[Prologue]

Chapter 1

Advanced spatial analysis: extending GIS

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To introduce this edited collection of contributions from members of CASA at University College London, we begin by setting them within the general historical context of GIS as it has developed over the last 40 years. We adopt a broad definition of GIS and define our purpose as showing how GIS has been and continues to be extended to encompass a wide range of theories and methods that are applicable to processes that require spatial analysis. We identify three main themes that recur again and again throughout this book; these themes are about ways in which time and space should be represented within GIS, ways in which agents and institutions communicate and function, and ways in which networks are changing how we communicate, process and visualise data across the full range of geographic scales. From these themes we identify seven issues that are elaborated through the various contributions to this book. These are scale in mapping form and representing process; confidentiality and ethical issues in geodemographics and spatial behaviour; incompleteness of representations across space and time; visualisation in communication and user interaction; representation in the space of the third dimension and beyond; representation of dynamics and spatial processes; and policy applications through planning and design.

1 How we got here: a short history of GIS

Geographic information systems (GIS) are integral to a wide, applications-led field, with diverse roots in many spatial sciences ranging from geography and the earth sciences to architecture, urban planning and ecology. It is widely accepted that the term GIS was first coined by Roger Tomlinson in 1963 (figure 1), and Tomlinson is also accredited with developing the 'first GIS'—the national natural resource inventory for Canada created under his directorship (Tomlinson 1998). However, GIS as a cognate area and as a significant domain of commercial activity developed only in the late 1970s and 1980s after the costs of computer processing had made hardware, particularly display devices, affordable with the commercial costs of GIS software development then becoming shared amongst a wide range of users.

Popular reviews of the field (for example, Burrough and McDonnell 1998; Longley et al 2001) trace the principal roots to at least four distinct activities. First, the early innovations in computer graphics in the late 1940s, when various engineers working with machine diagnostics used oscilloscopes to experiment with graphics in order to simulate bouncing balls and various other entertainments. This ultimately led to the development of computer cartography in the mid-1960s and the creation of rudimentary maps using line plotters and printers. The micro-revolution, which began in earnest after the invention of the microprocessor in 1971, dramatically changed these possibilities as computer memory itself came to be associated with pictorial representation.

The second motivation arose through mainstream developments in database technologies and information systems. Representing spatial units required the development of algorithms to search spatial data structures and to solve problems such as the 'point in polygon', and these did not evolve until the late 1960s and 1970s. A third force was generated by the development of environmental remote sensing, initially to service the military satellites of the 1950s and subsequently the civilian systems of the 1960s. The fourth motivation arose out of the development of techniques to merge data representing different layers of activity such as terrain and land use. A variety of associated simple but effective overlay techniques, particularly developed for problems of landscape planning and best illustrated in the work of McHarg (1969), were first automated using early ideas of map algebra with their rudimentary display on line printers. All of these ideas came together in the 1960s at places like the Harvard Laboratory for Computer Graphics that served as a focal point for conceptual developments and for the basic software. It is from these beginnings that public domain and commercial software subsequently evolved (figure 1).

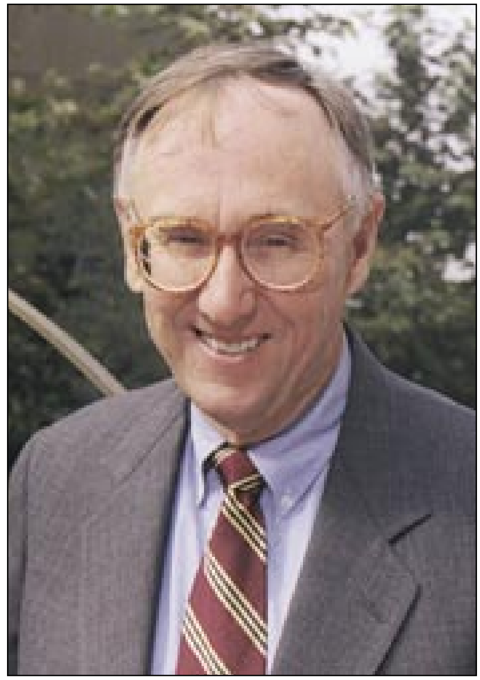

Figure 1 Roger Tomlinson who coined the term GIS, and Jack Dangermond who developed the first commercial software

Parallel to these developments, spatial analysis emerged largely from the advancement of quantitative methods in geography, geology and the earth sciences, as well as from regional science and macro-economics. Spatial statistics and locational analysis dominated geography in the 1960s, and the protagonists of geography's 'Quantitative Revolution' were responsible for the development and application of techniques that together laid the foundations of a new scientific geography (Johnston 1999). *Spatial Analysis* (Berry and Marble 1968) illustrated the rapid growth of the field, and symbolised the quantitative revolution in geography. The approach retained a core following in geography and set the agenda for the next generation. GIS emerged in parallel to developments in spatial statistics and locational analysis during the 1970s and 1980s, with a number of researchers moving between quantification and computer application. In this way, some of the more general of these techniques became slowly but systematically incorporated into GIS software. By the mid-1990s, GIS had broadened its remit sufficiently to embrace spatial analysis, while modelling and simulation were being developed in complementary fashion to GIS. Our own edited book *Spatial Analysis: Modelling in a GIS Environment* (Longley and Batty 1996) summarised the field at the time. This current book attempts to take our definition much further based on our perception that GIS is now extending into many fields of spatial representation, analysis, modelling, policy and design. This, then, is what we mean by the slightly precocious term 'Advanced Spatial Analysis'.

Spatial analysis takes GIS a major step forward, from a restricted range of 'off-the-shelf' representational forms to custom-made depictions of the world and critical interpretation of the assumptions that are invoked to represent it. It extends GIS to the concept of the model and beyond, to ideas about policy and design, to how we might change as well as simply understand the geographic dimension. Moreover, because of this, spatial analysis also points the way to advanced applications. The standard functionality of GIS provides a framework for data manipulation and visualisation, and this provides a supportive environment for structuring routine applications in operational management. However, harnessed to spatial analysis techniques, GIS also provides powerful ways of generating and evaluating strategic policies and plans.

As with most other software applications, the cumulative development of GIS software has been accompanied by transitions from the mainframe to workstation to desktop, with the packaging of particular GIS functions in software (and sometimes also data) products designed for particular applications. Today's commercial GIS provide a family of products ranging from light Internet browsers through to analytical engines encompassing a comprehensive range of functions for spatial data manipulation. It is not within the scope of this introductory chapter to attempt a broad-ranging history of the technical challenges and changes in computer architecture that have characterised the recent development of GIS (see Longley et al 2001: 9-25), although before introducing the research areas that make up this book, it is relevant to sketch out some of them. First, it is clear that the universality and generality of GIS has increased as hardware has become more pervasive. Second, until the mid-1990s, most of the emphasis in GIS was on developing fast, reliable software that made conversion between different data structures routine and safe, and thus diversified the range of data sources that could be combined within GIS. Third, the 1980s mission of commercial GIS to 'satisfy 90 percent of applications needs 90 percent of the time' has broadened as applications themselves have become more demanding. This has led to the adaptation of methods and models of spatial analysis to GIS software, and a range of new functions has been incorporated into desktop software in particular (for an early review, see Maguire 1995).

Fourth, modularity has become the dominant procedure for adding new functionality. Fifth, developments in 3-D representation have also provided a cutting edge to research. Sixth, the miniaturisation of computer devices, allied to ongoing developments in computer networking, is taking some of academic geography back to its roots in field measurement and environmental cognition, and this poses important new challenges for relaying real-time applications to the field. In fact, the move from fixed hardware installations to networks on the one hand, to small mobile devices on the other hand represents a new cutting edge of GIS development. This is part of the massive decentralisation of computing that is still ongoing, where data and software and even applications themselves are being distributed across networks and access is increasingly being effected through wireless devices. We will point the way to some of these applications in this book, but in our final chapter, the epilogue, we will also argue that these are likely to be the most important directions in which this field will evolve in the next decade.

2 Themes in this book

All GIS-based representations are selective abstractions, simplifications of reality. What we choose, or are forced, to leave out can be as important as the aspects of reality that we choose to retain. Fifty years ago, the idea of the model as a simplification of reality entered our vocabulary (Chorley and Haggett 1967), and in the social sciences in particular, the idea that models could be based on mathematical relationships rather than physical materials fitted very well a world in which simulation on computers was becoming ever more important. When we classify models, we usually fall back on the idea of simplification in that the essence of a model is to gain understanding through simplification. But in order to retain realism as well as simplification, we can embody models through very different media.

In general terms, we may distinguish between iconic and symbolic models, where iconic models tend to be scaled-down versions of the real thing often with working parts which are similarly scaled down. In their most superficial form, such physical models are often thought of as ‘toys’ and the way young children learn is through such media. In practical terms of some relevance here, the architect’s block model, where buildings are made from balsa wood or cardboard or the scientist’s wind tunnel or sediment tray, perform the same function. In contrast, symbolic models are based on logical relationships, usually mathematical and statistical where less obvious attributes of the system in question are modelled or simulated. Spatial analysis is part of this latter symbolic domain, while paper maps are best thought of as iconic. Digital maps that embody topological relations are best thought of as symbolic, as the notion of scale has no physical meaning within the confines of the computer. In passing, we should also mention the halfway house of analogue modelling where the model is generated in analogy to some other system, for example, simulating the interactions within a local economy using electrical networks whose various components represent different flows, resistances and potentials.

The computer revolution has taken us one step further by enabling us to not only model symbolic representations of systems but to model the physical representations within which such symbolic interactions usually exist. This has largely happened through computer graphics, but in terms of GIS, this means that the physical map is now the object of simulation. Indeed, GIS is a very clear example of a medium in which physical models of the system—its geography—merge with symbolic models of this geography through spatial relationships. This is what makes it so powerful. An excellent illustration of this merging, which we will exploit extensively in this book, is the move from the 2-D map to the 3-D scene, but the superficiality of this development masks the real power of such developments. Extending geographic representation from the icon of the map to the icon of the building or landscape gives us the possibility of extending symbolic modelling from 2-D to 3-D.

The picture of GIS that emerges today is of powerful ideas embodied in software and capable of immediate visual communication and that have important implications for many aspects of our day-to-day activities. Today's GIS:

- selectively integrate time and space across a far wider range of spatial and temporal scales than has been the case hitherto. Effective management of the granularity, or detail, of time and space can preserve the unique attributes of places and particular time periods, whilst retaining the power of generalisation between places and times.
- promote use by a wide range of agents and institutions in a wide range of casual as well as specialist settings. GIS has become not only a widely used tool for scientists to generalise and theorise about human activity patterns, but also an important visual communications medium for improving and promoting wider understanding of such generalisations. As such, it improves not just our scientific understanding of the public domain but also the public

understanding of our science, providing, that is, that the GIS is efficient, effective and safe to use (Rhind 1999).

- link the smallest handheld devices into a global network of computing, for exploration, simulation and analysis of geographic phenomena. Computer networks thus connect ideas in 'organized activity by which people measure and represent geographic phenomena, then transform these representations into other forms while interacting with social structures' (Chrisman 1997).

Several pertinent issues arise from these themes. In particular, there are issues of:

- scale
- representing human behaviour
- understanding the implications of ethics for spatial analysis
- incompleteness of spatio-temporal representations
- visualisation and our limited abilities to communicate amongst ourselves and to others
- representation in the third dimension and beyond
- understanding dynamics and spatial process
- policy application, planning and design

These issues emanating from our themes are clearly evident in the research at CASA contributed here, and we will elaborate in much of the rest of this chapter.

3 Some issues arising out of these themes

Scale in mapping form and representing process

At the finest scale of granularity, GIS depicts humans as mobile point georeferenced 'events' and human agency and activity patterns as changes in their relative locations. It has long been recognised that the best ways to represent such events are grounded at the level of the individual, epitomised, for example, in microeconomic models of travel choice (Hensher and Johnson 1981) and the behavioural geography of cognition and mental maps (Golledge and Stimson 1987). However, in the early days of spatial analysis, the restricted processing power of computers made analysis of multiple individual activity patterns impossible, and such data were, in any case, simply not available prior to the development of digital data capture technologies. The pragmatic response that has ensued is familiar to any geographer—representation through zonal aggregation with a strong emphasis on searching for patterns through choropleth mapping. But a fundamental paradox in geography as a scientific discipline is that aggregation is fundamental to achieve generalisation across space, yet the aggregated zones that are created to facilitate such generalisation usually have no validity independent of particular applications (or, indeed, any validity at all). Geography is unlike many sciences in that the basic atoms of information—points located in time and space—can rarely be aggregated into units that are obviously 'natural'. Moreover, the scale at which aggregation occurs and the configurations of areal units that are adopted often exert a critical influence upon the outcomes of the spatial analysis with contradictory conclusions being generated for the same data at different scales (Openshaw 1984).

The outcomes of such spatial pattern analysis may be misleading if zones are configured or aggregated in unusual ways—the whole notion of gerrymandering (Schietzelt and Densham, this volume) emerged as a consequence. The core problem is that there are few general guidelines to inform us whether a zonal scheme is unusual. These problems are compounded when the focus is upon spatial interaction and spatial process or the representation of temporal dynamics. Early digital representations of spatial interactions were usually framed within very coarse zonal geographies. Typical were intraregional representations of shopping patterns in the 1960s and 1970s where critical interactions were present between only a handful of zones. Over time, these constraints were relaxed to some degree so that by the mid-1990s retailers, for example, were building much more partial models of systems around finer-scale zonal geographies based on much more restricted domains of socio-economic behaviour.

Constraints on data availability, the depiction of smaller-scale objects, and their model-based processing, have also relaxed as data and simulation technologies have become more powerful. The consequences of this can be seen in many contributions to this book. Most obviously, the models of individual pedestrian flows presented by Batty (this volume) represent human beings as individual agents and appraise behaviour through a series of scenarios at scales from the architectural to the neighbourhood. The spirit of this approach is to develop plausible models of individual movement based around sensory attraction to features (sound systems in the case of the Notting Hill Carnival or exhibits in the case of the Tate Gallery) within the constraints of built form and street geometry. In these examples, the geographic units of analysis are individual human agents, and, as such, the application is the logical end point of the trend to successively finer levels of granularity. Although still foremost a research application, there is clear interest in this approach from a number of applications areas, such as retailers who have followed the trend down-scale from aggregate to small area data and now consider models of pedestrian flows as the ultimate level of disaggregation in devising performance measures for all store formats.

Although this approach has methodological strengths beyond representing the true unique individual, similar approaches can be taken with respect to other aggregations, as illustrated by Torrens (this volume) in his appraisal of the broad swathe of cellular automata (CA) and related agent-based approaches to urban development. In its simplest form, CA can be thought of as a form of digital analogue modelling, whereby the properties of cells (which may represent individual land parcels of developed space or individual buildings) are deemed to interact according to prespecified rules. With regard to urban development, most research to date has related to cities in the developed world, and thus the wider applicability of agent-based approaches has received little attention. Barros and Alves-Junior (this volume) go some way towards resolving this deficiency with a far-reaching study of peripherisation dynamics in Latin America and empirical reference to São Paulo and Belo Horizonte. Although these chapters all involve a move down-scale from the aggregate to the individual, such applications are temporally dynamic as well as spatially disaggregate, a trend that is evident in all GIS as we come to embrace more detailed data at ever finer scales.

Confidentiality and ethical issues in geodemographics and spatial behaviour

It is clear that developments in software, linked to vast increases in the capacity and processing power of hardware, now make it possible to simulate the movements of large numbers of individual points and to conduct spatial analysis at very fine levels of granularity. The case studies reported here by Smith (this volume) illustrate the recent development of digital 'framework' data by national mapping agencies (Rhind 1997), and there have also been improvements in the accuracy and precision with which conventional socio-economic data sources can be anchored to such sources. It is unfortunate, but perhaps inevitable, that the creation of socio-economic digital data infrastructures to support these developments has not sustained a similar pace of development. Indeed, fine-grained public sector datasets, such as national censuses, today make up a smaller real share of available data, given the rise of private sector data warehouses.

The maturation of global positioning system (GPS) technologies, coupled with the advent of portable GIS devices, allows much more detailed monitoring of individual activity patterns, as well as tagging of individual characteristics and actions (Li and Maguire, this volume). In important respects, these are some of the developments that take geography back to its roots in the measurement of conditions in the field, potentially reinvigorating the field of behavioural geography (Golledge and Stimson 1987). However, although this is undoubtedly the case in the research domain, there are few individuals who are likely to allow computers to monitor the intricacies of their daily activity patterns—and those that do are unlikely to be representative of the population at large. Thus, most GIS applications that require multi-attribute socio-economic data that are representative of populations will remain constrained to a more limited range of data sources, aggregated in order to preserve respondent confidentiality. Such are the datasets used by Evans and Steadman (this volume) to develop urban indicators consistent with the more aggregate land-use transport modelling that is being adapted to GIS. The technical niceties of scale and aggregation involve constraints on socio-economic data availability arising out of ethical considerations to protect privacy. The chapters in this book that describe coarse zonal geographies are those that require multiple attributes of individuals to be measured.

Other contributions to this book suggest more adaptive solutions to the available range of socio-economic data. The field of geodemographics has become accustomed to fusing records pertaining to individuals with aggregations, as in the use of lifestyles data to freshen up and extend the remit of census-based geodemographic classifiers. Much time in analytical geography has been spent trying to bridge scales, and the late 1990s generation of geodemographic classifiers to some extent epitomise the problem of how to relate rich, pertinent indicators of social conditions with the local scales that concern many business and service planning applications. The related approach taken by Webber and Longley (this volume) seeks to exploit the properties of social similarity and locational proximity by examining the area effects that are not specified in geodemographic classifiers.

Incompleteness of representations across space and time

The contribution by Webber and Longley (this volume) also raises a point that strikes back at the heart of a representation—namely, how to specify and, hence, generalise about 'place' effects of present or past environments that are either unmeasured or even immeasurable (in practical terms). In applications to the contemporary world, it is important to recognise that the effects of place are not wholly encapsulated in individual agents, that we cannot capture the effects of all individuals in all places and all time periods, and, even if we could, it would be wasteful to do so. It is not just the agents existing today that create place effects, and Webber and Longley demonstrate that GIS can be used to identify place effects that encapsulate different event histories and simplify historic chronologies.

In other applications settings, representations are simply incomplete. Sometimes, as in the cellular models described by Torrens (this volume) and the agent-based movement models developed by Batty (this volume), it is not possible to observe and record the data on individual decision making that embody the rules for action and interaction. For example, data on where people originate and where they are destined are notoriously difficult to collect for large crowds and although advances in laser scanning and remote sensing are able to produce aggregate volume data, there is no fix other than direct interaction with the objects and subjects of the simulation to generate the data required. Representations may also be incomplete because relevant information has been destroyed. This is the case in using GIS to reconstruct past environments as illustrated by Grajetzki and Shiode (this volume) where information about the past is incomplete and fragmented. In such circumstances, GIS do enable information to be assembled from different sites and different time periods, in order to create as complete and as consistent a representation as possible.

Visualisation in communication and interaction

The illustrations and scenarios presented by Grajetzki and Shiode (this volume) not only illustrate the advances that have been made in visualisation, but the persuasive power of the visual medium in conveying the interpretations of the past that particular researchers may wish to impart. They also illustrate how changes in computer architectures enable interrogation of databases from a distance across networks, and how GIS can create a better sense of immediacy in remote locations. Today, the ubiquity of GIS in developed countries means that more people than ever can use it to gain an impression of different places and different times.

The implication of this is that the desire, even of rather novice users, to perform advanced spatial analysis implies the need for guidance. Improved methods of visualisation and user interaction are key to this requirement. Tobón and Haklay (this volume) and Lloyd et al (this volume) each illustrate how public participation in GIS (PPGIS) can be encouraged through new techniques and procedures that foster clearer perception, improved interpretation, and more thorough interrogation of spatial data. The techniques presented in this contribution make it possible to visualise the effects of outlying points: the medium does not dominate the message, but rather is sensitised to revealing it in a data-led way. The important point here is that ‘advanced’ spatial analysis does not necessarily imply 'complicated': in the spirit of other developments at the research frontier (for example, Fotheringham, Brunsdon and Charlton 2001), advanced tools of spatial data exploration can be readily assimilated by an increasingly broad user base.

Some of these approaches are already used in full-fledged applications of GIS to scenario development as illustrated by Evans and Steadman (this volume) in the context of the urban sustainability debate. One of the problems with scenario analysis is the length of time required to refresh a simulation. Schietzelt and Densham's (this volume) research on location-allocation can similarly result in generating a wide range of scenarios for emergency management under any conceivable system state (for example, preprogramming the daily commuting rush), and this can reduce the processing needed for real-time analysis. This creation of a scenario base then also creates demands on human-computer interaction to manage the scenarios—that is, to make the selection of the most appropriate scenario from meta scenario categories as easy as possible.

Hudson-Smith et al (this volume) provide a wide-ranging example of how GIS and related multimedia information is being used to communicate ideas about the spatial urban environment. Visualising built environments in effective and easy to understand ways requires the development of multimedia techniques that need to communicate in direct and immediate ways. PPGIS and its extensions into multimedia are increasingly being aided by developments in 3-D GIS and CAD that are delivered to the public across networks rather than residing on the desktop. Visualisation can be thought of as the domain of GIS, but effective communication also requires good networking. It is in the general area of visualisation that extensions to 3-D and to the networked and wireless worlds are all coming together.

Representation in the space of the third dimension and beyond

Extending GIS to the third dimension has relied heavily on developments in hardware speeds, rendering and computer graphics software. It is now possible to display 3-D environments almost as quickly as the 2-D flat map, and this is providing new insights from visualisation that translate more abstract information into a form that many non-expert users can immediately understand. Sometimes these extensions are referred to as 3-D models or even urban models, but these are very different from the symbolic models that have dominated quantitative geography and spatial analysis. In fact, the extension of iconic but digital modelling from 2-D to 3-D also enables us to extend symbolic modelling of spatial relationships. The third dimension remains much underplayed in geographic and geometric analysis. For example, urban land use is largely collected at the ground floor level and in dense cities, much of the variety of land use and urban activity locations is lost because of this simplification. GIS in 3-D makes it possible to extend GIS functionality to analyse such diversity while providing a much more complete picture of how cities and landscapes work.

Hudson-Smith and Evans (this volume) illustrate how these extensions are being developed through the idea of the virtual city. They show how 3-D GIS is converging towards computer-aided architectural design (CAD) and providing a new lease of life for CAD, which to date has often remained preoccupied with issues of aesthetics and rendering. The media that they introduce is used in the application of Web-based public participation, and Hudson-Smith et al (this volume) also use these media in an application of urban regeneration in Woodberry Down. Some of the more architectural techniques presented in both of these applications are taken further by Grajetzki and Shiode (this volume) in their reconstruction of temple sites in ancient Egypt, while the kinds of spatial infrastructures needed to sustain such representation are considered by Smith (this volume). For example, thin clients, which perform little processing locally, are now widely used to support the kind of Internet browsing that is being developed for applications described by Hudson-Smith and Evans (this volume).

A related question involves the way in which such 3-D representations scale to smaller handheld devices. The frontier question is how such devices, already used in the field and associated with field data capture and field location of static objects, can be refreshed to contribute to the challenges of navigating urban environments and wayfinding. This is part and parcel of bringing GIS closer to our direct experience and our need to understand how location-based service (LBS) technologies become incorporated into behaviour. The historic demarcation between direct and indirect experience blurs when handheld devices are used as an adjunct to reality in the field. In this context, Li and Maguire (this volume) reflect that it is spatial knowledge acquired via the survey method, such as map reading, that is usually assumed to be the most advanced level of spatial knowledge. This implies that GIS are now more directly about spatial knowledge acquisition than just data input and the translation of data into information. In this sense, extensions of 3-D GIS into other forms of multimedia based on virtual reality (VR) systems are likely to dominate the future. Thus, the methods used in constructing multimedia Web sites that link photogrammetric with 3-D graphics and other forms of multimedia delivered across the Internet will be central to future developments in GIS.

Representation in time: dynamics and spatial processes

Like the third dimension, ideas about time provide a clear challenge to new ways of representation within GIS. GIS are manifestly spatial and, hitherto, have largely treated questions of time as simply static spatial snapshots. Dynamic processes are hard to represent within GIS, and typical GIS structures focus largely on spatial representation as the starting point. Yet throughout this book, we develop tools in which dynamics figure strongly. Agent-based, CA and the more macro-population models developed, for example, by Batty and Shiode (this volume) all involve dynamics which cannot be represented in conventional GIS software, and this poses a challenge to researchers in the field. In fact, fully functional temporal GIS software of a proprietary nature is long overdue, for there are a plethora of problems that require explicit dynamic representations. A primary reason why such systems have not yet emerged is that there is no single large niche area of application that is forcing the pace. It is easier to structure GIS around spatial variation and representation because this provides a much more common base, while dynamics, insofar as they can be represented, are still regarded as an add-on to be represented as part of the modularity that is a feature of contemporary GIS software. Indeed, some of the techniques developed by de Smith (this volume) involve transformations of distance mapped directly onto the kinds of dynamics that are needed in terms of temporal GIS, and he shows that the challenges that need to be addressed in the future will take us back to fundamentals despite the advances that have been made during the last half century.

Shifting spatial analysis from statics to dynamics or, in other words, from product and structure to process and behaviour, is another challenge for the future. In particular, most applications require at least an implicit form of dynamics through thinking about changes to the systems that are represented, or more formally through forecasting or even policy and design. Besussi and Chin (this volume), for example, develop implicit dynamics to their analysis of urban sprawl, although the project that they describe uses GIS extensively in the form of snapshots of growth and change. In the same way, Barros and Alves (this volume) have a different take on what in the United States and Europe is termed ‘sprawl’ but in Latin America is considered to be ‘peripherisation’. In fact, as in many applications reported here, this analysis of sprawl uses a variety of models and techniques to represent urban development, illustrating the obvious but often overlooked feature of GIS usage where many related methods and software are used for any application. GIS is employed here in its very widest sense, almost as a shorthand for spatial analysis, modelling, design and policy. This suggests how different conceptual frameworks for GIS can be formulated into different models to drive different scenarios, thus adding dynamics to GIS through its wider usage.

Finer scale dynamics still constitute a challenge for GIS, especially where models based on 'far-from-equilibrium' concepts are important. Batty (this volume) illustrates some of these ideas in the context of pedestrian modelling, but in most of this book, there is a strong sense in which applications of GIS require relatively stable problem structures and well-defined forecasting methods. The idea that systems are never in equilibrium is one which is hard to embrace within an applications-oriented paradigm, although it is very likely that one of the challenges of the next decades in GIS will be the notion that the world is never in equilibrium, that change is central to any problem that we care to consider, and that our methods must be adapted accordingly. This will require new ways of exploration, simulation and optimisation that we will address at the end of this book in our epilogue.

Policy applications through planning and design

Policy is woven throughout the applications described here, for many of the projects reported are motivated by problems resulting from urban change and which require planning and design. Even the new and speculative methods and models that we report on, such as those that pick up in agent-based technologies, are influenced by policy issues such as crowding in shopping malls, problems of containing sprawl, urban regeneration, and problems in developing appropriate information infrastructures. Here we present a range of policy applications with different motivations. For example, Thurstain-Goodwin (this volume) develops techniques of representing data in a form which is immediately relevant to retail policy applications. His techniques aid communication, while Evans and Steadman (this volume) adapt GIS technologies for the same kinds of purpose—to give decision makers and users of these technologies more user-friendly interfaces and more organised ways of representing data and forecasting for problems of strategic land use-transportation planning.

Longley et al (this volume), in their chapter on the complexity of the retail system and the need for new ways of dealing with retail geodemographcis in terms of location, show that it is no longer satisfactory to represent retail space in a uniform way. Activity must be differentiated according to more general patterns and objectives which, for aggregates of individuals, bear an identifiable correspondence with time of day, type of land use, mode of transport, and a whole range of much more individualistic factors than have been considered by retail planners and developers hitherto. This poses enormous challenges in terms of how we can represent retail centres as discussed by Thurstain-Goodwin (this volume), involving issues such as secondary retail centres and the emergence of new forms of organisation through the concentration of retail capital.

The policy and design processes within which the new technologies of advanced spatial analysis might be set are explored by Alexiou and Zamenopolous (this volume) in their analysis of planning processes in terms of distributed learning and control coordination. They develop models of the planning process itself. This process is somewhat different to others in this book for it deals with ways in which we might plan and design, although the models that are used (based on neural nets) are close to many of the techniques currently being developed in the spatial analysis of geographic systems. In a sense, these methods relate to those developed by Schietzelt and Densham (this volume) in their work on location-allocation models where the choice of optimal solutions within formalised solutions spaces is central to their application. Once again, policy, although important to our survey of advanced applications, is an area that we feel will dominate GIS in the next decades as we develop and improve our applications through experiences such as those reported here.

4 Ways forward: a connected world

When we compiled our book *Spatial analysis: modelling in a GIS environment* (Longley and Batty 1996) nearly a decade ago, the idea that computing would move so quickly from the desktop to the network was still fanciful despite the facts that the Web had been invented in the early 1990s and that most of us were using e-mail routinely. What we will see here in the many contributions that constitute much of 'advanced spatial analysis' is the use of very diverse software, albeit much of it associated with proprietary GIS but much of it also based on wide linkages between different types of software on the desktop. In wider context, many of the applications that we include also use the Web not only to retrieve and store data but also to operate software. However, the biggest advantage that the Web offers is the ability to communicate not only amongst ourselves as researchers and professionals but also to those who provide our mandates and those who we hope will benefit from the kinds of data and information that we work with. Visualisation is thus a major theme and issue throughout this book, and every chapter translates GIS technologies into a form that must be communicated visually. The various themes and issues identified here recur throughout the chapters that follow, and in an epilogue at the end of this book we will draw these together and point to the future.