



Historical GIS: structuring, mapping and analysing geographies of the past

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Abstract: The last 10 years have seen a sudden rise in interest in the use of Geographical Information Systems (GIS) in historical research. This has led to a field that has become known as ‘historical GIS’. This development started in the more quantitative ends of the discipline but has spread to encompass qualitative research as well. Interest in historical GIS is not restricted to researchers who would previously have regarded themselves as historical geographers, but has in fact led to an increased awareness of the importance of geography from across the discipline of history. This paper introduces historical GIS and critically evaluates how it is affecting the practice of historical geography.

Key words: geographical information systems, GIS, historical geography, historical GIS, spatiotemporal analysis.

I Introducing historical GIS

Writing about the state of historical geography in 1997, Ogborn (1999) made no mention of the use of Geographical Information Systems (GIS) in the discipline. This was not a significant omission because at the time historical GIS, as the topic has since become known, was in its infancy. Since then the field has grown rapidly and is becoming increasingly acknowledged as an important development in historical geography. It received significant amounts of attention in Holdsworth’s two more recent reviews of the state of historical geography (Holdsworth, 2002; 2003), while

Baker (2003: 44) describes it as ‘an exciting and challenging development’. It seems opportune, therefore, to describe the current state of historical GIS and to examine the challenges it faces.

Many historians and historical geographers regard GIS as primarily being concerned with mapping. Although mapping is one of the key abilities of GIS, it is perhaps better regarded as a database technology. A GIS is a specialized form of database because each item of data, be it a row of statistics, a string of text, an image, or a movie, is linked to a coordinate-based representation of the location that the data refer to.

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Thus GIS combines *spatial data* in the form of points, lines, polygons, or grid cells, with the *attribute data* held in conventional database form. This provides a structure that is able to answer queries not only about *what* features are in the database, but also about *where* they are located. This is what makes GIS unique (for general surveys of the field, see Burrough and McDonnell, 1998; Longley *et al.*, 1999; Worboys and Duckham, 2004).

Gregory *et al.* (2001a) identify three advantages of using GIS in historical research. First, as spatial data tell us where the data are located this can be used to structure a database and to integrate seemingly incompatible data simply through where they are placed on the Earth's surface. Second, it allows data to be visualized using maps and more advanced techniques such as animations and virtual landscapes. Third, GIS enables forms of spatial analysis where the coordinate locations of the features under study are an explicit part of the analysis.

Together these abilities make GIS an excellent tool for geographical research and have spawned much interest, some might say hype, into the extent to which GIS might reinvigorate or even revolutionize geography (Openshaw, 1991). This led to a backlash that criticized the early use of GIS on a number of fronts, some of which are more relevant to historically related inquiry than others (see, for example, Pickles, 1995; 1999). Of particular significance in the present context was a claimed dependence on positivist assumptions of 'objectivity, value-neutrality and the ontological separation of subject and object' (Lake, 1993: 405). Slightly more prosaically, epistemological limitations of computer-based technology on the type of research questions that could be asked (Veregin, 1995) and the kinds of information that could be analysed (Curry, 1995) were also identified. Fortunately, later commentators have distanced themselves from a simplistic identification of GIS with positivistic assumptions (Wright *et al.*, 1997). Also, early antipathy, if not animosity, between champions of the field and its detractors has largely been

replaced, either by accommodation, given that GIS is increasingly embedded in the technological fabric of society, or a welcome rapprochement between cultural geographers and GIS specialists in new research areas, such as public participatory GIS (see Schuurman, 2000, for a very balanced review of the issues; see also Goodchild, 2006, and Pickles, 2006, for recent reflections on the debate).

This article will examine the ways in which GIS is making a contribution to historical geography. We identify three primary themes: the creation and dissemination of historical GIS databases, the use of GIS to perform quantitative and qualitative analyses, and the underlying conceptual issues that underpin GIS. The chosen order for discussion of these areas is based on the extent to which they are currently developed in the existing literature.

II Creating and disseminating historical GIS databases

1 Database creation

Building databases has long been recognized as the most time-consuming and costly stage of any GIS project (Bernhardsen, 1999; Knowles, 2000). The lack of academic credit for investing this time and money is currently a major obstacle to creating such resources. Historical GIS databases are rarely a simple digital facsimile of a single source. Instead they take data from multiple sources, integrate them in a manner that is sympathetic to the sources' limitations, and create metadata and documentation to record the sources and standards used. They are thus substantial works of historical geographical scholarship in their own right (Healey and Stamp, 2000). Traditional works of this nature such as Darby and Versey's (1975) *Domesday gazetteer* were published by academic presses, which gave credit to the authors and credibility to the work. Electronic databases are far more useful and useable than their paper counterparts, but ironically it is harder for them to gain academic standing and for their creators to receive due recognition. Resolution of this

problem is urgently required to enable and encourage researchers to invest the time in creating historical GIS resources and to share resources that they hold the copyright to while providing means to respect their intellectual property rights. This will help to ensure that expensive data resources are widely used over the long term.

In spite of this problem, there has been major progress in developing historical GIS databases, much of it focusing on national historical GISs. At their core these usually hold the changing boundaries of districts and other administrative units linked to large statistical databases that hold censuses and similar forms of data. These systems usually contain data from the early nineteenth century, when most counties started to conduct modern-style statistical data collection, to the present. A good example is the Great Britain Historical GIS (GBHGIS) (Gregory *et al.*, 2002). This holds census, vital registration and Poor Law data from the early nineteenth century to the 1970s. The core of the system is a GIS database that holds the changing boundaries of the major administrative units as they changed from 1840 to 1973. This was built up using information taken from maps at different dates combined with textual sources that provided precise dates for boundary changes. The GIS is structured in such a way that a user can specify any date and the system will return the boundaries that were in existence on that day. These can then be joined to the statistical data. This means that data from a single snapshot such as a census year can easily be georeferenced, but further it provides a framework for exploring temporal change as the GIS effectively locates all of the data in space and time.

The usual approach to creating a national historical GIS involves large amounts of research into where administrative boundaries were in the past and when they changed. An alternative approach is provided by the China Historical GIS (Berman, 2005; Bol and Ge, 2005). This covers 2000 years of Chinese history and is faced with the problem

that many administrative boundaries were either never defined or are now unknown. To cope with this, they use points to represent settlements and define spheres of influence based on these. Other countries that have built or are building national historical GIS systems include the United States (Fitch and Ruggles, 2003; McMaster and Noble, 2005), Belgium (De Moor and Wiedemann, 2001), Russia (Merzlyakova, 2005) and South Korea (Kim, 2005). Reviews of some of these are provided by Gregory (2002a) and Knowles (2005).

Urban development is another area that has attracted considerable interest among researchers building historical GISs. Good examples include Siebert's (2000) historical GIS of Tokyo, Wilson's (2001) historical GIS of Sydney, and Orford *et al.*'s (2002) GIS of London as represented by the Booth maps. Each of these has a slightly different emphasis. The Tokyo GIS aims to be a comprehensive GIS of the major features of Tokyo from the nineteenth century to the present. It includes data on the physical landscape, administrative boundaries, data from population and economic censuses, information on commercial and industrial activities, information on the growth of the road and rail networks, and information on land ownership. The Sydney GIS is more focused on museum artifacts and locating these in space by complementing them with a variety of series of maps of the development of the city from the very early days of European settlement to the present. The London GIS is more specifically based on a single source, Charles Booth's maps of poverty in London in the late nineteenth century. One thing that unites these systems is that they are quicker and cheaper to build than national systems and thus are able to allow researchers to move more quickly from the database creation phase of projects to the dissemination and analysis phases.

Urban and national systems both tend to be data led. They are built because a significant body of data exists that it is believed will provide a valuable research resource in GIS form rather than to answer specific

research questions. To a certain extent, this assumption is still unproven and it can be argued that more effort should be made to encourage their use by a wide audience. This must be done by funding agencies who invest in these resources and the agencies charged with disseminating their data, rather than the projects that created them, which are usually short-term projects funded by soft-money. One possible option would be for funders to put out calls explicitly to conduct research on resources of this type.

The alternative motivation for building a historical GIS is to investigate a specific research topic. A good example of this is a GIS of economic development in the northeastern United States. This was developed specifically to provide a spatial and temporal framework within which the detail of economic development could be explored. It includes data on industrial plants such as blast furnaces and coal mines, the railroad network, and areas of natural resource deposits, land parcels and so on. The GIS enables large volumes of this data to be located in time and space and studied without resorting to the inference from aggregate statistics that frequently hampers research on historical aspects of regional economic growth (Healey and Stamp, 2000).

Significant progress has been made in the development of historical GIS databases but there are still significant conceptual issues that require further work. GIS databases are notoriously poor at handling uncertainty, incompleteness, inaccuracy and ambiguity in the data that they are representing. These are generally termed 'error' (Unwin, 1995) and are a particular issue for historical GIS because they are common within historical sources. Three broad approaches to handling error in historical GIS databases can be identified: the mathematical, the representational, and the documentary.

The most common mathematical approach is based on fuzzy logic (Zadeh, 1965). In a conventional GIS database every feature has a precisely defined and unambiguous location

in both space and time. Fuzzy logic uses probability to allow the degree of certainty that we have in our information to be included in the data. Thus under fuzzy logic it is possible to say, for example, that prior to around 1850 a boundary was in approximately this area but after the change it definitely followed this line. A conventional GIS requires exact boundaries and an exact date at which they change. Plewe (2002) uses fuzzy logic to create what he terms an *Uncertain Temporal Entity Model*. This allows error to be handled in either the spatial, temporal or attribute components of a historical GIS database. He applies his approach to the early counties of the state of Utah to show how uncertainties in locations of boundaries, times of boundary changes, and populations within boundaries can be handled. Conceptually his model is very thorough, but functionality of this type is not available in standard GIS packages, so whether it can be applied effectively to a large-scale historical GIS remains to be seen.

Bartley and Campbell (1997) use a representational solution to error. They create a historical GIS of land use in England prior to the Black Death of 1348 using 6000 *Inquisitiones Post Mortem* (IPM), basically wills of English tenants-in-chiefs, for which they have approximate locations. They use these data to create a raster surface which uses pixels to represent how land use changes continuously over space. For each pixel values are calculated using nearby IPMs. They are able to estimate the financial value of each pixel and its probable land-use type for which they allocate first and second choices to further handle the error in their data. This approach enables them to build up a detailed picture of land use in medieval England while allowing for the fact that there are clear uncertainties with their source information.

These two solutions are both essentially technological; however, ambiguity, uncertainty and missing data are problems that have always confronted historians. Traditionally they have been handled using documentation. This can be achieved electronically using

metadata, data that describes data (Guptil, 1999). Metadata can be provided at two levels: the data set level provides information about the entire data set, while the object level provides information about individual features within the data set. Metadata is often structured using particular standards to allow catalogues of metadata to be created and searched. The best known general-purpose standard is Dublin Core (Dublin Core Metadata Initiative, 2006). While this contains useful terms for broad description of entire data sets, it is not well suited for temporal data, detailed georeferencing parameters, or object-level specification of large statistical data sets. The second of these issues is more adequately addressed by the ISO 19115 Geographic Information Metadata Standard, based on developments led by the US Federal Geospatial Data Committee (FGDC, 2006). The third issue is covered by the emerging Data Documentation Initiative (DDI) metadata standard (DDI, 2006) and both of these standards aim to facilitate temporal data description.

While the DDI standard provides a means of specifying statistical parameters such as sampling error, the ISO 19115 standard does not provide for analogous treatment of errors in spatial data. Further to this, recent work on an ontology-based approach to metadata handling (Schuurman and Leszczynski, 2006) has highlighted an additional class of potential errors related to data categorization problems in mapping applications. They propose a new extension to the ISO 19115 standard to achieve this, in line with existing extensions for remote sensing and other types of data. Similar extensions to handle other error types relevant to work in historical GIS would be feasible, but this relies on persuading the relevant standards committees of their importance and general applicability.

Improvements in metadata show promise of allowing the problem of error to be addressed more adequately than at present and in a way that is perhaps more sympathetic to the historian's traditional approach to error and

uncertainty, namely footnoting. To date, however, the utility of metadata has been limited due to the plethora of overlapping and potentially inconsistent standards currently available. It is also important to heed a recent warning from research on burgeoning metadata infrastructures, where exhaustively documenting the content, lineage and context of large data sets has been shown to require more storage space than the data it is meant to describe (Goodchild, 2006).

2 Dissemination

As well as creating historical GIS databases, there has been considerable progress in disseminating these over the internet. The simplest form of dissemination is to publish the data on the internet using a cut-down version of a GIS software package which allows users to draw maps of the data, zoom in, pan around, turn layers on and off, and query the underlying data. Effective examples of this are Schaefer's (2004) online GIS of nineteenth-century tithe in England,¹ and the North American Religion Atlas² (NARA) (Lancaster and Bodenhamer, 2002). These sites are both based around what may be regarded as traditional GIS models with polygon-based spatial data and statistical attribute data which are primarily displayed using choropleth maps.

In developing the new system behind the 'Vision of Britain Through Time' website, the statistics and vector boundaries assembled for the original GBHGIS, described above, have been completely restructured.³ The core of the new system is a gazetteer of administrative units organized as an ontology or polyhierarchical thesaurus, which contains no digital coordinate data, so the system can hold information about historical units with unknown boundaries. Almost everything about an administrative unit can change, including names, hierarchical relationships, and boundaries. All polygons, geographical names and statistical data are held in a single column of a single database table, making for fast searching and relatively simple software.

Storing statistics this way depends on recording meaning entirely through the use of metadata, using the Data Documentation Initiative standard. Although this design may seem abstract, it drives a popular public website, heavily used by local and family historians. It also links in a substantial number of scanned and georeferenced historic maps, and the largest collection of historical British travel writing currently available on the internet (Southall, 2006).

Online historical GISs can also incorporate more qualitative sources using point data superimposed over raster scans of maps that provide context of where features are located. A good example of this is the International Dunhuang Project (IDP, 2006) based at the British Library. This project has been creating a major database of over 100,000 manuscripts, documents, document fragments, and other artifacts dating from the fifth to the eleventh centuries, excavated from near Dunhuang on the Silk Road in China. The database also includes field notes and photographs from the archaeologist who excavated them in the early twentieth century. Part of the documentation of this includes coordinates of the location of each artifact. These coordinates allowed the project team to create a GIS of the images. These are then placed online such that a user can query the database through a map-based interface, in addition to the more conventional forms of query such as using key words or by date.

A large number of other projects have also used GIS to assist in disseminating their data. These include: the Sydney TimeMap Project, a database of artifacts about the development of Sydney that includes maps showing the development of the city from the early days of European colonization to the present (Wilson, 2001); the David Rumsey Historical Map Collection,⁴ which is a database of over 11,000 maps mainly from the eighteenth and nineteenth centuries, that can be queried to find maps of a specific location through a map-based interface (Rumsey and Williams, 2002); the Alexandria Digital Library⁵ (ADL), which

is a digital map library that has evolved out of the University of California Santa Barbara Davidson Library (Goodchild, 2004; Hill and Janee, 2004); and finally the Perseus Project,⁶ which uses a GIS interface to help users find references to places in a large digital library that includes digitized manuscripts of texts that range from ancient Egypt to nineteenth-century London (Smith *et al.*, 2000). All of these systems effectively blur the distinction between data and metadata by using the location of features as a finding aid. The user is presented with a map-based interface and is able to ask queries such as 'what is at this location?', 'what other features are near here?' and 'where are artifacts of this type found?'.

To date, web-based technology for historical GIS has mainly been used to explore individual databases held at a single location. It is likely to be increasingly used to integrate data stored in multiple locations across the internet. One way that this can be achieved is through the use of metadata catalogues. These are websites that hold metadata from data sets held in more than one place. The user queries this website and it can either return the data from one of these external locations or tell the user what data exist and what they have to do to gain access to them. While this works with any form of query, GIS adds an additional dimension to it because it allows searches to take place based on coordinates. The simplest way that this can happen is for users to enter coordinates by clicking on a point or a bounding-box on-screen and these are compared with coordinates in the metadata. The Electronic Cultural Atlas Initiative's (ECAI) Metadata Clearinghouse⁷ is a good example of a historical site that does this (Lancaster and Bodenhamer, 2002).

The concept can be taken further in two ways: first by using portals that search many metadata catalogues from around the internet, and second by using place-name gazetteers that convert place names into coordinates (Harpring, 1997). This potentially means that, rather than simply searching for GIS resources, a search can find any databases that contain

place names and convert the relevant data quickly into GIS format. It is claimed that these developments mean that we are approaching a stage where e-Science technology will allow a user to type a place name into a portal and a list of all data sets containing data that intersect with or are near to that place will be returned. If this is eventually realized it will have huge potential for research into specific places, as it means that all data relevant to that place that have been published on the internet can be rapidly assembled and integrated.

III Analysing data within historical GIS

Although creating and disseminating GIS databases is important, the real test for historical GIS as a discipline is to create new insights into the geographies of the past. GIS originated primarily from a quantitative paradigm and although it has spread beyond this, quantitative analysis has proved a fertile ground for its use in historical studies. A key advantage of using GIS is its ability to include location explicitly into an analysis, enabling questions of pattern and distribution to be addressed. Further to this, it facilitates accurate identification of features such as individuals, industrial plants or settlements, where names and organizational identifiers may be ambiguous. The potential importance of this in relation to historical data has received insufficient emphasis in the literature to date. A second key advantage is that the use of layers within a GIS database also allows data to be integrated from different sources and potentially different dates. Recent work has also begun to facilitate the incorporation of more qualitative data and reasoning into the field, through a variety of natural language processing and visualization methods (eg, Clementini *et al.*, 1997; Wang, 2003; Yao and Jiang, 2005).

GIS can aid the advancement of historical scholarship in three ways: first, by providing revisionist studies that challenge existing orthodoxies; second, by tackling questions that have not been resolved to date; and, third, by providing approaches that enable researchers

to ask completely new questions. Significant progress has been made under each of these headings in three distinct areas: quantitative studies that look at a single point in time, quantitative studies that look at change over time, and qualitative studies.

1 Quantitative studies of single points in time

Hillier (2002; 2003) provides an example of revisionist study that uses GIS to challenge a historical orthodoxy. Her study is on 'mortgage redlining' in the city of Philadelphia during the 1930s Depression. In 1933 the US government set up the Home Owners' Loan Corporation (HOLC) to help home owners and mortgage lenders by making low-interest loans to cover defaulted mortgages. The HOLC subdivided cities according to the perceived risk of lending into particular areas. It became an orthodoxy that the HOLC's highest-risk areas, marked with red lines on their assessment maps, were subsequently doomed to decline due to the difficulties in getting mortgages in these areas. It was further argued that areas with large Jewish or African American populations tended to be overrepresented as high risk.

Hillier tested this by using GIS to integrate data from a sample of individual mortgages, with data from a 1934 property survey, and the 1940 census. Her results suggest that areas with high African American populations were more likely to be red-lined than other areas, but contradict the orthodoxy that once an area was red-lined it was difficult to get a mortgage. She showed that mortgages on properties in these areas had only slightly higher interest rates than those in other areas.

Pearson and Collier (1998; 2002) use GIS to tackle an issue that has not been satisfactorily resolved even though the source they use has been extensively studied in the past. They used the tithe survey to investigate agricultural productivity in Wales in the mid-nineteenth century. The tithe provided them with a detailed inventory of each field in the parish under study including the owner, the occupier when the field was tenanted, the crop type,

and the rateable value of the field. They used GIS to integrate this with modern data that provided information on the physical characteristics of each field, such as its relief, slope and aspect. Statistical analysis of the resulting data showed that, while many of the variations in agricultural productivity could be explained by the physical characteristics of the field, owners and tenants could both have a significant impact on this. In particular, tenants seemed to have had a bigger impact than owners.

GIS also allows entirely new questions to be asked using completely new techniques. A good example of this is the use of virtual worlds and digital terrain models. These involve creating a representation of the landscape that appears to be in three dimensions. Harris (2002) used a terrain model to recreate the landscape and vegetation cover around a burial mound in Ohio prior to European settlement and urbanization. This allowed him to explore the significance of the mound on the landscape as it would have appeared to contemporary observers. Knowles (2006) goes one stage beyond this. She was interested in exploring the Battle of Gettysburg, one of the most studied topics in American history. She created a detailed terrain model of the Gettysburg area and used a technique called *viewshed analysis* to explore what an observer would have been able to see from any location on the battlefield. In this way she was able to identify what the various officers could see at each stage of the battle and how this might have influenced their decision-making at key moments.

2 Change over space and time

In many cases, historical GIS will be required to explore how geographical change over time has occurred. This is an area that has traditionally been severely hampered by the complexity of data and analysis.

Cunfer (2005; see also 2002) presents an analysis that very effectively shows how GIS can present a revisionist argument about geographical change over time. He investigates dust storms on the Great Plains in the

mid-1930s, traditionally thought to have been caused by overploughing of unsuitable soils. This was argued to have led to the destruction of topsoils by high winds; thus the blame for the Dust Bowl could be placed firmly on insensitive agricultural practices by farmers driven by market forces. He argues that this explanation was based on detailed case studies of only two counties in the centre of the Dust Bowl region during the New Deal period, the peak time for dust storms. In contrast, he investigates all 280 counties in the Great Plains using annual agricultural and environmental data over a period stretching back to well before the mid-1930s. The results show that dust storms prior to the Dust Bowl period were in fact more common than had previously been acknowledged, that the link between agriculture and dust storms was not particularly convincing, and that drought in the mid-1930s seems to have been a far more significant factor than insensitive agriculture. Thus, by covering a larger area and longer time period than individual county studies, he is able to challenge the historical orthodoxy in an effective manner.

An alternative example is provided by Diamond and Bodenhamer (2001). They explore the impact that *white-flight*, the out-migration of whites from the centre of American cities, had on the religious geography of an American city, in this case Indianapolis, Indiana. They argue against the prevailing orthodoxy developed in the 1950s, which states that mainline Protestant churches left the inner cities in response to their congregations moving to the suburbs. This left a lack of churches in downtown areas, which in turn led to social problems. By using GIS to explore the changing locations of churches and the changing ethnic make-up of tracts in Indianapolis, they show that there was limited evidence to support this orthodox view. They found only a small number of churches actually moved, but those that did generally moved from inner-city areas with large African American populations to white suburbs. Thus, while there was some

evidence for churches relocating in response to population changes, this was not as widespread as might be expected.

Historical GIS is also being used to provide new insights into unresolved questions about geographical change over time. An excellent example of this is provided by Skinner *et al.* (2000) who perform an analysis of fertility in China from the 1960s to the 1990s that makes innovative use of familiar geographical concepts. They employ Central Place Theory to divide China into what they term *Hierarchical Regional Space* (HRS). They do this by subdividing places into an eight-level urban-rural hierarchy based on information about settlement sizes, industrial structure and so on, and a seven-level core-periphery hierarchy based on a variety of socio-economic indicators. This allows them to allocate the data from each place to a location on a matrix that they simplify to divide every place into one of eight categories from inner-core urban areas to far-periphery rural areas. An analysis of geographical variation in fertility over time is then possible, using these non-contiguous regions rather than focusing on individual administrative units. In this way they are able to show the impact of China's fertility policies in different geographical areas.

In a second example, Knowles and Healey (2006) re-examine long-standing problems in understanding the development of the US ante-bellum iron industry by building an historical GIS of ironworks in the mid-nineteenth century, using data from Lesley's 1859 Directory, county histories and historical mapping. Their spatiotemporal analysis allows detailed substantive conclusions to be drawn about the adoption of mineral fuel technologies in blast furnaces, the influence of transport costs on supply and demand in regionally segmented iron markets, and the relationships between regional patterns of investment in the iron industry, transportation developments, business cycle changes and national tariff policy.

One area where GIS has clear potential to shed new insights into geographical change in

ways that help to answer unresolved questions and ask entirely new questions is using the census and similar sources to explore change over time. Traditionally, although these sources are rich in both geographical detail and temporal scope, it has not been possible to make use of both of these together due to the problem of intercensal boundary changes. This has meant that researchers have typically either looked at a single census date, or have had to aggregate to the level of British counties or US states. Considerable work has gone into using GIS to allow data to be compared over time at more spatially detailed levels. This is done using techniques called *areal interpolation* that allow data to be recast from one set of administrative areas to another (Gregory, 2002b; Gregory and Ell, 2005a). Doing this is relatively straightforward, but the data that are created are estimates that inevitably contain error. Gregory and Ell (2006) have developed techniques that not only allow this error to be minimized, but also allow researchers to know which data values are likely to contain error.

Three studies provide illustrations of how these techniques have the potential to reinvigorate the study of long-term change using the census and related sources. First, Dorling *et al.* (2000) give an example of the potential of this in a comparison of poverty in late Victorian London, as measured by Charles Booth, and 1991 mortality patterns. They show that the most poverty-stricken parts of London a century ago still have the highest poverty rates today and also still have high rates of mortality from many diseases. This, they argue, shows that the characteristics of areas have remained remarkably constant over time and that area types are closely associated with the mortality characteristics of their inhabitants. The specific value of GIS in this analysis is that it allows the researchers to compare modern ward-level data with the areas used by Charles Booth. Second, Gregory *et al.* (2001b) provide a national-level example of the potential of this approach in an analysis of changing patterns

of poverty in England and Wales through the twentieth century. They take data on infant mortality, overcrowded housing and unskilled workers from the 1890s, 1930s, 1950s and 1990s and explore how patterns of these variables change once all of the data have been interpolated onto 1890s registration districts. They show that the inequality between the areas containing best and worst off population deciles appears to have risen over the twentieth century for all three of these variables, and that the increase has been most pronounced since the 1950s. Third, Gregory and Ell (2005b) explore the potential of using areal interpolation in combination with a variety of spatial analysis techniques to explore population change following the Irish Potato Famine.

These three pieces of work all explore techniques and demonstrate potential. To date, no study has taken census data for every decade for the entire twentieth century and perhaps beyond and compared these at a spatially detailed level for the whole country. All of the methodological innovations required to do this are now in place and it is only a matter of time before these are used with a national historical GIS to provide new insights into long-term demographic change.

3 *Qualitative analysis*

Although GIS originated in the quantitative arena, developments in database technology mean that there is no good reason why it cannot be used at least as effectively with qualitative data such as texts and multimedia formats including images, sound and video. Two projects that use qualitative data provide exemplars of the approach and potential of qualitative historical GIS. These are Ray's (2002) study of the Salem Witchcraft Trials, and the Valley of the Shadow project (Sheehan-Dean, 2002; Thomas and Ayers, 2003) that explores the origins of the American Civil War by contrasting the experiences of two counties in the Antebellum period.

Interestingly, neither of these projects started as GIS projects. In both cases they were concerned with creating large databases

of primarily qualitative sources of information about their topic. For the Salem Witchcraft project, this included a range of contemporary court documents, maps and transcriptions of the trials. The Valley of the Shadow project created digital archives of two counties on either side of the Mason-Dixon line around the time of the Civil War using sources such as diaries and letters, tax lists, the 1860 census returns, and contemporary newspapers, as well as information on soil types and relief. Both projects independently realized the necessity of including detailed mapping to locate individuals and places named in their sources.

Ray uses his database to present a convincing challenge to one of the conventional explanations of the Witchcraft Trials. Boyer and Nissenbaum (1974) had argued that the village was split by social and economic pressures, the accused being found in the east and their accusers to the west. Ray challenges this in two ways. First, he locates more individuals than Boyer and Nissenbaum and these people blur the clear geographical separation between accuser and accused. Second, Ray maps taxation and church attendance and shows that neither of the resulting patterns shows the clear split that Boyer and Nissenbaum were arguing for.

The Valley of the Shadow project enabled detailed comparisons between Franklin County, Pennsylvania, in the North and Augusta County, Virginia, in the South. They question the paradox that while it is claimed that slavery made a profound difference between North and South, repeated studies have shown little difference between the two in terms of voting patterns, distribution of wealth, employment, and related factors. Their research shows that there were clear differences between the two counties that they studied, but that these were relatively subtle. They reflect these differences in their conclusions on the underlying causes of the Civil War. They argue that it was not a conflict between industrialized and urban modernity in the North, and rural stagnating forces of

the past in the South. Instead it was a clash between two thriving variants of modernity.

It should be clear from these two projects that GIS need not be a quantitative, 'number-crunching' technology, but can instead provide a geographical framework for almost any approach within historical research where geography is deemed to be important.

IV Theoretical and conceptual issues

Perhaps surprisingly, the development of practical applications of historical GIS appears to have taken place largely without reference to the more theoretical literature on spatiotemporal GIS, which has been building up over the last decade or more (although De Moor and Wiedemann, 2001, provide an exception). Two aspects of this problem highlighted by O'Sullivan (2005) are continuing inadequacies in the handling of time in GIS and lack of uptake by empirical practitioners of methods that are actually available. Another is undoubtedly the need to move empirical projects forward to satisfy funding bodies, but it should also be remembered that many current projects are based around census data gathered at more or less regular intervals. While this type of study generates numerous challenges, as noted earlier, these are largely tractable using customized off-the-shelf software and a comparative statics approach. Looking more to the future, steady progress on retrospective capture and structuring of historical census data means that attention will turn increasingly to much more intractable kinds of dynamic spatiotemporal problems. These are more problematic for a number of reasons. First, unlike census tabulations, the data are not extant in any systematic or standardized form that can readily be automated. Second, the data are finely disaggregated by time and location. Third, the 'objects of study' on which they are measured (Chapman, 1977) may change asynchronously and in a variety of ways. This means their behaviour cannot be analysed in lockstep, as is possible for census intervals. Fourth, related to the previous point, to an

increasing extent it will not suffice merely to analyse changing patterns at specified intervals. Instead it will be necessary to hypothesize or model processes that are acting to generate the observed spatiotemporal dynamics. Associated visualization of such evolving processes is taken as given (MacEachren *et al.*, 1999).

Interestingly, some of these types of problems have clear potential to bring historical GIS from the margins of several cognate disciplines into the forefront of empirical inquiry in these areas, because of the possibility of posing new substantive research questions or facilitating the re-examination of the long-standing issues in the literature. Good examples would be work on railroads and economic growth (Fogel, 1964; Schwartz, 1999; Healey and Stamp, 2000), or examination of the evolving relationships between immigration waves and demographic structure in the USA (Otterstrom, 2006).

Developments in both database and GIS software have moved the technology beyond the limitations of pure relational and feature-orientated systems towards the direction of object-relational databases and object-orientated GIS (Stonebraker *et al.*, 1999; ESRI, 2006). However, this significant step forward in basic software terms still only reaches the first stage in Worboys's recent categorization of stages in the development of spatiotemporal GIS (Worboys, 2005). His second stage, that of 'temporal snapshots', can be attained using these systems, by means of customized application development, to allow time stamping or temporal indexing. However, the focus remains on tracking sequences of static data layers, rather than on the changes that can happen to objects and their attributes, or to the interrelationships between objects over time. This type of problem constitutes Worboys's third stage and it has been extensively examined in theoretical terms by Hornsby and Egenhofer (2000). These authors identified a series of primitive operations to describe the creation, life history and disappearance of objects. During their existence, objects may also cause dependent

changes in other objects, but the authors acknowledged that further development of the primitives was required to handle operations such as the splitting and fusion of objects. It is apparent that such operations in a GIS context could be modelled using object-based or object-orientated languages such as ADA95, C++ and Java, linked via an application programming interface to a persistent object store, in the guise of a GIS or other spatial database. However, work of this kind is technically demanding, even before the data issues in a correspondingly complex empirical problem are addressed. Not surprisingly, we still await any serious application work, either in contemporary or historical GIS, that puts these theoretical ideas to the test. That said, arguably some of the recent work to interface agent-based models to GIS might fall into this category (Brown *et al.*, 2005).

The fourth and final stage identified by Worboys is that of a full event-orientated approach to GIS based on an ontological distinction between what he calls 'continuants' that endure through time, such as people and houses, and of 'occurrents' that happen and then are gone, such as traffic accidents or shopping trips. Through an examination of temporal logics, process calculi and Hoare's classic theory of communicating sequential processes, he finds it possible to represent time as a sequence of 'ticking' occurrents and location as arranged sets of occurrents, 'handshaking' or message-passing on the basis of adjacency relations (Worboys, 2005: 17–18). Although he does not specifically make the point, it is but a small conceptual and indeed implementational step to developing such a spatiotemporal GIS framework on a massively parallel computer, where a wealth of software tools to handle message-passing requirements are already available (Message Passing Interface Forum, 1997), as are persistent parallel database stores for tracking information pertaining to occurrents.

This rather abstract discussion can be made more concrete by reference to the type of case

study where such theoretical approaches may find future application. One possible example would be a time-geographic modelling study of the impact of network expansion by elevated railroad companies in Manhattan during the 1870s and 1880s (Reed, 1978) on journey-to-work times, residential patterns, property values and the location of employment opportunities. Such a study would also fit with the proposal of O'Sullivan (2005) to utilize simulation modelling and time geographic approaches to help establish more common ground between GIS and human geography, while avoiding too narrow an interpretation of process in purely computational terms. The empirical challenges of such projects would also allow historical GIS practitioners to evaluate available conceptual and analytical tools more effectively than at present, providing feedback and stimulus to colleagues working in more theoretical GIS areas, in a manner that has not really happened to date.

It is useful to engage in a limited amount of forward conceptual and technological gazing in this way, not least because it indicates the distinctively non-trivial nature of the future problems to be faced by historical GIS practitioners in examining spatiotemporal dynamics. Such problems, as Worboys is now suggesting, also have more in common than might originally have been anticipated, with other computationally demanding, if not 'grand challenge' problems, in the harder natural sciences.

V Conclusions

In less than a decade, historical GIS has emerged to become an accepted and evolving part of both the quantitative and qualitative spheres of historical geography. It has also increased awareness of the importance of geography among historians who previously would have had little interest in geography. Several of the projects discussed in this paper were originated by historians who would previously not have been interested in geography. These include the North American Religion Atlas, the International Dunhuang Project, the

Salem Witchcraft Trials and the Valley of the Shadow project. A further example of this is that an East Asian historian, Professor P.K. Bol, set up and directs the Harvard University Center for Geographic Analysis. Professor Bol became interested in GIS through his work on the China Historical GIS project. This led to him being responsible for bringing geography back to Harvard after an absence of over 50 years (Richardson, 2005).

To date, a major factor slowing the development of historical GIS has been the length of time it takes to build databases. Valuable progress has been made in this area and there are now a significant number of databases that are either complete or approaching completion at both national and urban scales. As stated above, it is important that these databases are widely used and it is hoped that funding agencies and national service providers will encourage this. It is also important that mechanisms for awarding academic recognition for such systems are developed, as creating them is a significant scholarly undertaking that will not subsequently need to be repeated by future studies.

Analytical results are inevitably lagging behind database creation but there are encouraging studies being produced across the discipline at a variety of scales. These have been effective in challenging historical orthodoxies, answering questions that had previously been too difficult, and posing entirely new questions. This is because GIS provides a number of key capabilities. One is simply that it is able to integrate data from a number of different sources, such as Pearson and Collier's (1998; 2002) integration of data on relief, slope, aspect and soil type, with data from the tithe survey. A second is that it is better able to handle both the spatial and the temporal complexities of the data. The advantages of this are shown at a range of scales and levels of complexities including local-scale studies such as Diamond and Bodenhamer (2001) and Ray (2002), regional studies such as Knowles and Healey (2006),

and national-scale approaches such as Gregory and Ell (2005b) and Skinner *et al.* (2000). One particular impact of this is to demonstrate the dangers of extrapolating the results of local case studies or data sets to make wider generalizations. Cunfer's (2005) work on the Dust Bowl does this particularly effectively by showing that dust storms did not only occur in heavily farmed areas. Perhaps the opposite criticism can be made of historical GIS studies, namely that they are better at identifying and describing patterns than they are at explaining them. Nevertheless, the ability to be able to recognize patterns will clearly lead to more robust explanations. Whether these explanations are derived through the use of GIS or not is surely a moot point.

The basic components of GIS software have been largely stable since the late 1980s. Three things are changing. First, the software has become cheaper and easier to use. This can be expected to continue although some barriers remain. Second, although metadata standards continue to evolve, it is important that these stabilize and that their use becomes more widespread. Third, while the ability of software tools to facilitate visualization and animation of spatial and spatiotemporal data sets is growing with each successive release, in the conceptual and operational modelling domains relating to historical or temporal GIS, progress has been slow. This slow rate of progress is matched only by the extreme challenges of assembling consistent and reliable long-run data sources to support the testing and validation of theoretical postulates or hypothesized processes.

It is fair to say that the rise in interest in historical GIS has been little short of dramatic. A possible criticism that can be levelled at the field is that, although it has delivered some new knowledge, it has yet to fulfil its true potential. The papers discussed here, however, suggest that such advances are well in hand and that GIS will play a significant role in historical geography for many years to come.

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Notes

1. http://tiger.iso.port.ac.uk:7785/www/web.html?p=tithe_intro (last accessed 27 June 2007).
2. <http://www.religionatlas.org/> (last accessed 27 June 2007).
3. <http://www.visionofbritain.org.uk> (last accessed 27 June 2007).
4. <http://www.davidrumsey.com/> (last accessed 27 June 2007).
5. <http://www.alexandria.ucsb.edu/> (last accessed 27 June 2007).
6. <http://www.perseus.tufts.edu/> (last accessed 27 June 2007).
7. <http://www.ecai.org/tech/mdch.html> (last accessed 27 June 2007).

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