PART 1

PRINCIPLES

Introduction

THE EDITORS

The term GIS is fundamentally about the use of digital data to represent space and time, and few of the readers of this book will be unfamiliar with the standard sequence of operations that GIS invoke to create such representations – data input, storage, manipulation, and output. For many users of GIS, this simple chronology of operations has provided an adequate framework for understanding what GIS is about. Yet reality is infinitely complex in its totality, and our digital representations are inevitably simplifications or 'models' of it. With experience, and perhaps the demands of wider domain and strategic applications, many GIS users will begin to get a feel (from the 'bottom up') for the nature of the simplifying assumptions, or 'transformations' (Martin 1996) which are inherent in reducing the myriad complexities of geographical reality to digital computer records. From a quite different perspective, the fundamental ('top down') views of social science and science held by some academics bring into question the very validity of GIS-based representations of the real world. The opening five chapters of this book seek to set out the context to GIS, as a contribution towards reconciling philosophy and science with practice, concepts with application, analytical capability with social context. As such, and although avowedly academic in emphasis, they contain material of relevance to everyone who has considered using GIS to formulate and analyse problems in the real world. Successive chapters begin to translate these abstract notions and ideas into firmer guiding principles of GIS, in order that principles in turn might coalesce into operational guidelines for implementation.

In the opening chapter to this Section, Helen Couclelis traces the disciplinary origins of interest in representing space and time to the disciplines of geography, mathematics, philosophy, and physics. The traditional paper map subsequently emerged as the dominant paradigm of spatial representation, with its goal of depicting spatial phenomena using established and recognisable schemes of representation. The more recent innovation of GIS has sought to develop and enhance such analogue models of the world using computer hardware, software, and digital data. More detailed and sophisticated than paper maps they may be, but most GIS-based maps remain similarly constrained – they must present a world that has been projected onto a flat plane; they must be static and 2-dimensional; they depict the world as if it were known perfectly, or at least as accurately as the scale of the map allows; and they must present the world at a uniform scale or level of geographical detail. These are all examples of simplifications of reality, yet the GIS medium is fundamentally more capable of relaxing these assumptions, constraints, and conventions than paper mapping. Thus it is with some confidence that Couclelis sees GIS as rising to the challenge of achieving 'the seamless integration of space and time, the representation of relative and non-metric spaces, the representation of inexact geographical entities and phenomena, and the accommodation of multiple spatio-temporal perspectives to meet a variety of user purposes and needs'.

Of the different disciplines that have sought to represent space and time, it has been geography that has identified itself most closely with the innovation of GIS – although (as a number of the contributors to this section note) geography has not been central to its technological development. Ron Johnston (Chapter 3) uses the debates that have developed within geography to explore the implications of the fundamentally empiricist view of the world that GIS provides – that is, a view founded upon the philosophical belief that there is a separate objective world that is outside and independent of any individual observer. Empirical scientific approaches have come to be viewed with disdain by some academics working in human geography, yet they remain the predominant *modus operandi* in physical geography. Johnston concedes that a pragmatic application-led science, couched in the world of appearances, is not universally attractive to all geographers (although it has undoubtedly enhanced the status of their discipline), yet his closing remarks suggest that the very richness of digital media no longer need constrain GIS in this way. If, as Couclelis asserts, GIS has already come a long way since the era of early computer cartography, then the rapidity and pace of current developments should in turn now begin to suggest ways in which GIS might inform other, non-empiricist, approaches to social science.

In Chapter 4, John Pickles develops the critique of GIS from a more functionalist perspective: that is, how its approach to science has impacted upon its technological capacities and social uses. The early 1990s critique of GIS within academic geography was fundamentally one of empiricism – that is, the approach to science in which, in Johnston's words, 'facts speak for themselves'. As such, it was to some extent a re-run of the critiques of quantitative geography that had developed in the 1970s and 1980s. This time, however, the detailed critique developed on two quite different fronts. First, what was different for some this time was the power of the technology, and the drive towards data-rich depictions of geographical reality capable of eroding privacy and increasing (social, political, military . . .) control. Second, empiricist approaches (in contrast to other social science approaches such as social and critical theory) were deemed most unlikely to shed light on questions of valid and intrinsic academic interest, and thus infusion of GIS into the discipline of geography would never create more than a diversion and irrelevant distraction. Although perhaps contradictory (if a technology truly is capable of eroding privacy, then it surely is a worthy focus of academic concern), these two perspectives shared the common sentiment that GIS has introduced a technological distraction to legitimate academic discourse and thus has reinvigorated an approach to social science in geography which by the 1990s many had thought discredited. Some of the later chapters in the Management Issues and Applications sections air these issues in much greater detail. Pickles' important contribution, here as well as elsewhere (Pickles 1995), has been to open up these issues to constructive dialogue between the 'top down' views of the best practice of science and the 'bottom up' empirical experience of GIS users. Such dialogue is likely to lead to GIS applications breaking free from notions of 'objective' reality and (echoing the views of Johnston) may also lead to supplementation of quantifiable attributes and characteristics of geographical reality with measures of local knowledge, place-based information and other qualitative considerations.

There are lessons here for even the most unequivocal advocate of GIS – namely the need for cognisance of the philosophical background and context to analysis, and the inherent subjectivity of even the most apparently 'objective' models of reality that are abstracted within GIS. In Jonathan Raper's view this relativist honing of GIS to context is not restricted to social science applications that embrace human agency, as suggested in his review of scientific representation (Chapter 5). Physical science lies much more uncontroversially in the empiricist domain than social science, and hence it might be taken as axiomatic that there is a strong correspondence between increased richness of digital information and the accurate and orderly depiction of real-world systems. Raper formalises the empiricist conception of GIS in natural scientific applications as representing a 'bridge' between scientific theory and the real world. Yet even within natural science the way in which this structure is fashioned is profoundly influenced by our information sources and scientific conventions. 'Scientific conventions' are the ways in which we define and give significance to geographical phenomena, and the ways that we identify phenomena in space and time within GIS (when is a sand dune not a sand dune? what are its boundaries? what sort of time increments should be used to represent and model its dynamics?).

Raper's view is that the spatial and temporal context to natural science representations in GIS should be specified inductively rather than deductively, in a context-sensitive manner and in a spirit of humility rather than conviction – a view developed later in this section with respect to digital terrain models by Hutchinson and Gallant. As such, empirical science should refocus more of its efforts on the ways in which simplified representations of an infinitely complex reality are developed within GIS, and greater detail and volume of information is seen as but one ingredient of an enhanced approach to model-building. Spatial representation is thus an intrinsic component of scientific method, and must be related to theory about the way the world works and how geographical reality is structured. This mapping of reality into model is seen as being accomplished through geographic information science (Goodchild 1992) – that is, the development of formal conventions and rules for the appropriate representation of phenomena within conventional and unconventional (3-dimensional models, video and multimedia) GIS representations.

The issues and problems that Raper identifies are at least as problematic as many in the socioeconomic realm, yet here there are additional problems arising out of the strictures of confidentiality (and consequent areal aggregation of data), the ways in which boundaries are imposed around continuous spatial features, and the ways in which time is discretised during data collection. These and other problems create some differences in the definition and handling of geographical objects of study between natural and social science applications. David Martin reviews these differences here (Chapter 6). Spatial boundaries and temporal intervals pose more than an analytical inconvenience, since they lie outside of the control of the GIS analyst and cannot be changed. Moreover, there are conceptual difficulties in assigning precise geographical coordinates to human individuals and describing their activity patterns. Martin describes how these provide additional challenges to effective representation, analysis, and display within socioeconomic GIS, and discusses how representational strategies may be used to contain ecological fallacy and modifiable areal unit effects.

Taken together, the contribution of these chapters is to steer GIS users towards a more relativist conception of reality and its representation within GIS, and thence to identify how GIS data structures and architectures can be developed to accommodate the widest range of information sources. This provides a general framework for enhancing GIS-based representations of reality which are tailored to the perceptions and needs of the many. In short, it presents a broad canvas to GIS applications: the remaining chapters in this section investigate a range of topics that can further improve representation within GIS.

One socially significant facet of this critique is that if GIS has been rendered accessible only to the scientific community, then successful users have been placed in the role of experts. As a consequence, GIS is intolerant of diversity of viewpoint. Cognitive interest in GIS stems from a desire to make it easier to use, by making its user interfaces and representations more compatible with the ways people naturally think and reason about the world around them. David Mark's chapter (7) reviews the current state of cognitive research in GIS, and discusses some of the issues that are raised by this line of reasoning. He begins by appraising the correspondence between the ways in which humans perceive real-world phenomena and the ways they are represented within GIS. His approach is avowedly empiricist in approach, and sets out to examine the possible mismatches between objective measurement and cognitive models of reality. He shares some of Johnston's optimism that GIS may provide a suitable medium through which realist models of geographical reality might be built. The detail of his empirical analysis of cognitive categories substantiates the views of Raper, Martin, Pickles, and Couclelis that boundaries are *de facto* often indistinct, fuzzy, and graduated. He also describes how distance, direction, reference frames, and topology are all subjectively manipulated in common parlance, and how variations may be compounded by natural language differences (when is a lake not a lake but a pond? why are 'lodge' water bodies apparently confined to northern England?).

As Raper has already intimated, our inability to deal with time, and thus to represent the dynamic elements of the geographical world, is perhaps the most compelling of the inadequacies of maps and traditional GIS. A technology that is forced to represent the world as static inevitably favours the static aspects of the world. Thus (as Martin describes) our maps show the locations of buildings and roads rather than people, and the same biases have been inherited by GIS. The chapter by Donna Peuquet (8) reviews the state of the art in the representation of time in GIS, and specifically the problems that arise out of the inadequate definition and representation of events and timeframes within GIS. She assesses the merits of different data structures for representing time in GIS – for example, as raster coverage-based snapshots, variable length (raster) pixels, entity-based (vector) representations and geographical objects. Peuquet then reviews modes of exploring and visualising space-time interactions using GIS. It is clear from this that query languages for identifying temporal change are much better developed for aspatial, rather than spatial, database management systems (DBMS), because of the reduced dimensionality of the queries. Nevertheless, in an upbeat conclusion, she anticipates considerable improvements in the representational power and analytical capabilities of GIS in this regard.

The remaining chapters share a pragmatic emphasis on the ways in which data models may be used to fulfil a variety of end-uses. Much of the conceptual debate surrounding GIS has arisen simply because the user of today's GIS is faced with many more options in representation. Choices must be made between different scales, or levels of geographical detail; between raster and vector options; and between various approaches to representing change. Nowhere are these choices more apparent than in the representation of topography, or the form of the Earth's surface. Data are available at various scales, and in three major representational schemes: the meshes of triangles known as triangulated irregular networks (TINs); grids of regularly spaced sample elevations (digital elevation models or DEMs); or digitised contour lines. But many more complex and subtle issues exist in finding accurate and useful representations.

Michael Hutchinson and John Gallant's main concern (Chapter 9) is with identification of the guiding principles for generating digital terrain models, and an area in which (firmly in the empiricist tradition) spatial analysis of form is frequently used to draw inference about environmental process. Digital terrain models are also used in the conceptualisation (cf. Raper) and display. Accuracy and extent of spatial coverage are of importance here, of course, but there is also a sense of the recursive relationship between the way that relevant phenomena are identified and defined (ontology) and the ways in which they are subsequently analysed. Additionally, the representation of 3-dimensional structures creates a potentially vast increase in the amount of data that might be stored within GIS, many of which are likely to be redundant: clear thinking, coupled with appropriate choice of analytical technique are thus required in order to create realistic yet manipulable models of real-world 3-dimensional structures. This raises a wide range of considerations in making the choice of data model: how to anticipate/manage errors associated with GPS data capture (Lange and Gilbert, Chapter 33), whether priorities favour capturing surface variability through use of variable point densities across a surface or by representing local properties of curvature, whether and how grids may be adapted to local terrain structure, the range of scales relevant to the end-user, and the ways in which features are defined and parameterised. As the previous chapters in this section imply, the model-building process does not then terminate with a single pass through the data, and Hutchinson and Gallant describe further recursive stages of data quality assessment and model interpretation.

Robert Weibel and Geoffrey Dutton (Chapter 10) broaden this analysis, looking at the generalisation of geographical objects and cartographic features. They develop a typology of motivations for generalisation within GIS, ranging from data storage, through improved data robustness to optimising visual communication. All of the preceding contributions have emphasised that good environmental and social science data models are sensitive to context in what, through abstraction, they retain and discard. Yet such reflection is clearly not practicable where a multitude of routine decisions must be made, or where the outcome of data modelling is a cartographic product for visual display. In such circumstances, sensitivity to context may nevertheless be achieved using a range of automated and semi-automated knowledge-based methods, such as generalisation algorithms and methods for structure/shape recognition, and further methods for evaluating the 'quality' of generalisations. The principles underpinning such methods are seen as an automated development of traditional map-making conventions, in which the cartographer was always to some extent the arbiter, even architect, of cartographic form. That said, progress towards automated generalisation of digital maps has apparently been rather slower than was anticipated in the first edition of this book: however, Weibel and Dutton provide evidence of encouraging prospects in this regard, suggesting that automated generalisation may not be a 'holy grail'.

The final chapter in this section (11), by Menno-Jan Kraak, extends the discussion of the theme of scientific visualisation – that is, the presentation, analysis, and exploration of geographical phenomena. Although we naturally tend to think of visual displays of GIS databases as the digital equivalent of making paper maps, there are significant differences and opportunities. The design of a paper map is permanent, but visual displays can be manipulated and transformed freely. Scale, for example, takes on a different and more interesting meaning in a world of zoomable displays.

GIS displays can be animated, raising a host of new issues for the user's ability to perceive and understand geography through visual display. Although computer display screens are approximately flat, their use allows us to re-examine the significance of map projections, and to ask whether they are actually necessary in a digital geographical world, since there are no flat surfaces in a digital computer that are as constraining as the inevitable flatness of paper. There are also echoes here of many of the previous contributions in the description of the 'overlay model' as a simplified, error-prone depiction of reality, and a review of the effective use of symbolisation and other cartographic conventions to present spatial distributions – as well as to interpret data reliability and quality. As such, visualisation is considered an important adjunct to explanation, which helps through query, re-expression, multiple views, dynamics, animation and changes in dimensionality. Kraak's view (cf. Raper) is that GIS provides a bridge between the map and the database 'text', and he anticipates some of the ways in which video and other multimedia are set to develop and enhance the links between digital models of reality and their visual front ends.

Other issues of representation are addressed elsewhere in this book. The representation of uncertainty, another missing element in traditional maps, is taken up in the next section; and object-oriented issues in representation are discussed later as Technical Issues. But research on data modelling is proceeding at such a pace as to make it impossible to achieve a complete coverage in the space available here. This is why we have presented an extended overview of guiding principles rather than fast-changing practices. The interested reader is referred to the references in each chapter, to recent collections (for example, Molenaar and Hoop 1994), and to the continual stream of new research papers appearing in the journals of the field.

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