data infrastructures (SDIs: Maguire and Longley 2005). It was the events of September 11, 2001 that put the term 'homeland security' into common parlance. The interest and funding for homeland security geographic information infrastructure projects has helped propel the rather stagnant SDI community into the modern era (see Section 4).

Looking forward we envision a bright future for hand-held and mobile GIS applications, as well as development of a new field that may be characterized as 'indoor GIS'. The latter is concerned with the location and movement of resources within buildings. Using RFID (radio frequency identification) tags (see Section 3(c) above) and other technologies it is possible to monitor the movement of people, and other inanimate resources, around buildings. This has many implications for security and for facility and resource management.

(a) Operational applications

In the new millennium GIS continues to be used to even greater effect in operational application areas. There can scarcely be a government in the world that does not use GIS either directly or indirectly in one way, shape or form for managing its assets, be they land and property parcels and easements, road/street/highway networks, or information about citizens (Tony Yeh, Chapter 62: *Urban planning and GIS*). GIS has played a central role in many of the big digital/electronic government initiatives of the past few years (Curtain et al 2004; Greene 2001; Song 2003). A similar picture can be painted for utilities (Jeff Meyers, Chapter 57: *GIS in the utilities;* Caroline Fry, Chapter 58: *GIS in telecommunications*) where GIS is extending from core network maintenance and mapping applications to a plurality of applications such as tree trimming, customer recruitment and retention, environmental management, pipeline routing, mobile workforce management, and transportation logistics. There is also a trend toward integrating GIS with other existing enterprise applications such as network optimization, SCADA (Supervisory Control and Data Acquisition), CRM (Customer Relationship Management) and ERP (Enterprise Resource Planning) systems. After a period of rapid expansion, the telecommunications industry is now in a period of stability, and consolidation is the order of the day in most geographies.

In Jeff Meyers' opinion, two major and related changes have driven the utility GIS industry in the past five years. First, GIS has become mainstream Information Technology (IT). This change began with the ability to store the geometry (spatial characteristics) of features in garden-variety, open relational database management systems. Partly enabled by improved server and network performance, the open storage of GIS features brought GIS into the fold of IT within utilities, initially encouraging and then demanding that IT professionals review platform requirements in the context of corporate standards. The standard technology trend continued with the development of core GIS tools written with standard programming languages. As programming standards emerged within the IT industry, GIS vendors (for the most part) adopted those standards, making GIS implementation and extension using standard programming languages possible.

The implications of standard technology are many. Among the most important, open GIS technology has reduced the barriers to IT acceptance within the utility organisation, and provided a means for more standard IT support. Software engineers and computer scientists with standard education can now be utilized as resources in GIS. Through data storage in non-proprietary formats, management can confidently invest in GIS to manage assets more effectively, without the fear that data might become obsolete or be costly to migrate from one proprietary format to another. Standard technology has led to integration of GIS within the backbone IT of the enterprise, sharing data and even function between core IT systems through standard interface techniques. In this respect, open GIS technology has drastically reduced the life-cycle cost of spatially enabled systems. And, perhaps most significantly, the availability of GIS technology based on computing industry standards has changed the debate about vendor selection from a preference-based choice between proprietary platforms to a focused decision based on business benefit and feature function.

The adoption of open, standard GIS technology has been a key driver in the second key change in utility GIS. As predicted and planned by industry experts and observers, utilities have moved GIS from a departmental tool to an enterprise solution. Enabled by standard technology, and driven by competitive factors within the energy industry, many of the best performing companies in the utility industry today use GIS as an everyday tool for asset management, work design, and outage management. Through the integration of disparate data sources about network assets, utilities use GIS today as an everyday resource for managing assets and communicating change across enterprises that serve large geographic areas. Additionally, standard computing technology has enabled the development of focused end-user GIS applications that allow business people to interact with data about customers and assets in a spatial context without becoming 'GIS experts'. End user GIS tools that solve business problems lead to the demand for more and more functionality. And since they can easily be supported through standard development environments, GIS core teams are happy to oblige with more development, which in turn leads to demands for more data and function, and the enterprise cycle sustains itself.

In terms of new GIS developments in transportation, Nigel Waters (Chapter 59: *Transportation GIS: GIS-T*) draws attention to Simon Lewis' lists of GIS-T 10 accomplishments and 10 challenges for the future (http://www.gis-t.org/yr2003/gist2003sessions/gist2003session5.htm). The accomplishments are largely technological while the challenges for the future relate to concepts and frameworks, people and institutions. Others besides Lewis have their own lists (e.g. Fletcher 2003; http://www.gis-t.org/yr2003/gist2003sessions/gist2003session4.htm). Looking forward Waters believes that there is an ongoing need for GIS-T Science integration, temporal modelling of transportation data, integration of web-based modelling, a new data model, markup language and data standards, and greater public participation in GIS-T (for more discussion see: http://esri.com/industries/federal/gis-business/transportation2.html). Waters' chapter on GIS-T discussed some of the pioneering attempts at integrating GIS-T and Intelligent Transportation Systems. This discussion concentrated on work being carried out on the ROMANSE project at Southampton, UK, and other parts of the European Community (http://www.romanse.org.uk). The field has moved forward since then but perhaps more slowly than might have been expected. This is especially true in Canada where a report by Transport Canada and Intergraph has detailed the problems and challenges of integrating ITS and GIS-T (http://www.its-sti.gc.ca/en/downloads/execsum/tp13224e.htm). The three main difficulties outlined in this report are the cost-recovery pricing policies of the Canadian Government and Statistics Canada, the lack of public-private partnerships (one of the great strengths of the ROMANSE project) and the lack of government involvement (another strength of ROMANSE). The UK government, like its Canadian counterpart, also implements punitive cost recovery policies, while the US remains one of the few countries where this is not the case. Thus it is in the US that GIS-T and ITS integration is likely to take off in the coming years. Key new works in this field include Lang's review of applications (Lang

1999) and Miller and Shaw (2001) that describes GIS-T principles and applications.

GIS provides the core organising framework for emergency management (Tom Cova, Chapter 60: *GIS in emergency management*). Today emergency management activities are focused on three primary objectives: protecting life, property and the environment. All phases of emergency management depend on geographic information from a variety of sources. The use of GIS ranges from displaying the effects of events, to managing the actual incidents themselves at command posts or emergency operations centres. GIS is the only tool capable of providing a common operating picture for emergency management, planning, response and recovery. State of the art emergency management centres allow managers to fuse real time GIS data (pertaining to the area affected or threatened by an event) with fixed or static GIS infrastructure data. This provides users with dynamic 'actionable information' in near real time. This information can be further enhanced within a GIS with event modelling tools and by importing real time weather data. With these tools, emergency managers can close roads, order evacuations, and route public safety responders efficiently and accurately. Radke et al (2000) review the application challenges for GIScience and their implications for research, education, and policy for risk assessment, emergency preparedness and response.

The awareness of the benefits of good land administration has grown over the last five years according to Peter Dale and Robin McLaren (*GIS in Land Administration,* Chapter 61), in part because of the better understanding of the role of land in poverty reduction. As a World Bank Policy Research Report states (World Bank 2003) 'Land Policies are of fundamental importance to sustainable growth, good governance, and the well-being of and economic opportunities open to rural and urban dwellers – particularly poor people'. De Soto (2000) has argued that open, efficient and enforceable property rights could release trillions of dollars of 'dead capital' in poor countries.

The recognition of the need for greater openness with regard to property rights has led to increasing opportunities to exploit land-related data. This has become possible as a result of technological developments both with regard to networking and also through the use of GIS as a data analysis tool – in addition to its established roles in creating and maintaining cadastral maps. Most countries are introducing computerized systems for handling their land administration data and some are now making these data available across networks in moves towards full electronic conveyancing, supported by e-signatures. In Europe, for example, all countries have computerized systems and the development emphasis has shifted from 'design and build' to 'sustain and maintain'. There are also moves through the European Union Land Information Service (EULIS) to exploit data across national boundaries so that all European countries might participate in a pan-European land market. Conveyancing is increasingly being perceived as an integral part of e-government initiatives and this service is being delivered by governments alongside other 'life events', such as the registration of births, companies, marriages and deaths, using 'citizen accounts'.

The money to pay for the upgrade of hardware and software systems has to come either from government or from charges for products and services. To achieve the latter, the agencies delivering land administration services must operate on a business basis and although they may not be run for profit, they are increasingly being asked to recover all their operating costs. While this is relatively easy for those handling text data, such as computerized versions of old deeds and paper documents, it still remains a problem for many mapping agencies whose costs are not so easy to recover.

What started as a question of how to fund the purchase of new equipment has led to a fundamental change in the culture of land administration agencies, making them much more customer focused and conscious of the costs of their operations. In addition it is leading to a reappraisal of the role of the private sector in land administration and the creation of various forms of public-private partnerships. Ultimately, in many countries the risk remains with the central government, but the delivery of various services now involves a wider range of stakeholders and is based on greater exploitation of the data that are now available. Many countries now provide information services to a wide range of stakeholders, including financial services, taxation agencies, economic development agencies, police, estate agents and the citizen, within the constraints of their legislative frameworks for access to information. Open access to Land Administration information is sowing the seeds for the introduction of participatory democracy.

These various developments are relevant to the use of GIS in planning (Tony Yeh, Chapter 62: *Urban planning and GIS*), where it has established roles in development control and general administration. The more strategic use of GIS in plan making has been explored by Benenson and Torrens (2004), particularly with regard to the development of applications of cellular automata. Yeh's discussion makes little mention of the use of GIS to plan expenditure on services that is incurred at the local level: recent years have seen increasing interest in the use of *geodemographics* (Harris et al 2005; Longley 2005) to understand and prescribe local spatial patterns of resource expenditure in policing, health and education. The greatly increased use of GIS in policing is discussed in detail by Chainey and Ratcliffe (2005).

David Swann observes that the last five years have seen an acceptance that GIS provides critical infrastructure for defence and intelligence (Chapter 63: *Military applications of GIS*). There has been a very swift deployment of commercial-off-the-shelf (COTS) GIS throughout the defence sector, representing a considerable advance from previous niche usage. The rapid uptake of GIS is part of a broader recognition that IT adoption creates and requires a transformation of defence activities. This revolution in military affairs manifests itself as 'Network Centric Operations' (NCO) – the use of the network to connect decision making across multiple defence domains. The horizontal nature of NCO demands a move to a modern services-oriented architecture that provides transparent interoperability between domains.

Modern COTS GIS platforms are capable of providing enterprise-class IT infrastructure for military applications. The resulting spatial infrastructure couples the sensors that monitor the battlespace to distributed geodatabases that contain knowledge of the battlespace (data, data models, process models, maps and metadata). These distributed geodatabases are coupled to distributed geoprocesses that provide powerful analysis and information filtering tools. The resulting information can be served across the network for fusion into embedded geovisualisation components. At every stage, interoperability is required with other enterprise class technologies such as supply chain management (SCM) and enterprise resource planning (ERP).

As a tool providing defence-wide infrastructure, GIS is simultaneously able to support war fighting missions such as command and control, business missions such as installation management, and a variety of strategic intelligence missions. Given the enormous expense of spatial data collection and production, this re-use across a common spatial information infrastructure offers immediate cost savings in addition to important new capabilities.

The massive increase in electronic information is not without its challenges. Prue Adler and Mary Larsgaard (Chapter 64: *Applying GIS in libraries*) highlight an explosive growth in the acquisition and use of electronic resources. These include resources that are available locally and via the Web. Research resources may include digital information, resources that are neither owned nor licensed by the library, resources digitized by the library or in partnership with others, and electronic publishing projects. As a result, there has been a dramatic rise in the digital services provided by research libraries. At the same time the continued evolution of information technologies including network services has greatly increased the ability of the research user to manipulate, analyse, and integrate data and information. There remain continuing challenges for long-term preservation and access to GIS and related datasets such as curation, meeting the needs of data users, data authors, and data managers, and the degree of centralisation of the support that is provided.

Today many in the academic and research communities are embracing open access – the sharing of information and data without restriction. In support of these efforts, many research libraries are establishing institutional repositories to capture, index and preserve the intellectual content of the researchers, faculty and staff in digital format. MIT Library's DSpace is illustrative of this digital library initiative and is available worldwide as open source software. As a consequence, a large and growing body of GIS information and datasets is available without restriction. At the same time as we are witnessing a move towards open access publishing, so there is also a rise in the use of licensing by many GIS vendors that may restrict how a user may utilize data, such as restrictions on how data may be shared or used. Today, nearly all major map libraries have a GIS facility of some kind. As a general rule, this does not include teaching classes, but may well include brief introductory sessions for individuals and groups.

Standard cataloging of Web resources is now commonplace. Libraries are now also deeply involved in the creation of metadata records for digital geospatial data. It is both understood and accepted that metadata records may be loaded not into the library's online catalogue but rather into some alternative database, with some form of Web interface to facilitate query.

(b) Social and environmental applications

David MacDevette, Robert Fincham and Greg Forsyth's account of the role of GIS in nation-building (Chapter 65: *The rebuilding of a country: the role of GIS in South Africa*) was written during a time of major upheaval. They offer some observations that are pertinent to contextualising GIS in today's developing African sub-continent where the situation regarding GIS has continued to alter, in many respects. Most notably, it is evident that GIS must be irrevocably tied into a strategic context of poverty alleviation and development. These are now major policy concerns of government and they require pursuance of service delivery on a scale unprecedented in the past.

They also observe that there is a need for a change in mind set of those who are purveyors of the GIS story. The technology has it roots outside of the continent – a European- and American-centric capacity that has been transferred to the developing world. 'Proudly South African' is a new motto in business that signals a new pride in indigenous capacities. For those working in the GIS arena it means an African context with a real commitment to the ideals and aspirations of the country as a whole. From an educational point of view there has to be a strong commitment to the notion of African scholarship. Such an ideal offers great prospects for contributing to better standards of living for more of the country's people than was the case in the past.

MacDevette et al's original contribution reminds us how GIS can contribute to major world events and can effect social and political change. In some respects GIS's role in South Africa is comparable to the events surrounding 9/11 and the December 2004 South East Asian tsunami referred to throughout this chapter. Since 1999 GIS in South Africa has followed a course more similar to that in many developed countries in America, Europe and Asia Pacific. One recent exceptional GIS project in South Africa has been Willem van Riet's Peace Parks Foundation of South Africa. Under his leadership the Foundation has established transfrontier conservation areas (TFCAs), also known as peace parks, which are large tracts of land that cross international boundaries. The purpose of these parks is to employ conservation as a land use option to benefit local people. Their pioneering spirit is forging international cooperation and is resulting in areas where wildlife can roam freely across borders. GIS has been used not only to help spark the adoption of the original peace parks concept, but to maintain existing parks and promote the concept in other countries.

The use of GIS in *Health and health care applications* (Tony Gatrell and Martin Senior, Chapter 66) has experienced significant recent growth, both in numbers of GIS practitioners and in organizations using GIS. The outbreaks of SARS in Asia, West Nile Virus in the US and foot-and-mouth in the UK, and the threat of global bio-terrorism all illustrate why GIS activities are essential. Among the ranks of the newest users are public health program managers responsible for health policy impact analysis, public health preparedness and disease surveillance. For example, in England and Wales there is now a network of regionally based Public Health Observatories in which GIS figures quite prominently. Increasingly, academic health science centres offer GIS as part of their health informatics and healthcare training programs. For example, US National Institutes of Health have recently funded a biomedical imaging research program that is GIS-centric, as well as a Geospatial Medicine program at Duke University Medical Center. Large public and private hospitals are establishing GIS departments to foster the wider use of GIS to meet the challenges of improving performance and lowering costs. On a global scale, the use of GIS to geographically enable national public health surveillance systems is one of the fastest growing markets for GIS technology and services. Perhaps one of the greatest unrealized values of GIS to health organizations lies in creating new knowledge about the convergence of environmental factors on human health status and healthcare delivery outcomes. Cromley and McLafferty (2002) provide a useful review of progress in the field.

Recent years have certainly seen very many profound political changes. Mark Horn's discussion of *GIS and the geography of politics* (Chapter 67) described the principles of gerrymandering and malapportionment and showed how they have been violated. While the effects of geographical jurisdictions were writ large on the outcome of the 2000 US Presidential Election (when the winning candidate failed to win the popular vote), it is argued that understanding of geodemographic detail is crucial to the US out-turn in 2004 and that in the UK in 2005. It seems that the availability of new technology through GIS can serve the interests of those that seek to manipulate the geography of voter turn out for political gain. It will be interesting to see if broadening of participation and engagement through PPGIS can counter such effects. On a brighter note GIS has recently been used successfully to communicate election results. CBS and other television stations used GIS in the 2004 US Presidential Elections: novel visualization techniques such as 3D perspective views and cartograms were used in near real time, perhaps for the first time on primetime television. In planning for future elections GIS-based redistricting remains as popular as ever.

The use of GIS in *Monitoring land cover and land-use for urban and regional planning* (Peter Bibby and John Shepherd, Chapter 68) dates back to the very origins of the GIS field. Recent advances in satellite geo-imaging have allowed the extents of land cover to be estimated ever more accurately and cheaply. Precise ascription of land-use, however, remains a difficult task, not least because of new and challenging policy requirements to differentiate between greater numbers of land use classes. Bibby and Shepherd concentrated on how GIS has been used to generate information for policy purposes, but, today, there remains a remarkable lack of awareness and willingness for senior politicians and policy makers to embrace science and technology.

GIS and landscape conservation (Richard Aspinall, Chapter 69) is a field closely related to land cover and land-use estimation, in that both involve wildlife and scenic resources, and have significant environmental policy implications. Richard Aspinall suggests that in the past few years there has been wider use of more flexible regression methods (generalized linear models and generalized additive models) for predictive modelling of species distribution (e.g. Guisan et al 2002) and development of rendering of landscapes for landscape assessment (e.g. Bishop et al 2001).

The business of agriculture is also an inherently geographic practice from the local to the global scale. In Chapter 70, *Local, national and global applications of GIS in agriculture*, John Wilson illustrated this with a number of examples. Improvements in global satellite-based sensors have provided many new opportunities for monitoring and modelling global changes. At a more local scale some of the advances in geoprocessing and visual modelling (for example, in Clark Labs IDRISI and ESRI ArcGIS) have helped progress simulation analysis and modelling efforts.

The final chapter in this section examined *GIS in environmental monitoring and assessment* (Lars Larsen, Chapter 71). A feature of this chapter was the interest in real-time monitoring, data quality and mathematical modelling. Increasing concern with the impact of pollution on the environment and the exploitation of natural resources have been major concerns for the environmental lobby and have led to interesting GIS applications in the last few years. The proceedings of the 4th International Conference on Integrating Geographic Information Systems and Environmental Modeling (Parks et al 2003) provide a useful update on progress in the field.

6 CONCLUSIONS

So, is everything progressing well, with the continuing advent of new technology driving ever-greater benefits to mankind? That is an unsustainably simplistic view of the GIS world. Yes, many of the current GIS tools are being used for real benefits to society and helping to generate wealth, employment, safety and improvements of the quality of life of some peoples at least. But, as ever with technology, we are exposed to risks through over-enthusiastic use of databases or the pursuit of wealth or power and influence irrespective of wider considerations. The GIS community exhibits all the usual characteristics of any group of human beings: it is sometimes fractious (even disputing the best name for the field — GIS or geospatial systems/engineering, as discussed in Section 2(a) above) or finding it difficult to establish consensus (e.g. on the best way forward for national spatial data infrastructures). It often lacks professionalism compared to some older professions or disciplines (such as engineering) so greater focus on this, on ethics and on regulation will probably be appropriate. But what we have now is a global movement which recognises that geography and the processes and actions which are manifested geographically can influence the lives of all humans. The next decade or so will show us whether this optimistic scenario really is what happens.

References

Baker J, Lachman B, Frelinger D, O'Connell K, Hou A, Tseng M, Orletsky D, Yost C 2004 *Mapping the risks: assessing the homeland security implications of publicly available geospatial information*. Rand Corporation Monograph (see http://www.rand.org/publications/MG/MG142)

Barrault M, Regnauld N, Duchene C, Haire K, Baeijs C, Demazeau Y, Hardy P, Mackaness W, Ruas A, Weibel R 2001 Integrating multi-agent, object-oriented, and algorithmic techniques for improved automated map generalization. *Proceedings of the 20th International Cartographic Conference,* Beijing China, 3: 2110-6

Bédard Y, Devillers R, Gervais M, Jeansoulin R 2004 Toward multidimensional user manuals for geospatial datasets: legal issues and their considerations into the design of a technical solution *Third International Symposium on Spatial Data Quality,* Austria

Benenson I, Torrens P 2004 *Geosimulation: Automata-based modeling of urban phenomena*. Chichester, John Wiley & Sons

Bishop I D, Wherrett J R, Miller D R 2001 *Landscape and Urban Planning* 52: 227-39

Bossler J D, Jensen J R, McMaster R B, Rizos C 2001 *Manual of geospatial science and technology*. London, Taylor and Francis

Chainey S, Ratcliffe J 2005 *GIS and crime mapping*. Chichester, John Wiley & Sons

Cho G 2005 *Geographic information science: mastering the legal issues*. Chichester, John Wiley & Sons

Cignoni P, Ganovelli F, Gobbetti E, Marton F, Ponchio F, Scopigno R 2003 Planet-sized batched dynamic adaptive meshes P-BDAM *Proceedings IEEE Visualization* IEEE Computer Society Press: 147-55

Cloke P J, Cook I, Crang P, Goodwin M, Painter J, Pluto C 2004 *Practising Human Geography*. London, Sage

Craig W J, Harris T M, Weiner D (eds) 2002 *Community participation and geographic information systems*. London, Taylor and Francis

Cromley E, McLafferty S 2002 *GIS and public health.* New York, Guilford Press

Curtain G G, Sommer M H, Vis-Sommer V (eds) 2004 *The world of e-government* Haworth, Haworth Press

De Soto H 2000 *The mystery of capital: Why capitalism triumphs in the West and fails everywhere else.* New York, Basic Books

Devillers R, Gervais M, Bédard Y, Jeansoulin R 2002 Spatial data quality: from metadata to quality indicators and contextual end user manual *OEEPE/ISPRS Joint Workshop on Spatial Data Quality Management,* Istanbul

Donnay J-P, Barnsley M J, Longley P A 2001 *Remote sensing and urban analysis*. London, Taylor and Francis

Dykes J, MacEachren A M, Kraak M J editors 2004 *Exploring geovisualization* Amsterdam, Elsevier

Foresman T W editor 1998 *The history of geographic information systems: perspectives from the pioneers.* Upper Saddle River, NJ, Prentice Hall

Fotheringham A S, Brunsdon C, Charlton M 2002 Chichester, John Wiley & Sons

Geertman S, Stillwell J C H (eds) 2002 *Planning support systems in practice*. Heidelberg, Springer

Greene R W 2002 *Open access: GIS in e-government.* Redlands CA, ESRI Press

Guisan A, Edwards T J, Hastie T 2002 Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling* 157: 89-100

Harris R, Sleight P, Webber R 2005 *Geodemographics, GIS and neighbourhood targeting*. Chichester, John Wiley & Sons

Heuvelink G 2003 Review of 'Spatial data quality' (Eds Shi W, Fisher P F, Goodchild M F). *International Journal of Geographical Information Science* 17: 816-8

Johnston R J, Hepple L W, Hoare A G, Jones K, Plummer P 2003 Contemporary fiddling in human geography while Rome burns: has quantitative analysis been largely abandoned – and should it? *Geoforum* 34: 157-61

Kyriakidis P C, Dungan J L 2001 A geostatistical approach for mapping thematic classification accuracy and evaluating the impact of inaccurate spatial data on ecological model predictions. *Environmental and Ecological Statistics* 8: 311-30.

Lang L 1999 *Transportation GIS.* Redlands CA, ESRI Press

Longley P A 2005 A renaissance of geodemographics for public service delivery. *Progress in Human Geography* 29: in press

Longley P A, Goodchild M F, Maguire D J, Rhind D W 2001 *Geographic information systems and science*. Chichester, John Wiley & Sons

Longley P A, Goodchild M F, Maguire D J, Rhind D W 2005 *Geographic information systems and science (Second edition)*. Chichester, John Wiley & Sons

Losasso F, Hoppe H 2004 Geometry clipmaps: terrain rendering using nested regular grids. *Proceedings, ACM SIGGRAPH 2004* ACM Press: 769-76

Maguire D J, Goodchild M F, Rhind D W 1991 *Geographical information systems: principles and applications*. Harlow, Longman

Maguire D J, Longley P A 2005 The emergence of geoportals and their role in spatial data infrastructures. *Computers, Environment and Urban Systems* 29: 3-14

McHarg I L 1995 *Design with nature*. New York, John Wiley

Miller H J, Han J, 2001 *Geographic data mining and knowledge discovery*. London, Taylor and Francis

Miller H J, Shaw S-L 2001 *Geographic information systems for transportation: principles and applications.* New York, Oxford University Press

Ord J K, Getis A 2001 Testing for local spatial autocorrelation in the presence of global autocorrelation. *Journal of Regional Science* 41: 411-32

Parks B O, Clarke K M, Crane M P (eds) 2003 *Proceedings of the 4th International Conference on Integrating Geographic Information Systems and Environmental Modeling: Problems Prospectus and Needs for Research* Boulder, University of Colorado Press

Photogrammetric Engineering and Remote Sensing 2003 Special issue on 'the National Map'. Volume 69.

Radke J, Cova T, Sheridan M, Troy A, Lan M, Johnson R 2000 Application challenges for GIScience: implications for research, education, and policy for risk assessment, emergency preparedness and response. *URISA Journal* 12:15-30

Reddy M, Iverson L, Leclerc Y, Heller A 2001 GeoVRML: open Web-based 3D cartography. *Proceedings of the International Cartographic Conference ICC2001,* Beijing, 6-10 August

Reddy M, Leclerc Y, Iverson L, Bletter N 1999 TerraVision II: visualizing massive terrain databases in VRML *IEEE Computer Graphics and Applications* Special Issue on VRML 192: 30-8

Romao T, Dias A E, Danado J, Correia N, Trabuco A, Santos C, Nobre E, Câmara A 2002 Augmented reality with geo-referenced information for environmental management *ACM GIS 2002* ACM Press: 175-180

Shapiro C, Varian H R 1999 *Information rules*. Cambridge, Mass., Harvard Business School Press

Shi W, Fisher P F, Goodchild M F, eds 2002 *Spatial data quality*. London, Taylor and Francis

Snow C P 1961 *The two cultures and the Scientific Revolution.* New York, Cambridge University Press

Song H-J 2003 E-government: lessons learnt and challenges ahead. In *Proceedings, 8th International Seminar on GIS: envisioning cyber-geospace and spatially enabled e-government*: 1-113 Seoul, Korea Research Institute for Human Settlements

Thomas C, Ospina M 2004 *Measuring up: the business case for GIS.* Redlands, CA, ESRI Press

Thrall G I, Campins M 2004 Mapping the geospatial community: parts 1-4. *GeoSpatial Solutions* (July, September, November) 14 (numbers 7, 9, 11); also 2005 15 (number 1)

Tomlinson R 2003 *Thinking about GIS: geographic information system planning for managers*. Redlands, CA, ESRI Press

Ware M, Jones C, Thomas N 2003 Automated map generalization with multiple operators: a simulated annealing approach. *International Journal of Geographical Information Science* 178: 743-69

Worboys M F 2005 Event-oriented approaches to geographic phenomena. *International Journal of Geographic Information Science*, in press

World Bank 2003 *Land Policies for Growth and Poverty Reduction.* Washington DC, World Bank

Addenda

Lubos Mitas and Helena Mitasova, Chapter 34: *Spatial interpolation*

Equation 3 should read:

$$\gamma(\mathbf{h}) = \frac{1}{2} Var\left[\left\{z(\mathbf{r}+\mathbf{h}) - z(\mathbf{r})\right\}\right] \approx \frac{1}{2N_h}\sum_{(ij)}^{N_h}\left[z(\mathbf{r}_i) - z(\mathbf{r}_j)\right]^2$$

Barry Boots, Chapter 36: *Spatial tessellations.*

Unfortunately some of the illustrations in this chapter were corrupted in the production process, and it has not been possible to replace them in this abridged edition. Professor Boots has made correct versions available for interested readers to consult at the following URL: info.wlu.ca/~wwwgeog/facstaff/bootscorrect.htm

Additional Acknowledgment to the Abridged Edition

Paul Longley's contribution to the Abridged Edition was completed during funding for ESRC AIM Fellowship RES-331-25-0001.