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Re-presenting Geographical Information Systems

Peter Fisher and David J. Unwin

1.1 Why 'Re-Present' GIS?

The increasingly widespread use of Geographical Information Systems (GISystems, widely known as GIS) has meant that a version of 'geography' has been exported to many other disciplines and walks of life where this technology has been found to be useful. As an undergraduate, one of us read *Applied Geography* by Dudley Stamp (Stamp, 1960). It is full of ideas and examples of the applications of geography in the real world, but it has taken the better part of half a century for much of Stamp's vision to become reality; the rest of the world – including many cognate sciences – have discovered the power of something they call 'geography'. It is wise to treat the word with caution, however, since there are at least three ways in which 'geography' is used. First, and at its simplest, geography is the places and spaces on our planet. Second, in the analysis of geographic information, 'geography' is often used as a short hand for the spaces and distances used to explain or model some phenomenon. Third, there is the Geography of our schools, colleges and research institutes; the academic study of the previous two readings. Typically, it is the usefulness of the second usage, in turn almost entirely a consequence of the phenomenon of spatial autocorrelation, which explains the evident popularity of GISystems.

In his essay in *Political Geography Quarterly*, Peter Taylor (1990) referred to this process as the 'imperialism of the new geography'. In the vanguard of this imperialism has been the technology of GISystems, which Taylor paints as the villain of the piece.

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GISystems have been the subject of much academic boosterism – verging on evangelism – from both geographers and others. A necessary condition for the widespread use of GIS has been the availability of relevant locational information and suitable computing environments, and recent decades have seen these both become commonplace. The imperialism of GISystems has, however, not been a case of geographers conquering the territory of other disciplines but rather of those disciplines generating an internal demand for GISystems fuelled by the discovery that 'geography', defined loosely as 'where things are', actually 'matters' (see, for example, Hall, 1992).

So, large parts of the world have discovered geography through the use of GISystems and this is only likely to increase with the recent introduction of Location Based Services (LBS) on the back of mobile phone technology. Arguably, GISystems technology has at least hastened, if not caused, the resurgence of 'Geography' as a discipline in US universities and schools, a resurgence that does not seem to be happening in the UK. Together with this widespread adoption of GISystems, however, can come the impression amongst users that GISystems *are* geography and, worse still, that the representations of geographical phenomena stored within GISystems are unproblematic in academic Geography. Nothing could be further from the truth. Since 1990 or so, there has been a geographers' version of the so-called 'science wars' in which cultural and social geographers have attacked something they call 'GIS'.

The first shot in this geographical war was probably that fired by Peter Taylor in his 1990 editorial about what he called GKS (Geographical Knowledge Systems). A few years later, John Pickles (1995) edited *Ground Truth*, a set of essays that led to conference debates and a collection of papers in *Environment and Planning A* (Flowerdew, 1998; Clark, 1998). More recently still, we have seen publication of Michael Curry's *Digital Places* (1998) and a typically forthright attack on these critiques from Stan Openshaw (1998).

A summary of the internecine war in geography over GIS is outlined by Taylor and Johnston in an essay on 'GIS and Geography' in *Ground Truth* (Taylor and Johnston, 1995). Their story is roughly as follows. During the 1960s something called quantitative geography grew up and was for a few years the dominant research paradigm. There are difficulties and contradictions in this approach when it is applied to social studies, and so in the last twenty years leading human geographers have moved on to find explanations grounded in critical social theory; dialectics, rather than data, have become the main research tool. A more recent articulation of a similar nature can be found in Hamnett's account of contemporary human geography (Hamnett, 2003). A spirited response from Johnston *et al*. (2003) points out that quantitative analysis in Geography has not gone away, but this rejoinder has little to say about the GIS phenomenon, one of the principal tools being used in the analysis of large social science datasets. So, while the academic debate has proceeded, some geographers, the 'unreconstructed quantifiers' of Taylor's account, together with spatial statisticians, cartographers and computer scientists, have contributed to the creation and use of GISystems. In turn, this has reinvigorated empirical analysis, often of a strongly applied nature, within the discipline. A large part of this group of academic geographers would nowadays almost certainly regard themselves as practitioners in a discipline they call geographic information science (Goodchild, 1992), with a content and concerns drawn in part from academic Geography but also widened to include geomatics, cartography and parts of computer and information sciences.

The need for GIS to be *Re*-presented to the wider world in an accessible form is grounded in the problem, both within the discipline and the wider world, that GIS may be seen as an unproblematic encapsulation of Geography, and that researchers developing or using GIS may not be aware of the distinction. This book is intended to give such a Re-presentation, dwelling primarily on representation which is at the heart of the issues raised by the critical geographers and also the roots of the possibly simplistic views of users of GISystems. In this introduction we note the separation of the GISystems and the GIScience that underlies it. Then, we discuss the basis of this representation issue and introduce the parts of this book that attempt to address it.

1.2 Separation of GISystem and GIScience

1.2.1 The GI Continuum

As noted above, those involved in the Geographical Information project have argued for a separation between the Systems and the Science (Goodchild, 1992). This separation seems to have been ignored by some contributors to the GI wars. To clarify the concepts, Wright *et al*. (1997) used an email discussion list to examine the relationship between GISystems and GIScience. Arising from contributions to the discussion, they proposed a continuum with Geographical Information Science (GIScience) at one pole, and Geographical Information Systems at the other. To them, GIScience includes all areas of interest to those engaging with the theory of the methods used, and GISystems is use of the software itself. Between the poles, they placed GIS as ‘toolmaking’, mediating between the science and the system. This model is, however, theoretically problematic, as suggested by Pickles (1997) and Fisher (1998). It results in polarisation of the subject material. Among other things, it implies that:

- users of a GISystem cannot be indulging in a valid scientific endeavour unless it is in the scientific domain of their subject (archaeologists using GISystems can be doing archaeology but not valid spatial science); and
- the unthinking use of a system by a soil scientist may be doing good soil science, but is never doing more than using spatial science.

This seems extremely unsatisfactory because the uncritical use of a GISystem can never be good science in any sense. Furthermore, this model has no explanatory power as to how either GIScience or GISystems develop.

It would appear that this continuum model has more to do with how people theorise (science), develop (toolmaking) and employ (system) GIS (in both the Science and the System sense). Neither the user nor the theorist of spatial information is necessarily an exclusive specialist. Many individuals develop new and interesting spatial theory using existing GISystems, or they may develop original computer programs because no GI System can be used for implementation of the concepts. The labelling of Application Sciences and Spatial Sciences is intended to illustrate the idea that soil scientists and demographers may add to spatial science in the course of their own domain research. Therefore, people do not see themselves at the poles but on the continuum from pure theory development to extensive system use. Indeed, the primary evidence for the model of Wright *et al.* (1997) is personal statements made on the email list. Pickles (1997) points out, however, that such statements are most commonly informed by opinion, rather than by critical reading or understanding of the issues in the philosophy of science. The continuum concept describes people well, but it fails to theorise the relationship of either the science or the system.

An alternative basis for exploring the interactions of GI Systems and GI Science is proposed by Fisher (1998) (see Figure 1.1). This cyclic metaphor recognises that theory of some kind underlies any tool and is implemented in the production of that tool. Thus the Tool, a particular GISystem, is no more than the realisation at a particular time of some of the theoretical spatial concepts of GIScience. This interpretation is based on how almost all scientific instruments work from, a Seismograph to an Atomic Absorption Spectrometer, which would not exist without scientific theory relating to transmission of shock waves through the earth in the first case and the resonance of atoms in response to electromagnetic radiation in the second.

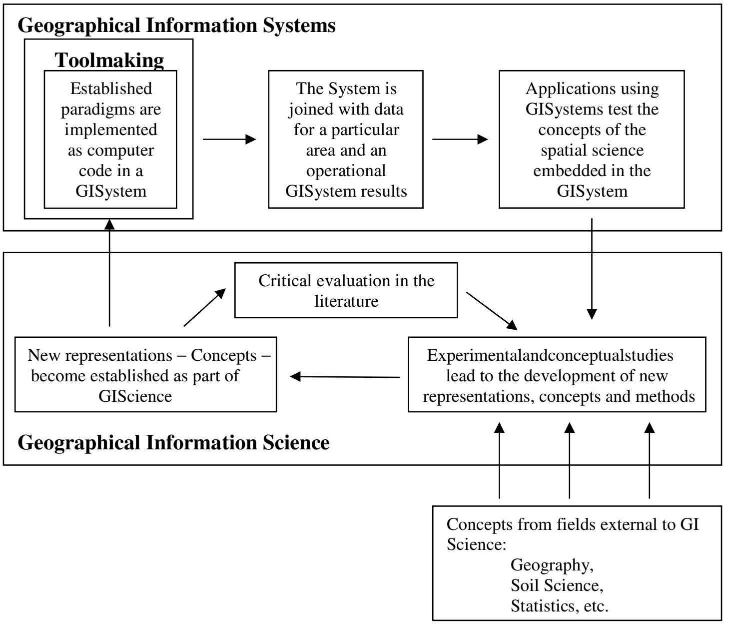

Figure 1.1 *The GI Science–System cycle (after Fisher, 1998)*

Many people will recognise the GIScience cycle of Figure 1.1. Here we can see the development of concepts resulting from the critical evaluation of existing ideas through publication and critique in the scientific literature, and resulting in the development of new concepts. This is not a closed system, but rather can take as input ideas from other spatial sciences including mainstream geography. This is similar to the advances in other sciences, but can be seen as the essence of spatial science and spatial theory, criticised though it has been as disembodied and denatured (Tilley, 1994; Pickles, 1995). The criticism seems to be that any method should be specific to data, and can only have any meaning in a particular context.

As well as the lower conceptual loop, Figure 1.1 shows an upper loop, the implementation of the GISystem itself. A GISystem is a realisation of a particular set of spatial concepts at a particular time, and so this loop shows that users of GISystems make use of the concepts embedded in that system in their applications. Therefore they are in a position to evaluate critically those concepts in the context of their application. Since the concepts at any one time are only a state of understanding, they may or may not work well for a particular application. If they fit well, the user of the system can provide valuable feedback and supporting critical valuation of the embedded concepts. If the concepts do not fit well, then the critical evaluation is equally valid and helpful to spatial theorists and system developers in revising either the spatial theories or the GISystem.

Some concepts may be used legitimately within a particular GISystem or indeed many GISystems for a considerable period of time. There is the risk that the majority of practitioners will not critically evaluate these concepts, and they may be considered paradigms in the sense of Kuhn (1970). Fisher (1996) has listed a number of GIScience concepts that might be considered in this way including the paradigms of the Boolean map, the layer-based raster or vector models, Euclidean metrics of space, production cartography, and the image. As with all paradigms, a concept that reaches such ‘heights’ does not have to be correct; it is merely a convenient and agreed way to conceptualise and interpret the world at a particular time. Critical thinking should always be evaluating such paradigms.

Arguably those using a particular GISystem may be so removed from the general theory of Spatial Information that they can only think in terms of the implementation with which they are familiar (anecdotal and empirical evidence of this abounds; Medyckyj-Scott and Hearnshaw, 1993; Davies and Medyckyj-Scott, 1994). Indeed, it follows from this that Taylor and Johnson (1995) and others among the GIS critics are correct, in that particular GISystems can be criticised for over simplifying spatial concepts and for (possibly unknowingly) imposing particular approaches on the data and ultimately on the people about whom decisions are being made. This does not mean that there are not more appropriate methods in the larger toolkit of spatial theory. Thus, either theoretically or practically, the inherited constraints in the implementation need not constrain the developer, but their level of knowledge of Spatial Information Theory in general (GIScience), and their ability to implement those concepts with the toolkit they have available, are constraints which may result in the inappropriate use of technology. Not every possible conceptualisation of spatial information in the totality of GIScience is implemented in some GISystem. If that were the case, there would be little research remaining in GIScience, which is certainly not the case! Rather, active researchers in the theory of spatial information are attempting to expand the concepts specifically to relax these constraints.

1.3 Why Representation?

Taylor and Johnston’s (1995) argument that ‘in GIS data are usually treated unproblematically except for technical concerns about errors’ is only true in the application of GISystems where it is a necessary evil in the use of such systems. However, it is anathema to GIScience researchers; in GIScience there is enormous concern to produce models that better match our existing domain knowledge and approaches. Object orientation, fuzzy boundaries and object classes, three and more dimensional models, multiple representations, spatial languages, and multi-media may be absurdly primitive, but they are all steps along a difficult road to revise continuously the representations of the world that can be said to be at the heart of the GISystems.

In most critiques of GIS, one issue that repeatedly arises is the tendency of GIS to promote or privilege certain types of representation at the expense of alternatives (Aitken and Mitchel, 1995; Martin, 1999; Raper, 1999; Sheppard, 1995; Sheppard *et al.*, 1999). This ‘problem’ is neither unique to geography, nor is it particularly new (see, for example, Tuan, 1957; Lowenthal, 1961). All disciplines have to address it and it is not clear that the issue of digital representation is either any more complex or more problematic than analogue or other representations. Some of the representational issues that arise in GIScience relate to:

- *Space vs. place*. GI theory articulates the idea of absolute Euclidean spaces quite well, but the socially-produced and continually changing notion of place has to date proved elusive to digital description except, perhaps, through photography and film.
- *Entitation*. What are the objects of interest and is it legitimate to ‘objectify’ individuals?
- *Description*. Objects of interest, be they areas or people, may well themselves be incapable of crisp description. In a technical sense they are ‘fuzzy’ and, if they are regions of the earth’s surface like a town centre, they have uncertain boundaries.
- *Temporality and change*. Digital geographies are usually static descriptions and the technology has found the representation of change in time extremely hard to operationalise.
- *Creating space and time*. The continued, and tightly coupled, creation of space and time conflates all the above issues into a single representational problem.

To some degree each of these issues is addressed in this volume, and in the remainder of this introduction we examine some of the progress that has been made and what remains to advance them further.

As in geography generally, scale is a fundamental aspect of the representation of geographical information. Treatments of this problem are varied, but this is not part of the agenda for this book. The interested reader is referred to the recent treatments of this issue in the GIScience literature (Quattrochi and Goodchild, 1997; Tate and Atkinson, 2001).

1.3.1 ‘Not Just Objects’

If a relational view of space is to be of any use, we need to represent objects that create and represent the ‘place’ in the space. Most GISystem implementations assume that objects of interest are uncontroversial, and have definite, fixed boundaries that can be represented in a digital world. This certain world of the GISystem is, of course, mostly a fiction and this has been recognised through more than two decades of work on error and uncertainty (Fisher, 1999). Does the unobserved or un-modelled detail matter? At least two sources of imprecision are of concern in GIScience: what we define as objects and how we delineate them.

Defining objects has a social dimension and so it is not a value- or culture-free operation. This matters, for example, in attempts to make databases interoperable, or in transforming geographic information for differing purposes when the context in which that information was created is ignored. For example, work by Bibby and Shepherd (2000) shows that even the apparently unproblematic idea of land use cannot readily be captured in a digital representation. Importantly, they show that the apparently abstract theoretical considerations raised by entitation have had important implications for a range of policy related research. Similarly, Thurstain-Goodwin and Unwin (2000) have attempted to define town centres, a project that immediately poses difficult problems of definition and delineation since the notion of a town centre can be viewed as an archetypal example of a fuzzy object with an uncertain boundary. Formal approaches have been proposed to this problem using fuzzy and rough set theory. In this book, Chapters 3–6 by Schuurman, Harvey, Bibby and Fisher *et al.*, address a selection of issues related to the social context of geographical objects and information.

In GIScience, these types of concern have usually been articulated by the notions of 'error' and 'uncertainty' in the ways in which we chose to model objects (Unwin, 1995). Uncertainty arises because information about 'geography' is always *imperfect*, being often either *imprecise*, *inaccurate*, *vague,* or some combination of all three. In Chapters 7 and 8, first Ahlqvist then Duckham and Sharpe address these issues. The latter recognise four different formal models that are being used to manage and describe uncertainty in geographic information:

- *Stochastic models*, using well-established ideas from both classic and geo-statistics (e.g. Ehlers and Shi, 1996; Heuvelink, 1998; Leung and Yan, 1998; Shi, 1998);
- *Fuzzy set theory.* This has been used successfully to describe the inaccuracy of land cover classifications (Woodcock and Gopal, 2000), boundary imprecision (Leung, 1987) and so on. The assignment of fuzzy membership values is the Achilles heel of this approach, and is still not clearly understood, but the approach is an attractive one.
- *Three valued logic*, most often using rough set theory in which elements are either 'in' 'out' or 'neither in nor out' of a set (Worboys 1998; Ahlqvist *et al.*, 2000).
- *A variety of alternative logic models.* Three value logics are themselves an example of the more general multi-valued logics that can also be applied to spatial data.

These models attempt to create a consistent representation of an inconsistent reality and, according to circumstances, all are valid approaches but none are well-handled by traditional relational database technology which sets great store by consistency.

1.3.2 'Not Just Space'

One of the great achievements of western science has been the notion of Euclidean space as an infinitely extended and infinitely sub-divisible continuum in which each point can be specified by means of a tuple of numerical co-ordinates. This physical conception of space has proved to be enormously useful in virtually all physical and natural science.

Whether implemented in a field or an object data model, this common sense view of space makes a number of assumptions:

- Space is a ‘given’ and is usually conceptualised in an absolute sense as providing a fixed frame of reference in which to locate objects Note that it is assumed to exist independently of the objects themselves.
- Entities are uncontroversial and are in some sense externally defined.
- Space is more important than time. If it is considered at all, time is seen as an attribute of objects.

This does not mean that the language is adequate for all needs (Mark and Frank, 1991), and it does not mean that these assumptions are a necessary part of space as people experience it. In fact, even in its own terms, it can give problems when the representation is created in a digital environment. In what Goodchild (1995) called the ‘absurdly primitive world of the digital computer’ we represent locations using (x, y) tuples in which the values are expressed in fixed, finite increments. This is fine – sooner or later we always have to do this – but outside of the computer we change the word length to suit the problem (‘no. of significant figures’). To argue that 32 bits is not enough for pure location would be silly, it almost always is, but:

- In calculations, all the problems listed by David Douglas (1974) in his classic paper ‘It makes me so cross’ are related to the inability to geo-reference objects with infinite precision. Similarly, many authors have pointed out and illustrated the computational problems of using a finite and fixed numerical precision (Unwin, 1975, for example), and Worboys (1995, p. 188) discusses the ‘problems arising from discretization and the Green-Yao algorithm’.
- The issues tend to be discussed in conversion of vector to raster data (or other tessellation-based data structures) and so cannot be avoided. Much of the technical literature is about the ‘errors’ rather than the necessary ‘artefacts’ introduced into derived fields (such as gradient) or objects (such a view and water sheds) from this discretisation.

More importantly, as Lefebvre (1991) points out, this representation of space has problems when attempts are made to use it in the study of the social world that people experience, whether it is in describing personal interaction or the physical environment. The space is not an infinitely empty space, it is a populated space. Indeed, mathematical and computational geometry are the realm of the study of that empty space, and surveying is its application to the world. At the heart of geography is the description of what populates the space on the surface of the earth. Geographical knowledge is far more than the specification of positions by means of co-ordinates, and, reasonably, to some it has nothing to do with that co-ordinate position. This has been recognised, at least implicitly, throughout the development of geography. Nonetheless, the traditional mathematical conception of space is widely perceived as constituting the dominant influence in providing a theoretical basis for GIScience, yet it falls dramatically short of the kind of rich and highly structured conceptions of space that are required to do justice to all the concerns of either the natural or social sciences (Egenhofer *et al.*, 1999; Yuan, 2001).

In this book, the essays in Part II address how we conceptualise space, examining so-called ‘qualitative’ (Galton), ‘network’ (Batty) and ‘perceived’ (Llobera) spaces.

1.3.3 ‘Time as Well’

In representation, time is seen by many as the ‘other’. As a concern, it lies beyond objects and space, but for representational completeness time should be explored as well (Raper, 2000). One of the major difficulties in using GIS to support science is still the poverty of the mechanisms we have for integrating time into our representations. In 1960, the integration of spatial and temporal description was taken by Henry Clifford Darby as the theme for his IBG Presidential address on ‘The problem of geographical description’ (Darby, 1960). First, Darby recognised the necessity to treat space and time *together* in the same representation and, second, the six literary and cartographic strategies he recognised as solutions to his ‘problem’ map very closely into what has been attempted in GIS.

There has been a range of different strategies and approaches to the representation of the spatio-temporal, including:

- transformations from 4D to 2D, 2D + time, or 1D plus time (Langran, 1992);
- addition of dynamic behaviour to spatial representations (Wesseling *et al.*, 1996)
- visualisation and animation of change (Hearnshaw and Unwin, 1994);
- use of concepts from the ‘time’ geography of Hagerstrand (1970) (Miller and Wu, 2000; Miller, Chapter 16, this volume);
- formalisation of qualitative spatio-temporal change.

The papers by Massey (1999, 2001; see also Raper and Livingstone, 1995, 2001) in which she explores the communalities between physical and human geography in conceptualising space, time, and space-time, address general issues in how we represent space and time in digital ‘geographies’. Massey directs attention to some emerging similarities of concern that have not as yet been articulated but which have both theoretical and practical implications for spatial science. Incorporation of time will not be easy, however, for three reasons:

- Emergent phenomena. In the context of a coastal spit, Raper and Livingstone (1995) devised a data model that enabled them to handle phenomena that emerge as time passes, common in all process studies. In this volume, Chapter 14 by Raper explores this issue.
- Different perceptions of time. In Chapter 15, Cheng looks at some different spatio-temporal structures.
- Simulations of temporal processes. Muetzelfeldt and Duckham (Chapter 17) introduce the interactive and object based Simile environment for simulation with particular emphasis on its spatial processing abilities.
- Personal descriptions of events. Finally, in this volume in Chapter 18, Guhathakurta describes an approach using narrative emerging from use of GIS as a way of investigating an area.

Of course, objects, space and time interact and a crucial task for GIScience is to further the integration of the three, in particular accommodating the challenges of each as articulated here, as well as challenges which have been set elsewhere and those which have not yet been devised.

1.4 The Uses and Ethics of GIS

Finally, two issues that greatly exercised some of the contributors to *Ground Truth* were the democratisation of access to GIS technology and the ethical implications of its use. We believe that it is in these areas that those of us who work in GIS have a great deal to learn from our social and cultural geographer colleagues.

In *Ground Truth*, Harris *et al*. (1995) (see also Weiner *et al*., 1995) pointed out that GIS can be used to pursue social goals through what they called participatory GIS (PGIS, also known as public participation GIS, PPGIS). This area is rapidly being developed, at least in the USA (see Rundstrom, 1995; Sieber, 2000; Talen, 2000), but perhaps less so elsewhere. It is tempting to suggest that the lack of development elsewhere can be explained by perhaps two major factors: first, the contrast in data supply policy between easy and essentially free access to 'framework' data in the US compared with notions of copyright and tradable information, with its associated high costs, in most other countries; and second, it might be that centralised government disempowers local people and hence provides little incentive for development of PPGIS.

A particularly taxing essay in *Ground Truth* was that by Michael Curry (1995a) in which he highlighted what he saw as inevitable ethical problems in the application of the technology, a theme he returned to later (Curry, 1995b; Curry, 1998). His argument seems to revolve around the idea that users of the technology are not worried about any ethical implications. In fact, there has been a steady flow of papers that have shown concerns for such issues, including Openshaw (1993), Rix and Markham (1994), Dale (1994), Obermeyer (1995), Onsrud (1995) and Crampton (1995), to name a few which appeared before or very soon after Curry's paper. It would have been a good conclusion to this volume to have extended its scope to cover the issues that arise here but, to our regret, this has not proved to be possible.

1.5 Conclusion

All the papers in this book challenge the current paradigmatic models of space represented within current GISystems. None leaves the current models unquestioned. This book will have been a success if the reader finishes with the impression that the representations we use within current GISystems are problematic for the GIScience community. It will be even more successful if some of the representational issues raised in the chapters have an influence on the development of future GISystems, something only time will tell.

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