CHAPTER THIRTY-NINE

Postscript: New Directions for GIS Research

MICHAEL GOODCHILD

39.1 Introduction: research themes

The Organising Committee for the 1995 Summer Institute at Wolfe Neck identified six topics to serve as themes for the conference: Geographic data infrastructures; GIS diffusion and implementation; Generalisation; Concepts and Paradigms; Spatial Analysis; and GIS and Multimedia. The themes provided the organising framework for the conference, and all six are represented in this volume; together, they capture much of the active research in GIS and geodata on both sides of the Atlantic.

Almost 10 years ago, Ron Abler, then director of the Geography and Regional Science programme at the US National Science Foundation (NSF), was faced with a similar problem of identifying the research themes of GIS and geographic information analysis as the basis for NSF's solicitation for the new National Center for Geographic Information and Analysis. He picked five, after lengthy discussions with the research community: spatial analysis and spatial statistics; spatial relationships and database structures; artificial intelligence and expert systems; visualisation; and social, economic and institutional issues. The five make an interesting comparison with the Wolfe Neck six, and indicate how much priorities and thinking have changed in a decade. All but one of them are essentially technical, indicating the much higher and almost exclusive priority we gave to technical issues 10 years ago. Our understanding of social and institutional issues, a topic included almost as an afterthought in 1986 to cover a miscellany of issues that were then just beginning to be important, had become much more refined by 1995 and had expanded to include the public policy issues of national spatial data infrastructure.

For the second of these trans-Atlantic summer institutes to be held in Berlin in 1996, the organising committee has identified a further six topics: data quality; spatial models and GIS; remote sensing and urban change; spatio-temporal change in GIS; geographic information and the information society; and GIS and emergency management. 'Remote sensing and urban change' and 'GIS and emergency management' take us into domains of the application of GIS and geodata where the specific issues of the domain may be as important as the generic issues normally associated with GIS. This tension between generic and specific may also underlie other topics, such as 'spatial models and GIS', where the need to deal with the specifics of modelling hydrologic process, for example, may compete or even conflict with the need for generic modelling tools.

Of the six Berlin topics, the fifth, 'geographic information and the information society', may be the most significant indicator of deeper changes and trends in the field. In 1977 it was possible to assemble a substantial proportion of the entire research world of GIS in a conference of no more than 100 people, and for the discussion to focus solely on issues of software and hardware. The participants at the Endicott House meeting that year (Dutton, 1978) could hardly have imagined that by 1995 the field would have grown to the point where a legitimate topic of research interest would be the impact of geographic information technologies on society. Yet the attention given to the recent book *Ground Truth* (Pickles, 1995) is a clear indication that the time has come to take such issues seriously. One of the more interesting questions in this area concerns the nature of the geographies that will emerge in the information era, as telecommuting and the net bring us closer to a world in which 'there is no more "there"; everything will be "here"'.

The range of research issues associated with GIS and geodata has clearly expanded enormously in the past 20 years, as technical questions have been augmented and to some extent replaced by social ones. The pressures to work with experts in other fields have grown, as have the dangers of trying to build a new discipline in isolation. As GIS discovers new questions, there are often theoretical and conceptual frameworks already established in other disciplines to address them, and there is thus always a need to look carefully for appropriate analogues. Recently, researchers in GIS and geodata have begun to look to the library community, where structures and frameworks already exist for handling information search and resource discovery, as a way of cross-fertilising research in geodata cataloguing and metadata.

This apparently endless process of expansion of the GIS and geodata research agenda raises important and nagging questions: is the process potentially infinite, or limited; are there logical bounds to the field; does the field have a permanent core? What exactly is this field variously called GIS, geodata, geomatics, or geographic information science? If we can define it, then are there significant gaps in our current research programmes and emphases? Should we be doing more in some areas and less in others? How do the Wolfe Neck and Berlin themes fit within the broader framework? What choices should a young scholar in the field be making today to ensure a prosperous and productive future?

39.2 Defining the field: the limits

First and most clearly, the field is defined by geographic information, where 'information' is taken broadly to encompass facts, data, knowledge, and understanding, and 'geographic' implies a specific tie to locations on the Earth's surface. Because 'location' can refer to anything from the Atlantic Ocean to a position defined by coordinates to the nearest millimetre, the range of possibilities included in this definition is so enormous that it may be easier to define geographic information by its exceptions, which clearly include facts that are true everywhere on the Earth's surface, and facts that are true only at unspecified locations. Not surprisingly, it is often asserted that the majority of information is geographic in particular domains, such as local government.

'Geographic' is often replaced by 'spatial'. On the one hand this may mean a generalisation to any two- or three-dimensional frame, not only the Earth's surface; this would include medical imaging, where the frame is the human body, and it would also include engineering and architectural design problems where it is not necessary to tie the project frame to the Earth's geodetic frame. Clearly, many issues of geographic information extend to spatial information under this definition. On the other hand 'geographic' is often replaced by 'spatial' or even 'geospatial' for no other reason than the baggage the first term is believed to carry, although for many people 'spatial' probably carries stronger associations with outer space than with the Earth's surface.

So far so good. But why is geographic information worth singling out, rather than any of a myriad of other ways of partitioning the information pie? Why not a science of geriatric information, or genetic information? Are the issues of geographic information of sufficient importance, and sufficiently separable from issues of non-geographic information? Clearly we believe so, but we may have difficulty putting our collective finger on the reason, and may even feel a little nervous from time to time that there may not be anything particularly special about a database that happens to contain geographic coordinates. At the very least, many of the issues of geographic information also underlie spatial information, and there is little sense in separating research into the processing of raster information in GIS from research in image processing and pattern recognition. After all, geographic information in raster form may even fail the simplest test of being geographic: that of the presence of a geographic coordinate.

In summary, concern with geographic information is a necessary but not a sufficient condition for the field. There are issues of geographic information that may be better studied in other fields, because the geographic tie does not imply a strong enough separation. Many of the social and institutional issues of geographic information, for example, are not sufficiently different from similar issues of other information types to warrant their being studied separately, or to suggest that associated and distinct theoretical and conceptual frameworks need to be established.

39.3 Defining the field: the core

If the limits of the field are inevitably indistinct, then perhaps it is easier to define the core, by identifying the central, fundamental questions associated with GIS and geodata. Here again the presence of a geographic coordinate seems a weak basis on which to define a field. On the other hand, the concepts that are formalised and implemented in GIS go far beyond the description of point position, to include a much wider and more sophisticated set. They include the topological relationships of adjacency, connectedness, and intersection; geometric concepts of direction and distance; concepts of simple and complex geographic objects, from points, lines and areas to watersheds, viewsheds and anticlines; and the concepts embedded in models of the processes that affect the landscape.

Not all geographic concepts can be captured in a digital computer, in which everything must be expressed in terms of discrete binary representation. The Earth's surface is infinitely complex and continuous, so inevitably digital representations must be approximations or generalisations of the truth. This gives us one of the core defining problems of the field: that of finding useful approximations and representations, or data models for short, that capture significant aspects of real geographic phenomena in digital form. Moreover, the constraints on representations in digital computers are rather different from those of the human mind, leading to a second core problem: that of the tension between human cognition of geographic concepts and their digital representation. If these are not equal or at least equivalent, a digital database can be inherently difficult to comprehend and use. Finally, having built a digital database of geographic phenomena, we must then ask about the impact such a database has on the society that built it, and about the institutional problems inherent in building and managing it.

This line of argument leads to a vision of the core of the field: the study of geographic concepts; their role in human cognition; their formal representation in digital databases; their use in modelling, prediction and decision-making; the issues of the management and use of such databases; and their impact on society. Our earlier definition of geographic information, and the associated test of the presence of Earth coordinates, must be revised to allow for a more sophisticated range of geographic concepts that extends well beyond point location and simple geometric primitives to include all of the concepts used to represent, learn and reason about, model, and express our understanding of the patterns and processes found on the surface of the Earth. Some of these are generic, and some specific to particular domains and disciplines.

There are many contenders for an appropriate name for the field. 'GIS' is a popular contender, but it might suggest that one's research consisted of nothing more fundamental than the routine application of currently available software tools. The interpretation of the acronym seems to have drifted somewhat recently, from a type of information system, and therefore essentially software, to a shorthand for digital geographic information; hence the need to qualify 'GIS' further as in 'GIS system' and 'GIS data'. 'Geomatics' and 'geoinformatics' say little but are easily translated. My own preference is for 'geographic information science', which seems logical and informative, and plays nicely on the familiar acronym (Goodchild, 1992).

39.4 Where next?

If geographic concepts form the core of the field of geographic information science, then how well is the research community covering the core, exploring the periphery, and providing the basic research that will sustain new developments in GIS and geodata? How well do the topic sets of Wolfe Neck and Berlin address the fundamental needs of the field? These are large and challenging questions, so perhaps I can be excused for addressing them with a number of examples, rather than by attempting any kind of comprehensive analysis.

As sciences age they tend inevitably to institutionalise themselves, driven no doubt by the pressures of academic life, which tend to be centrifugal rather than centripetal. Small communities of like-minded scholars sustain themselves through the processes of peer review in publication, funding, and promotion, in ways that can seem almost completely detached from any larger agenda. Multidisciplinary fields like geographic information science are perhaps better equipped to avoid these patterns of behaviour, through a constant process of cross-fertilisation from other disciplines. At the same time it is important not to lose sight of the core, and to ask the kinds of questions outlined earlier is this topic best studied in this field; does its focus on geographic concepts provide a unique set of problems; and are there established theoretical or conceptual frameworks in other disciplines that might inform the problem?

One of the most challenging aspects of geographic information is its essential diversity. The problems of data quality, for example, are vastly different for raster images, vector representations of topographic features, and linear networks, and it is not at all obvious that there are benefits to be gained from studying them together. Arguments for the viability of geographic information science must look outward, as in the earlier discussion of limits, but also inward.

Research in geographic information science must also be informed by the essential nature of geographic data, which is so diverse and idiosyncratic as to make generalisation exceedingly difficult. It may be pointless, for example, to compare algorithms for performance when it is quite likely that for any given algorithm a set of geographic data exists for which that algorithm's performance is optimal. Geographic data sets do have generalisable characteristics: it is hard, for example, to find a data set that violates Tobler's 'first law of geography' that nearby places tend to be more similar than distant places; and it is also difficult to find a geographic data set that does not exhibit spatial heterogeneity (Anselin, 1989). The structure of geographic data is subtle and complex, as one can readily demonstrate by deleting all annotation from a map or image and asking questions such as 'What map is this?', 'Where is this?', or 'What scale is this?'

With these points in mind, I would like to suggest three areas where we are not yet doing enough geographic information science; as I noted earlier, this is very much a personal list and I make no claim to be inclusive or even fair to all of the GIS research community.

39.5 Metadata: describing data to others

The term 'metadata' has been called the least loved in science, in part I suspect out of frustration that solutions to such a seemingly simple problem are so hard to find. 'Data about data' allow us to locate useful information through processes of information resource discovery, much as one browses through a library; to describe the contents of data sets to others so that they can input and use them, or assess their fitness for use; and to capture technical information necessary to the successful packaging and handling of data in systems. In the case of geographic information, our current inability to do this is appropriately summed up in the acronym 'SAP', or spatially aware professional — that only someone with extensive experience in the field is capable of understanding someone else's description of a data set, or statement of needs. This is not to say the process is inefficient to a SAP — the information passed by the initials 'DCW' in a file header is useful and complex. To a non-SAP, however, the initials are meaningless and must be replaced by a detailed and exhaustive description. Our problem is that

we have no accepted means of expressing that description. We lack a common, rigorous vocabulary that gives precise meaning to terms like 'layer'.

The momentum to find solutions to these issues is now very strong, through efforts like the US Federal Geographic Data Committee's Content Standards for Geospatial Metadata (http://fgdc.er.usgs.gov/metaover2.html), the Open Geodata Interoperability Specification (OGIS; http://www.ogis.org), and the efforts of Technical Committee 287 (CEN, 1995). What is missing at this point is a sound, general theory of geographic information on which a unified approach could be based, with appropriate extensions to the third spatial dimension, time, problems of multiple scales and accuracy. Such a general theory is a necessary precursor to a rigorous vocabulary and the implementation of a comprehensive approach to metadata. Further complicating the issue is the need to describe both analogue and digital data resources with the same vocabulary, since at least some information resources will continue to be in a traditional analogue form for some time to come.

39.6 Paradigms of spatial decision making

Not long ago, a computer was a machine that executed a series of instructions provided by a user, either in batches or interactively. The arrival of client–server architectures stimulated new ideas about how to interact with computers, leading most recently to the explosive impact of the World-Wide Web, with its metaphors of information publication and casual browsing. Peer-to-peer architectures will stimulate another round as they become more widely accessible with suitable software tools; one could argue that this is happening already in the 'chat-rooms' of the Net.

The same progression of architectures has stimulated new thoughts about spatial decision-making, and the role of computers in solving problems in areas traditionally reserved for professional planners. Batch computing allowed only the solution of problems that could be completely posed in advance, and reinforced the role of the professional as the custodian of an authoritative technology. Interactive computing, which began to appear in the late 1960s, led to the development of spatial decision-support systems, where ill- or incompletely posed problems could be refined through a human–computer dialogue, and allowed the technology to become a more intrinsic part of the decision-making process. It also promoted research on spatial reasoning, and other links between computing and spatial cognition. Client–server tools like the Web allow information about the decision-making process to be published for all to see, promoting citizen involvement and concepts of electronic democracy. Newer technologies like the Web are far easier to adopt and use than their precursors, which in part explains their explosive growth, but also puts great pressure on the research community to explore their implications.

39.7 Data fusion

The third example is more technical, but is similarly driven by changes that have occurred in computing and the increased interest in digital geographic information over the past two decades. As it becomes easier to share and exchange data, and greater and greater resources are invested in creating digital geographic data sets, it becomes increasingly likely that one will discover more than one source of the same geographic fact. The spurious polygon problem, a term given to the slivers that appear when two versions of the same line are overlaid, was an early example, occurring whenever a particular geographic line appeared in more than one layer or coverage. Software products have continued by and large to emphasise high geometric precision, and to deal with sliver polygons on a purely geometric basis rather than through a comprehensive analysis and tracking of positional accuracy.

Data fusion, or the successful merging of apparently conflicting geographic information, is increasingly necessary where GPS measurements disagree with positions digitised from topographic maps; when data must be updated with new measurements; when vector representations of features must be made consistent with raster backcloths; or where information must be reconciled across map boundaries. Besides purely technical issues of algorithms, it suggests the need for more comprehensive statistical models that are analogous to traditional methods for scalar measurements, and raises interesting questions of quality control, costs and benefits.

39.8 Discussion

The three areas described in the previous section as potentially fruitful for new research are all concerned with geographic information, and in each case it seems clear that the geographic dimension presents problems that are to some extent unique. In addition, they are all to some degree technology-driven; the need for research has been created to some extent by the technological advances of the past few years, and the impact these have had on society. The need for research on metadata, for example, is precipitated at least in part by the development of new search tools on the World-Wide Web, and the technologies of digital libraries, although one could argue that a much older motivation derives from the problems of finding maps and atlases in map libraries.

The idea that research should be driven by technology is itself somewhat new, and might have surprised the GIS research community of even 10 years ago, when computers and their applications were seen strictly as tools. Today, and particularly following the explosive interest in the Web of the past two years, it seems entirely reasonable that the research community should study, if not try to anticipate, some of the more significant effects of technology on society. In this sense our research priorities are changing, as computer technology's influence on late twentieth-century society continues to grow. Our new tools allow us to do things we never thought necessary, let alone possible, 10 years ago and, like it or not, many of the changes we now observe in society are indeed technology-driven.

This last seems an appropriate concluding point for this short postscript. The ESF/NSF Summer Institutes are one of the few series of meetings that have tried to achieve a comprehensive coverage of the field of GIS research in recent years, and they demonstrate both the field's vitality, and its essential coherence. The field has evolved from a relatively exotic speciality built around a small but powerful computer application, to something approaching a discipline in its own right, with a strong and well-defined intellectual core. It must continue to evolve rapidly if

it is to keep up with the extraordinary changes that are occurring in society driven by computer technology, and we can expect to see evidence of that even in the short 12 months between the two Summer Institutes. By doing so, it will help ensure not only the future vitality of GIS, but also our understanding of the broader implications of the digital representation and manipulation of geographic concepts.

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