THE HISTORY OF GIS

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Computer-based GIS have been used since at least the late 1960s: their manual predecessors were in use perhaps 100 years earlier. Acknowledging the paucity of well-documented evidence, this chapter describes the background to the development of such systems, stressing the context in which such development took place, the role of organizations and individuals where this can be ascertained, and the applications which the systems were intended to meet. A broad definition is taken of GIS so as not to exclude any significant developments; computer mapping systems of all types (including those with line-printer graphics, the forerunners of contemporary raster systems) are included.

It is demonstrated that most, but by no means all, of the early developments originated in North America. The roles of key organizations such as the US Bureau of the Census, the US Geological Survey, the Harvard Laboratory for Computer Graphics and the Experimental Cartography Unit are described and the activities of the commercial sector are exemplified by a case study of Environmental Systems Research Institute. Reasons are suggested for significant international differences in the development of GIS, such as the attitudes to ownership of data and the perceived role of the state. It is concluded that several stages of evolution of GIS can be defined. These overlap in time and occur at different moments in different parts of the world. The first, or pioneering age, extended from the early 1960s to about 1975; in this, individual personalities were of critical importance in determining what was achieved. The second phase, approximately from 1973 until the early 1980s, saw a regularization of experiment and practice within and fostered by national agencies; local experiment and action continued untrammelled and duplication of effort was common. The third phase, running from about 1982 until the late 1980s, was that of commercial dominance. The fourth (and current) phase is one of user dominance, facilitated by competition among vendors, embryonic standardization on open systems and increasing agreement on the user's perception of what a GIS should do and look like.

INTRODUCTION

A variety of information indicates that the field of GIS has expanded rapidly in recent years (see Maguire 1991 in this volume). From where did all this business and the resulting jobs arise? Unhappily, we scarcely know. GIS is a field in which history is little more than anecdotal. To rectify this, a search through the archives of government departments and agencies would certainly help. As yet, however, few organizations have given any thought to formalizing the history of their involvement in GIS and at least one major player (Ordnance Survey; see Finch 1987) has refused to let its detailed records be examined by external researchers. Less certainly, the records of computer hardware and software companies could also be a source of relevant information but no such material has been uncovered. Unfortunately for those writing the history of GIS, neither staff of commercial companies nor government officials have a tradition of writing books or papers on their experience of an emerging technology. Research staff in government or private sector research organizations are exceptions to this rule but, even for them, writing papers for the benefit of the scientific community at large has a relatively low priority. As far as is known, the only official attempt anywhere to provide a broad overview of the field as a whole is that given by the Report of the Committee of Inquiry into the Handling of Geographic Information (Department of the Environment 1987; Rhind and Mounsey 1989).

The main source of information, with all the risks of partisan bias, remains researchers in the academic community. In reality, however, even the numbers of academics working in this field were quite small until the expansion of the last decade. Moreover, as Chrisman (1988) and Rhind (1988) both testify, those active in universities in this field in the early stages of the development of GIS were often outside the formal academic career structure and were so heavily involved in project work that they had little time or inclination to write papers. In any case, at the beginning there were no obvious outlets for publication in a topic that was seen as marginal to a large number of interests; Rhind's (1976) report, for instance, may well be the first example of a record of GIS conference papers which were described as such in a mainstream academic publication. While the advent of specialist GIS conferences (often disguised by use of other titles such as AUTOCARTO) provided one publishing mechanism from 1974 onwards, the early conference proceedings were intermittent and were not easily accessible to those who had not attended the gatherings. We do not believe this postulated paucity of recorded history represents incompetence on our part: a correspondence prompted by the editor of *Photogrammetric Engineering and Remote Sensing*, for example (Marble 1989; Tomlinson 1989), generated great controversy and revealed a lack of documentation on the first use of GIS in the refereed literature.

Finally and most crucially, the content of any history of GIS depends in large measure on the definition adopted. A strict definition, as a computer-based system for *analysing* spatially referenced data, would greatly restrict the field because, with the major exception of the Canada Geographic Information System (Tomlinson 1967), this was not a common feature until the 1980s. A more general interpretation, as any system for handling geographical data, would greatly widen the field and hence enlarge the number of contributors. Such a definition would embrace, not only the whole field of automation in cartography (which was often the precursor to any involvement in GIS and provided, in terms of computer-generated graphics, the most common form of output for most early systems), but also many general-purpose statistical and database packages capable of handling x,y,z point data. Formal definitions of GIS are not, therefore, of much help and relatively little reliance is placed on them in this book as a whole. In any event, the field evolved not from some *ex cathedra* definition of the subject but through sets of interactions. The main backgrounds of those involved have been cartography, computer science, geography, surveying, remote sensing, commercial data processing, mathematics and statistics. The purposes to which the systems have been put include environmental protection, urban and regional planning, land management, property ownership and taxation, resource management, the management of utilities, site location, military intelligence and tactics, and many others – as later chapters in this volume testify. The field has developed, then, from a melting pot of concepts, ideas, practice, terminology and prejudice brought together by people from many different backgrounds, interacting with each other often on a chance and bilateral basis in the early days and normally proceeding in blissful ignorance of what was going on elsewhere. The essence of GIS is thus its multidisciplinary character, with some at least of those involved in developing this technology having little previous involvement, or even interest, in the handling of geographical data as such (see Maguire, 1991 in this volume for further discussion of the definition of GIS).

This review of the history of GIS is inevitably a consequence of the authors' accidental exposure to early developments and their own set of value-judgements; different views certainly exist, such as that manifested in Cooke's portrayal of the genealogical structure of geoprocessing systems in general (Fig. 2.1). In particular, it is suspected that the role of those who did not contribute to the formal literature has been underplayed, especially those working in the military. While regrettable, this is probably unavoidable: history very often consists solely of what has been written down.

THE GRASS ROOTS EVOLUTION OF GIS

What seems clear is that there were many initiatives, usually occurring independently and often in ignorance of each other, concerned with different facets of the field and frequently originating in the interests, often disparate, of particular individuals. Like the reality (as opposed to the reporting) of scientific research, there was no strictly logical progression towards the development and implementation of GIS, but rather a mixture of failures, set-backs, diversions and successes. Inevitably, more is known about the successes than about the failures which, according to both Dangermond and Smith (1988) and Tomlinson (1988), have been numerous and often attributable to bad advice, ignorance and a determination to go it alone. This is unfortunate because failures are often as illuminating as successes, if not more so (Giles 1987). What also seems clear is that particular individuals and institutions played key roles, acting as examples or as sources of expertise, advice and often skilled personnel; since these contributions are now better recorded than is the generality of progress, this account will tend to emphasize them, particularly those of Howard Fisher in the Harvard Laboratory for Computer Graphics (LCG), Roger Tomlinson in the Canada Geographic Information System (CGIS) and Jack Dangermond in the Environmental Systems Research Institute (ESRI) in North America, and David P. Bickmore at the Experimental Cartography Unit (ECU) in the United Kingdom. Many others played significant parts (e.g. Tobler 1959; Nordbeck 1962; Cook 1966; Hagerstrand 1967; Diello, Kirk and Callander 1969 and Boyle (see Rhind 1988)), but these four have been the subject of particular articles in a special and invaluable issue of *The American Cartographer* (Tomlinson and Petchenik 1988). Fortunately, these individuals seem to typify the interests, attitudes and commitments of those working in the vintage era of GIS from the late 1950s to the end of the 1970s.

The motivations for developing GIS or components of such systems have varied very widely. They have ranged from academic curiosity or challenge when faced with the possibility of using new sources of data or techniques, through the desire for greater speed or efficiency in the conduct of operations on spatially referenced data, to the realization that desirable tasks could be undertaken in no other way. The last was undoubtedly a powerful motive in two key developments which are discussed in more detail below – the Oxford System of Automated Cartography and the Canada Geographic Information System. It was the experience of publishing the *Atlas of Great Britain and Northern Ireland* (Bickmore and Shaw 1963) and the criticisms this attracted of being out of date and unwieldy that convinced D. P. Bickmore, probably in 1958 but certainly no later than 1960, that only the computer could provide a cost-effective mechanism to check, edit and classify data, to model situations and to facilitate experiments in graphic display (Rhind 1988). Similarly, it was the impossibility of analysing maps of East Africa at an acceptable cost that first led R. Tomlinson (1988) to think of a digital approach. A calculation made in 1965 indicated the need for some $Can 8 million in 1965 prices and a requirement for 556 technicians for three years in order to overlay the 1 : 50 000 scale maps of the Canada Land Inventory; this unacceptable level of resources acted as an incentive to develop a more automated approach.

It was, of course, the advent of the digital computer and the order-of-magnitude decrease in computing costs every six years over a 30-year period (Simonett 1988) that made such alternative digitally based approaches viable. It is interesting to note, however, that not all early work used the digital computer. Thus perhaps the earliest attempt to automate map production, the preparation of the *Atlas of the British Flora*, employed a modified punch card tabulator to produce maps on pre-printed paper from cards on which had been punched the grid references of recorded occurrences (Perring and Walters 1962). Although this approach was not repeated and Perring (1964) later recognized that the analysis of voluminous data could more easily be undertaken by computer, it anticipated the widespread mapping in the late 1960s by line printer. It is also interesting to note that Perring was a botanist, with no training in cartography, who was faced with the task of providing 2000 maps from data that had been

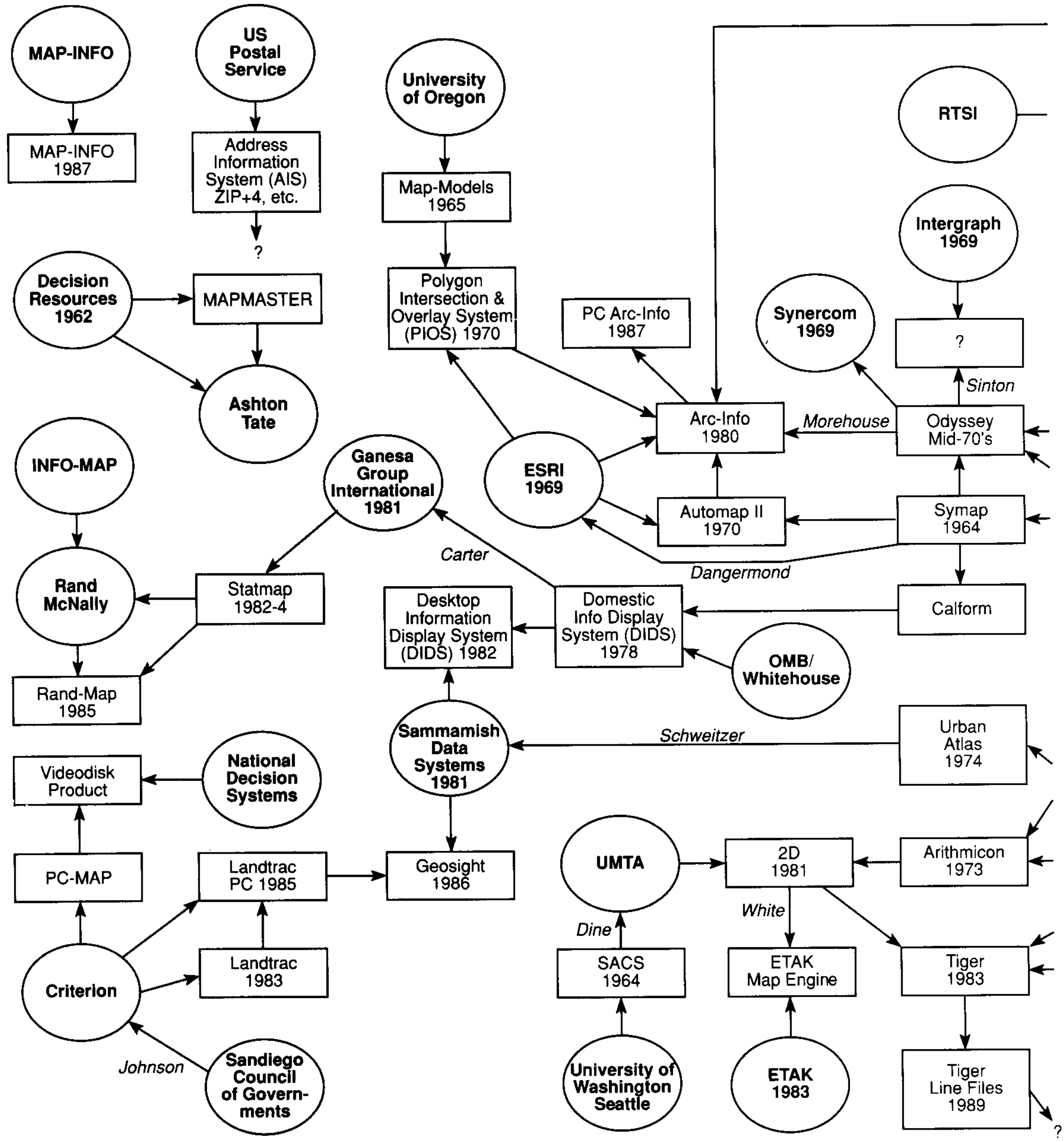
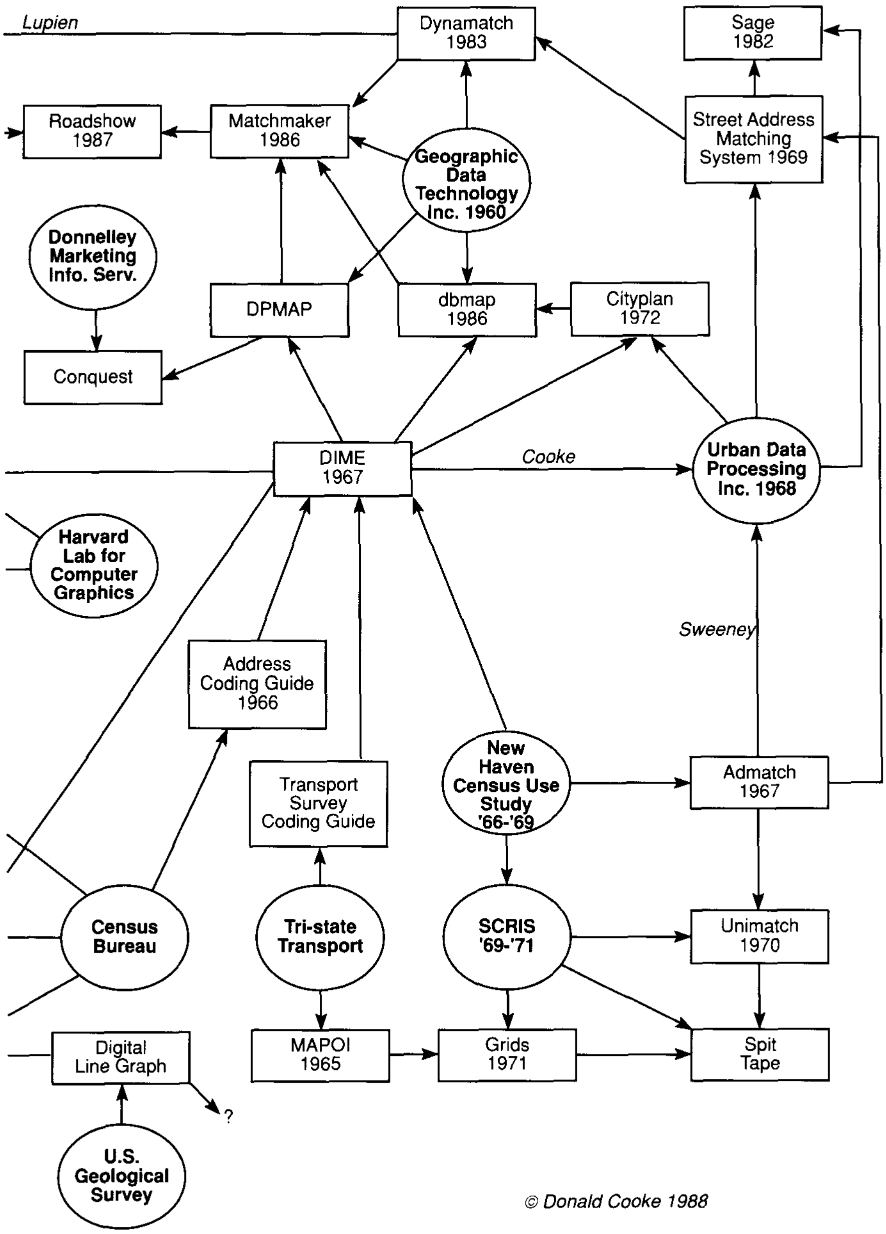


Fig. 2.1 An individual perception of the genealogy of geoprocessing in the United States (Pers. Comm. Don Cooke, 1990). Circles are 'places', i.e. companies, government agencies, universities, etc.; rectangles are ideas or concepts, often embodied in a software package or database; directed lines show direct or indirect migration or influence in a number of different ways. Examples of flows or lack of expected ones include:



- Harvard Labs influence on GIS vendors (Morehouse to ESRI, Sinton to Intergraph; Odyssey to Synercom)
- DIME was independent from the SACS (Small Area Census Studies)
- the diagram suggests that the USGS and the US Postal Service had very little influence on most developments.

recorded on punch cards. His initiative also illustrates an aspect to be repeated in many later projects where the application of technology was driven by an urgent need of the users, that such a task would have to take advantage of the best available technology – whatever its limitations – rather than await the ideal solution; it was also similar to many later applications in that it was a 'one-off' development which, having served its purpose, was not taken any further. Slightly later work (around 1967) by Bertin in Paris involved the modification of IBM 'golfball' typewriters driven directly by punch card readers to produce proportional symbol maps.

It is also clear that it was in North America that most of the significant early developments in, and applications of, GIS and related technology were made. By the early 1980s, Tomlinson (1985) estimated that there were probably more than 1000 systems in North America, a figure that must have represented a very high proportion of the systems then existing in the world as a whole. The bulk of this account will accordingly focus on North America, with later references to the United Kingdom and other European countries and to developments elsewhere in the developed world. It is only in the late 1980s that any significant developments have occurred in developing countries and then often through the aid and encouragement of developed countries (see Taylor 1991 in this volume).

THE NORTH AMERICAN SCENE

Aangeenbrug (pers. comm. 1990) has argued that the earliest antecedents of GIS in the United States can be traced back to the University of Washington. In the 1950s, both geographers (notably Garrison) and transportation engineers (notably Horwood) developed quantitative methods in transportation studies. Garrison's colleagues and students included Berry, Tobler and Marble; Horwood's included Barb and Dueker (see Dueker's important 1974 paper). Much of the original leadership of the Urban and Regional Information Systems Association (founded in 1963) and that of other key bodies was derived from or directly influenced by this group.

By the early 1960s, at least in North America, large mainframe computers were becoming widely available. In 1964, IBM introduced its 360/65 computer, with a processing speed 400 times faster and a memory 32 times as great as its predecessor, the IBM 1401 (Tomlinson 1985). These machines were employed primarily for one of two very different purposes: for routine administrative and data management tasks in business and government (such as pay-roll, stock control and record keeping of various kinds) and for scientific applications involving extensive computations, notably in chemistry, mathematics and physics. There was inevitably a good deal of discussion in government departments and agencies about the possibility of applying computer technology to handle numerical data, especially where these were already in machine-readable form, as with many censuses, where punch-card technology was widely used. In 1965 the US Bureau of the Budget compiled an inventory of automatic data processing in the Federal Government, in which it noted the significant use of computers to handle land use and land title data (Cook and Kennedy 1966). The following year, a conference on a comprehensive unified land system at the University of Cincinnati was advised that a system must be designed such that it obtained the maximum benefit from electronic data processing equipment (Cook 1966). The conference also heard that the District of Columbia already had a property data bank, which could be searched, updated and retrieved, and that Nassau County in New York would be the first to provide fully-automated access to records of land ownership.

The significance of the developments at the US Bureau of the Census, stemming directly from its need for automated address matching, is difficult to overemphasize. This need arose from the predominantly mail out/mail back nature of the US census and the requirement to produce area based tabulations from records whose only geographical reference was the postal address. An early advisory committee on small area data included Garrison (see above), who urged a development project to test automated data linkage procedures. A director hired to run the test, Caby Smith, recruited a team which included Corbett, Cooke, Maxfield, White, Farnsworth, Jaro, Broome and others who appear elsewhere in these pages. The first demonstrations of address matching, computer mapping and small area data analysis were provided through the 1967

New Haven Census Use Study (USBC 1969–73). Subsequent studies elsewhere in the United States, the launch of the DIME workshops in 1970 and the development and widespread distribution of ADMATCH (address matching software) all had major impacts upon government and academia in the United States. Indeed, the Census Use Study also sponsored the First International DIME Colloquium in 1972, leading to the creation of the Segment (later re-named as the Spatially) Orientated Referencing Systems Association (or SORSA), an organization which still holds international conferences.

Increasing availability of computers in universities was undoubtedly instrumental in the development of the quantitative revolution in academic geography in the early 1960s (James and Martin 1978; Hudson 1979), particularly in the field of spatial analysis (a term which was in general use by the late 1960s – see Berry and Marble 1968), with its emphasis on the statistical treatment of geographical data and on modelling. However, these applications, despite their potential relevance to handling geographical data, had little interaction with computer mapping, primarily because the statistical methodology was largely aspatial. One exception is a paper in an edited collection on computers in geography which related modelling to a crude cartography using the line printer (Rushton 1969). It is only in the middle and late 1980s that successful attempts have been made to develop closely coupled spatial statistics and 'geographical' displays.

Computers in the 1960s had, in general, no explicitly graphical facilities, usually operated in batch mode and were very expensive by today's standards. Despite this, Tobler (1959) had early recognized their potential for automating cartography, as had Nordbeck (1962) in Sweden. There were, indeed, developments in automating cartography in several national agencies concerned with mapping and in military establishments which could afford equipment that was prohibitively expensive to others. The US National Ocean Survey was creating charts on a Gerber plotter for the production of 'figure fields' or matrices of depth values and such organizations as the Aeronautical Charting and Information Center at St Louis, the Rome Air Development Center and the Central Intelligence Agency were active in aspects of this field (Diello, Kirk and Callender 1968; Tomlinson 1972). By the end of the 1960s, map production assisted by computer appears to have become widespread; for example, the Canadian Hydrographic Survey had automated display facilities in operation and Surveys and Mapping had embarked on a programme to apply automated cartography to the 1 : 50 000 series in Canada. In the main, however, the aim in computer applications in national mapping agencies was to mimic manual methods of production and so to produce maps that were virtually indistinguishable from their manual counterparts. Little information appears to be available on the extent to which these methods were cost effective, although Tomlinson (1985) suggests that the high cost of hardware placed them at a disadvantage in competition with manual systems: continuing evaluations of costs by the Ordnance Survey in Britain, for example, did not find automated approaches to map production as a whole to be cost effective until the 1980s. Unlike the situation in Britain, where a digitizing production line was in operation from 1973, the Topographic Division of the United States Geological Survey did not implement plans to automate the production of topographic maps until the start of the 1980s – a severe handicap to the development of many geographically-based information systems in the United States.

An entirely different approach to the automation of cartography was adopted elsewhere, notably in the universities, using the standard line printer as a mapping device. In cartographic terms, the results were crude, but this was not the point; the aim was to produce maps quickly and cheaply so as to display the characteristics of the data (especially statistical data for census tracts and the like) and to undertake simple analyses of such data by relating different parameters. It was here that Howard Fisher made a significant contribution and this approach found ready applications in landscape design, in urban and regional planning and, to a lesser extent, in resource management.

The Harvard Laboratory for Computer Graphics

Fisher was not a cartographer but trained and practised as an architect. He had begun work on a computer mapping system in 1963 while at the North Western Technical Institute (Schmidt and

Zafft 1975). On his retirement, he succeeded in obtaining a grant from the Ford Foundation to develop this work and, after making unsuccessful approaches to Chicago and Northwestern Universities (both strongholds of non-spatial computer applications to the analysis of geographical data), established the Laboratory for Computer Graphics (a title subsequently lengthened by the addition of 'and Spatial Analysis') in 1965 in the Graduate School of Design at Harvard University – from which he himself had graduated. There he built up a team of programmers and others to create a mapping package (SYMAP) which used the line printer as a mapping device and was capable of producing isoline, choropleth and proximal (Thiessen polygon or Dirichlet tessellation) maps. The package was easy to use by the standards of the day, particularly in relation to data for census tracts, incorporated default options when nothing was specified by users and was widely distributed. In addition to many pirated copies, over 500 institutions acquired SYMAP (Schmidt and Zafft 1975; Chrisman 1988); half of these were in universities, with the remainder equally divided between government agencies and private institutions. Copies were acquired not only in North America but also in Europe and elsewhere and the manual was translated into several languages, including Japanese. A subsequent program, CALFORM, which produced higher quality choropleth maps by pen plotter and reflected the increasing (if still sparse) availability of these plotters, seems to have had less success although it too was a pioneering effort. SYMAP was important as the first widely distributed computer package for handling geographical data. It introduced large numbers of users to the possibilities of computer mapping; it was the precursor, and possibly the progenitor, of a large number of other programs using the line printer; and it found a wide range of applications particularly through the connection between the Harvard Laboratory and landscape architects in the Graduate School of Design, notably C. Steinitz and his associates – one of whom, D. Sinton, produced a cell-based program (GRID) which permitted multiple overlays of data. Somewhat surprisingly, the appointment of a theoretical geographer, W. Warntz, to succeed Fisher as Professor of Theoretical Geography and Planning and head of the Laboratory in 1969, had little effect on the work and apparently stimulated little interaction between quantitative geography and computer mapping.

The Laboratory generated a wide range of contracts which, after the expiry of its grant from the Ford Foundation, became the main source of finance, along with income generated by the sale of mapping packages. It never developed a teaching programme (which might have prolonged its life) and thus only directly added a few new professionals to the field, although it did organize a highly significant symposium on topological data structures in 1977 and hosted influential Harvard Computer Graphics Weeks between 1978 and 1981. It also attracted at various times talented individuals who contributed in many ways to the development of computer mapping and, by extension, to geographical information systems. Among these are N. Chrisman, J. Dangermond, G. Dutton, S. Morehouse, T. Peucker and D. Sinton, several of whom contributed to the design and construction of ODYSSEY, arguably the prototype of contemporary vector GIS (Chrisman 1988). Unhappily, the subsequent history of this system was characterized by a series of unsuccessful marriages between the Laboratory and commercial enterprises and the departure of key staff from Harvard. As a consequence, numbers of staff declined and the Laboratory finally closed in the late 1980s. Overall, probably its most important contributions were in sparking creative thinking on GIS, creating a widespread awareness of the possibilities of handling and (to a lesser extent) analysing spatial data, and in stimulating programmes elsewhere which have contributed to the longer term development of GIS.

The Canada Geographic Information System

At about the same time as Fisher was developing his ideas on computer mapping at Harvard, R. Tomlinson (Tomlinson 1988) was involved in creating possibly the first true GIS – and certainly the first to be so entitled. Tomlinson can be thought of as the father of GIS through his role in persuading the Canadian Government that the creation of the Canada Geographic Information System (or CGIS, as it became known) in 1966, was a worthwhile investment. The origins of this, however, go back to 1960 when he was working for an air survey company, Spartan Air Services, which was undertaking a forest survey in East Africa. The firm had been asked to analyse all available map sources to identify locations for new plantations and for a new mill. The estimated costs of doing this manually were so high that the proposal was rejected. Tomlinson had argued that such analyses could be undertaken by computer and was given the opportunity to develop a digital methodology. None of the computer companies he approached was interested, although a subsequent chance encounter led to an expression of interest by IBM, which was already involved in digitizing air photographs. Another chance encounter on an internal flight found him sitting next to Lee Pratt, an administrator in the Department of Agriculture, which was then planning a Canada Land Inventory (CLI) involving the production of many maps of land capability for the whole of settled Canada; the analysis of these maps was expected to throw light on the agricultural rehabilitation of marginal farms. Tomlinson again expressed his belief that computer-based techniques would perform such analyses both faster and more cheaply. He clearly succeeded in impressing Pratt, whose subsequent support was critical to the development of the system. A contract was awarded to Spartan Air Services to undertake a feasibility study of a computer mapping system for the CLI. With the help of computer expertise from the staff of IBM, Tomlinson compiled a report which was accepted by the Department of Agriculture and he was then invited to direct its development within the Canadian Agricultural Rehabilitation and Development Administration (ARDA).

This development involved a large number of people both within ARDA and in IBM, and led to several significant developments for the future of GIS – among them, the creation of a drum scanner for the rapid digitization of maps (based on earlier IBM work of digitizing aerial photographs), of a data indexing scheme (the Morton Index 1966, which was subsequently widely emulated) and of a topological coding of boundaries involving the first known use of the link/node concept of encoding lines. The drum scanner, together with digitizing tables, provided the input to the system which was then based on an IBM 360/65 mainframe computer; output could be by line printer for numerical results and by ponderous Gerber plotter if a graphical output was required. It is interesting to note that there was minimal contact between CGIS and other bodies engaged in automated cartography and quantitative geography.

Tomlinson left the CGIS project in 1969, by which time Pratt had also left the Department of Agriculture. Although the various capabilities of the CGIS had been successfully demonstrated by this time, it was not until 1971 that the system was fully operational and subsequently it was reorganized and simplified. It now contains a digital archive of some 10 000 maps on more than 100 different topics. From the outside, it is difficult to evaluate the success of CGIS. Excluding those systems based on remote sensing data and the much more recent TIGER system (see Rhind 1991 in this volume), it may still be the largest GIS in operation and the only one to cover an area of continental extent in such detail; but its use seems to have been limited, in part no doubt because it took much time to build up the database as maps became available and because it came successively under four different departments, being given a different remit on each occasion. No doubt the facts that 'land' is a provincial responsibility in Canada and that CGIS was, for most of its existence, a passive organization, administered by technicians waiting for users to seek its services were also contributory factors. Its location in Ottawa, the lack of computer networking at the time and the prior availability of easily distributed printed maps of land capability – which users elsewhere in Canada may have regarded as more accessible – were other possible factors in its limited operational (as opposed to technical) success.

Early government activities in the United States

Tomlinson departed in 1969 to become a private consultant within the GIS field, one of an initially rare but increasingly necessary breed as proprietary systems multiplied and salespeople sought to persuade clients of the desirability of their systems. In addition, he continued to play an important role as Chairman, for the first 12 years of its existence, of the International Geographical Union's Commission on Geographical Data Sensing and Processing, which had been established in 1968 and which sponsored two major international conferences in Ottawa in 1970 and 1972, the first such conferences to be specifically identified with GIS. This emphasis helped to give currency to the name which the CGIS had pioneered, to promote contacts between delegates from a wide range of disciplines and locations, and to provide an overview of developments in the early 1970s (Tomlinson 1970, 1972). Subsequently, the Commission undertook an evaluation of the handling of digital spatial data within the US Geological Survey which, in 1976, had more than 15 information system activities concerned with the gathering and handling of spatial information in the fields of geology, geography, topography and water resources. The Commission also published, under the auspices of the UNESCO Natural Resources Research Series, a major monograph on the computer handling of geographical data (Tomlinson, Calkins and Marble, 1976).

These investigations also revealed that by 1976 there were at least 285 items of computer software handling spatial data which had been developed outside the USGS; by 1980, when a revision of the findings of this project was published, the number had risen to over 500 (Marble 1980). These figures are one measure of the rapid progress in this field in the late 1960s and the 1970s. They also illustrate one feature of that development which the CGIS had earlier demonstrated, that there was relatively little contact between the developers of such software. As a result, there was also considerable duplication, with programs being developed independently by different agencies to perform the same function. In part this was a consequence of a growing awareness of the possibilities provided by computers for handling spatial data and for displaying results of analyses through automated cartography. Within the universities, too, individuals were writing programs, often to fulfil a contractual obligation with a locally based agency that lacked the expertise to do so itself.

Tomlinson (1988) described the 1970s as a period of lateral diffusion rather than of innovation and there is considerable piecemeal evidence to show an increasing interest among a variety of agencies at all levels of government – federal, state, county and city. These include military and security establishments (such as the Central Intelligence Agency, which developed a world data bank for its own purposes and then made it available in the public domain (see Anderson, Angel and Gurney 1978); land management agencies such as the US Forest Service (Shumway 1986); conservation bodies such as the Fish and Wildlife Service (Christianson 1986); the Department of Housing and Urban Development (Goldstein, Wertz and Sweet 1969); the Bureau of the Census (see earlier description and USBC 1969–73)) and others at federal level; states such as California, Maryland, Minnesota, New York and Oregon; counties such as Fairfax in Virginia (Lay 1975) and cities such as Kansas City and Oakland. Some took existing software, as in the application of SYMAP in the Oakland Planning Information System (Goldstein, Wertz and Sweet 1969); others developed their own software in-house.

No comprehensive record exists of these various, local approaches but those adopted in the Bureau of the Census and in the USGS may be taken to represent the federal level. Initially, they developed quite separately, but have partially come together in the late 1980s to link digital cover from the USGS 1 : 100 000 topographic map series with census tracts for the 1990 population census, developments that will provide the basis for a variety of GIS initiatives throughout the United States (Callahan and Broome 1984).

As already indicated, the Bureau's substantial involvement in geographical data processing began with the New Haven Census Use Study in 1967 (USBC 1969–73) which led to the Dual Independent Map Encoding (DIME) scheme as the standard method for encoding data for census areas and (later) the preparation of experimental computer-generated maps of census data (Schweitzer 1973). The essence of DIME was a method of describing the urban structure through recording the topological relationships of streets; the earliest DIME files contained no coordinates. The advantage of proceeding thus was to provide an automated method of checking the completeness of areas built up from street boundaries – of particular importance since the US Census is substantially a mail out/mail back operation and the descriptions of the geography were assembled in many Census offices across the country (Dewdney and Rhind 1986). During 1972, the Bureau decided to embark on the creation of atlases for the major metropolitan areas (Schweitzer 1973), a task with which the Harvard Laboratory became involved in 1975 (Chrisman 1988). The Urban Atlas Project required the digitizing of maps of some 35 000 census tracts in the metropolitan areas and demonstrated the cost effectiveness of such an approach. It also required the development of software for handling this large quantity of data. Particularly significant in all these developments in the Bureau was a small group of mathematicians led by James P. Corbett and including Marvin White. Although it appeared subsequent to the Loomis (1965) paper, Corbett's definitive paper on the topological principles underlying cartography and GIS appeared in 1975 and a readily obtainable version of it was later published by the Bureau itself (Corbett 1979); it is clear that much of the credit for defining how topology theory is applied in the field of GIS is due to this group and to others working in applications areas in the Census at the time, such as Don Cooke. From this beginning came the subsequent extensions to DIME, the development of ARITHMICON and, ultimately, the creation of TIGER (see Rhind 1991 in this volume), possibly the largest and most all-embracing civilian GIS project yet and on which the success of the 1990 US Census critically hinged.

The practical involvement of the USGS in the GIS field is exemplified by the development of a system to handle and analyse land resource data, the Geographical Information Retrieval and Analysis System (GIRAS), developed from 1973 onwards to handle the increasingly large data sets becoming available (Mitchell *et al.* 1977). This was developed specifically to handle information on land use and land cover, held on manually produced maps at a scale of 1 : 250 000 derived from aerial photography, although these are subsequently derived/updated directly from imagery without manual intervention, using data from the Landsat series of satellites. Such maps had first to be digitized in polygon format to provide the input to the system which had been designed to store, manipulate and analyse these data, together with others on political and administrative subdivisions and public land ownership. GIRAS was developed initially as a batch processing system (GIRAS 1) but an interactive version was subsequently developed (GIRAS 2), with access via remote terminals. Output could be produced either in statistical or graphical form, the latter through display on a CRT screen or as a plot from a Calcomp drum plotter. The system also had a capacity to convert polygonal data into gridded data, an attribute of increasing importance with the use of remotely sensed data. The USGS has since made a myriad of other contributions to the development of GIS, not least in converting many data from paper map or stereo photo to digital form. Starr and Anderson (1991 in this volume) have summarized its recent activities and future plans.

State systems may be exemplified by the Minnesota Land Management Information System (MLMIS) which appears to be one of the more successful of such systems and illustrates the transition from a university research facility to an operational system within a state agency. It is described in more detail by Robinette (1991 in this volume) but it illustrates the difficulty of finding a secure financial base for such a system and the weaknesses deriving from an early decision to collect data on a rather coarse grid. MLMIS was started in 1976 as a research project located in the Center for Urban and Regional Analysis in the University of Minnesota, where the emphasis was on pilot projects but where some limited production work was carried out (which proved to be unsuited to a university environment). The system was based upon a digital land use map of the state, prepared from aerial photography. It was subsequently taken over by the state and established as a service bureau within the state planning agency, where it operated on a 'fee for service' basis, an approach which nevertheless required that the system operation and management be subsidized. It appears that very few users were at that time willing to pay for database development and the service found that it had to take on an increasing number of projects that were marginal to its main purpose in order to remain viable. This requirement to pay its way also led to raised fees and a consequent reduction in use. Nevertheless, it has undertaken several hundred successful GIS projects during its lifetime.

The commercial sector: the example of ESRI

MLMIS is interesting as one of the systems that had a continuing existence. Many others came into being, often created by university groups under contract to local or national agencies, and subsequently disappeared for lack of funding or because a key member of the team left. Little is known of the many equivalent developments in the commercial sector although the later history of the Harvard Laboratory provides one illustration of a commercial system that failed to get off the ground. After reaching a low point in the 1970s, following the exhaustion of the original Ford grant and the withdrawal of support by the Harvard landscape architects, the Laboratory had grown again, developing software and applications. One of its central activities was the development of the vector-based GIS system, ODYSSEY. A working version of this system was in operation by 1979 and a 'hazy deal' was struck with ISSCO, a software firm involved in computer graphics, to market it. The firm advertised the software but then withdrew, leaving the Laboratory with heavy debts which left it unable to recover as a major innovator in this field.

A happier example, also with roots in the Laboratory, is represented by the success of the Environmental Systems Research Institute (ESRI), founded in 1969 by J. Dangermond, a landscape architect who had gone to Harvard in 1968 to complete a master's degree and had then returned to his native California. ESRI was not, of course, the only firm operating in this field. Intergraph (again involving a product of the Harvard Laboratory, D. Sinton, and led by James Meadlock), ComputerVision and Synercom were other major players even in the 1970s. Most of these – apart from ESRI – came into GIS from the CAD/CAM area. But, in the light of published knowledge and because it is a highly successful enterprise, ESRI must serve as an exemplar for them all.

ESRI began as a non-profit organization engaged in the field of environment consultancy, although a brochure published in 1970 identified computer graphics as one of the professional services provided (Dangermond and Smith 1988). It used and developed the cell-based package GRID as its main applications package until the launch of ARC/INFO in 1982, and also developed a three-dimensional version called GRID TOPO; in the mid/late 1970s, it developed and sold a vector-based system, the Planning Information Overlay System (PIOS). A few years after its launch, it became clear that ESRI would not succeed in raising the necessary finance for growth as a non-profit organization and it consequently became a with-profit enterprise. The firm initially used the University of California mainframe computer but, with falling costs of hardware and increasing computer use, found it more convenient and cost effective to acquire its own minicomputer. By the mid-1970s it was also advertising its competence in GIS and by the early 1980s was providing a turnkey GIS. This proved very popular and a large and growing number of such systems has been installed. ESRI's ability to make its ARC/INFO system function across computer platforms ranging from personal computers, through workstations and minicomputers up to the largest mainframes has clearly been beneficial to the company.

Initially, most of ESRI's project work was on relatively small applications, relating to site or location analyses, but it became increasingly involved in environmental questions, reflecting the growing recognition of environmental problems in the United States. In 1973, it began work on its first state-wide system designed for mapping environmental suitability, the Maryland Automatic Geographic Information (MAGI) system, which became a model for other state systems. It had earlier participated in several applications in town planning in the United States, Australia, Canada, France, Japan and Venezuela. Other projects were undertaken in wastewater management, biological conservation, land reclamation, floodplain management, recreational planning and other topics.

Throughout the 1970s and early 1980s, staff of ESRI undertook a great deal of the project work themselves in the absence of appropriate expertise in commissioning agencies. It is unclear how far this widening range and increasing number of applications was due to a growing awareness of ESRI's capabilities and its own efforts to make these known, and how far it was due to an increasing need by potential clients to find efficient ways of handling large quantities of data. Dangermond and Smith (1988) have suggested that, in the 1970s and early 1980s, it was a matter of pressing GIS solutions on unaware and unwilling potential users, involving constant selling and subsequent support. Nevertheless, the fact that ESRI staff were heavily involved in the projects meant that they identified any flaws in their own software at an early stage and had a strong project-oriented approach, a fact that helped to build confidence in the firm. In contrast to the 'selling job' of the 1970s, the 1980s were characterized by an increasing and accelerating trend towards acceptance of GIS, with increasing numbers of requests for information and advice (Dangermond and Smith 1988). In the circumstances where this has been the case for over a decade, users can undertake projects with little outside advice or help although ESRI seeks, through its ARCNEWS and user conferences in different parts of the world, to provide continuing support. Of all GIS vendors, ESRI has probably been the most successful in the 1980s: much of its success can be attributed to ARC/ INFO. Many other factors played a role, including the personality of the ESRI founder and the forging of close links with users in education and other sectors. By the end of the 1980s, more than 2000 systems of GIS software for use on personal computers were being sold each year and ESRI had expanded from a staff of 15 in the early 1970s (though already operating throughout the United States and overseas) to one with over 350 staff and operating in a global market.

Spreading the word

Two other aspects are worthy of note, the development of teaching (initially in computer cartography and then, in the 1980s, in GIS itself) and the growing communication between workers in these fields. Many of those who had attended the early SYMAP conferences at Harvard began to develop teaching applications and, as early as 1972, a monograph on computer cartography (on which a whole chapter was devoted to SYMAP) was available in the Association of American Geographers' Resource Papers Series (Peucker 1972). Among those developing competence in this field were the University of New York at Buffalo, Simon Fraser University and the University of Saskatchewan in Canada, although Tomlinson (1988) has argued that in the 1970s there was probably more on-the-job training in commercial and government agencies than in universities.

The roles of conferences and publications in this field have already been noted. One of the first groups to publish a newsletter was the Urban and Regional Information Systems Association (URISA), founded in 1963 and holding annual meetings thereafter. Like many maturing organizations, it has eventually found the need to create its own journal and the founding issue in 1989 was largely devoted to GIS. The roles of the Harvard Graphics Weeks and the two Ottawa conferences under the auspices of the IGU Commission have already been noted. The most significant other development was the AUTOCARTO series begun (although not under that name initially) in 1974 as an International Symposium on Computer-Assisted Cartography held at Reston, Virginia (Chrisman 1988). It is interesting to note that, whereas some 40 people attended the first Ottawa conference in 1970, 300 attended the second and some 500 the first AUTOCARTO meeting (Tomlinson 1970, 1974; Chrisman 1988). Such meetings have been held at biennial or shorter intervals since that time. Such conferences became a fruitful outlet for publications by those involved in this field, although other papers were being prepared in a wide variety of professional journals (notably in the *International Journal of Geographical Information Systems*, co-edited in the United Kingdom and United States). Of course, developments in related fields must not be forgotten. Relevant papers appeared in the conferences of the Association for Computer Machinery, in publications devoted to computer-aided design, and in computing and engineering journals, especially those of the latter related to the utility companies.

By the late 1980s, then, GIS can be said to have become widely accepted in North America. The numbers of systems, courses, conferences, projects and facilities continue to multiply. Central, regional, state and local governments are increasingly involved, as are those in retailing and service delivery (see Beaumont 1991 in this volume) and in asset management (see Mahoney 1991 in this volume). The field has also acquired a degree of scientific recognition in the establishment of a National Center for Geographic Information and Analysis (NCGIA), funded by the National Science Foundation, as a cooperative venture between the Universities of California, Maine and New York (Abler 1987; see also Morrison 1991 in this volume). What is particularly interesting to an outsider is the speed with which acceptance of GIS has accelerated, to a stage where GIS is now a 'buzz word', and the extent to which the development has largely happened outside the political process, at least at a federal level. There seems, at a national level, to have been no official declaration of policy that this is a desirable path to follow. Initiatives and investments seem largely to have been effected through the bureaucratic system, although the USGS has been recognized by other federal agencies as having a coordinating role in this field at the federal level. As far as can be seen, the decision of the USGS and the US Bureau of the Census to develop what became the TIGER files and the associated line graphs for the whole of the United States was largely an internal, inter-agency agreement, unprompted by wider political considerations.

THE BRITISH EXPERIENCE

The British experience in the GIS field is in marked contrast in this regard, although there are some similarities – notably in the influential role of key personalities at an early stage in the development of GIS. Perhaps because there is little publicly owned land in the United Kingdom (and hence little direct responsibility for land management) and because the small size of the country and the highly centralized government have made for limited appreciation of spatial contrasts, the official pressures to develop computer-based methods of handling spatial data have been more limited. Moreover, local government, where such systems might usefully be applied, has experienced increasing financial constraints and a reduction in several of its key functions throughout the late 1970s and 1980s. These differences, have, however, been turned to advantage.

As in North America, the first beginnings can be seen in the 1960s in a number of areas, in the national mapping agency, in local planning and in the universities and polytechnics. A proto-GIS was proposed to the short-lived Natural Resources Advisory Committee in 1964 but, with the demise of that body, no further action was taken (Coppock 1988). A growing perception that computers provided a potential aid to land-use planning led in the late 1960s to the formation of joint working parties of officials from both central and local government and to the publication in 1972 of a report entitled General Information Systems for Planning (or GISP). This report (DoE 1972) outlined an approach that local authorities might follow, although there was never much encouragement by central government to do so nor any indication that it would adopt such an approach in its own agencies.

Bickmore, the ECU and the Ordnance Survey

Again, as in North America, a driving force in the automation of cartography was a research group, established almost entirely through the persistence and persuasiveness of one individual, D. P. Bickmore (Rhind 1988). He had been the cartographic editor of the Clarendon Press and one of the two editors of what was in effect a national atlas (Bickmore and Shaw 1963). This experience led him to the conclusion that the computer offered the only possibility of undertaking such a project reasonably expeditiously with up-to-date data. In collaboration with R. Boyle, later to be a major player in the development of automated cartography in North America, he secured funds from the Press to develop the Oxford System of Automated Cartography and, although this led to the manufacture of the world's first free-cursor digitizer and possibly the first map-making using a photohead on a high precision plotting table, no complete system was ever produced. However, Bickmore was successful in persuading the newly formed Natural Environmental Research Council (NERC) to fund a research unit in automated cartography. The Experimental Cartography Unit (ECU) became fully operational in 1967–68 at the Royal College of Art in London and focused its attention initially on the computer-assisted production of high-quality printed maps (see, for instance, Experimental Cartography Unit 1971; Rhind 1971). From 1973 onwards, it largely concerned itself with GIS issues. In 1975, the ECU was absorbed into the Natural Environment Research Council headquarters at Swindon and later became the NERC Unit for Thematic Information Systems at Reading University.

Like the Harvard Laboratory in its later years, the work of the Unit was highly project based, in collaboration with the Ordnance Survey (the national mapping agency), national agencies for geology, soils and oceanography, and planning agencies. Software was developed for changing projections, editing, data compression, automated contouring and so on, and experimental maps produced for the cooperating agencies. No marketable software analogous to SYMAP or other Harvard Laboratory programs was developed although plans were laid in 1971–72 to market the Unit's interactive editing software which ran on a DEC PDP 15 computer. But like the Laboratory, it exercised an important influence on thinking about automation and Rhind (1988) has argued that, without the Unit, the Ordnance Survey (OS) would not have begun its investigations into digital mapping or the production of digital maps until several years later at least.

The path initially followed by the ECU was not directly concerned with GIS. Nor, indeed, did the OS involvement in automated map making at first have any direct bearing on GIS. The approach adopted by the OS from 1971 onwards (see Sowton 1991 in this volume; Finch 1987) was to simulate manual production of its maps as closely as possible, an approach which facilitated map production but made it impossible to use the resulting digital data in an information system because they are unstructured. By 1973, the OS had established a production line to digitize and plot automatically versions of its large-scale plans as they came up for revision, a process that was necessarily random in its spatial occurrence. This approach did not become cost effective until the late 1980s, but it gradually came to be appreciated (both within the OS and outside) that a digital map framework could provide the base through which digital records of soil, geology, vegetation, assets and plant and the like could be related. An attempt was, therefore, made as early as 1974–75 to restructure the digital data through the development of appropriate software. The approach to preparing such a digital base through the process of map revision was not only random but also slow and the OS has come under increasing pressure to accelerate production of digital maps, at least for the bulk of the populated areas (which now seems likely to be completed not later than 1995). If this is achieved, OS will have well in excess of 200 000 maps in computer form – a total unmatched anywhere else in the world. In the British situation, where a consistent and large-scale series of maps exists, compiled to a common standard and datum and updated continuously, this coverage provides a highly valuable spatial framework on which other data can be assembled and linked (see Sowton 1991 in this volume).

Finally, it may not be appreciated by readers outside the United Kingdom that there are two Ordnance Survey departments within the nation state: one for Great Britain and the other for Northern Ireland. The latter became committed to a database approach rather than a map reproduction one earlier than did the former (see, for instance, Brand 1986). The Northern Ireland OS operates in a quite different – and generally more favourable – government and financial environment from that responsible for mapping the rest of the United Kingdom, but its task is much smaller and less onerous.

Other British developments of GIS

A variety of other historical developments has influenced the current GIS scene in the United Kingdom. For example, research staff in the Department of the Environment (DoE) had developed a mapping system for use in the Department and in central government as early as 1969 (Gaits 1969), but it seems to have had only limited application there, presumably because its usefulness was not recognized by administrators and planners. The Scottish Development Department, the planning ministry in Scotland, did fund a pilot rural information system, the Rural Land Use Information System (RLUIS), involving a large number of national agencies and two local authority districts in Fife, but this work was discontinued when the originating body, the Standing Committee on Rural Land Use, was abolished (Lyall 1980). Probably the greatest interest in GIS was expressed by the agencies concerned with environmental matters but these were small, with limited budgets, and were largely dependent on data collected by others, so that until the 1980s only limited progress was made. In Scotland, however, a consortium of three agencies (the Countryside Commission for Scotland, the Forestry Commission and the Scottish Tourist Board) did commission a university research unit, the Tourism and Recreation Research Unit, to construct and operate a simple GIS, the Tourism and Recreation Information Package (TRIP), to assist them in planning and policy making (Duffield and Coppock 1975).

Initiatives taken within planning authorities in local government to establish information systems following the 1972 GISP Report varied greatly, although in total they can only be described as disappointing until the late 1980s (Rhind 1987). The National Gazetteer Pilot Study in the Metropolitan County of Tyne and Wear was the first of a number of property-based systems, probably taken furthest in the now-abolished Greater London Council and the Merseyside Metropolitan County. The experience of several such systems, with particular reference to Berkshire, Nottinghamshire and Warwickshire, has been reviewed by Grimshaw (1988), who suggests that, probably for a variety of institutional reasons, the use of such systems has declined. Certainly the encouragement offered by the GISP Report led to only limited development, in part because of the determination and ability of central government to restrain expenditure by local authorities. There appears to have been an increasing interest in the use of automated map production in planning departments, initially by line printer maps using programs such as SYMAP; a study sponsored by the DoE and the Scottish Development Department to develop a proto-information system for planning in Scotland led instead to guidance through workshops and consultancies on the ways in which such mapping could assist the planning process (Coppock and Barritt 1978). There was, too, an increasing attention to management information systems in local government, as exemplified by the innovative Local Authority Management Information System (LAMIS) developed by International Computers Ltd (Rhind and Hudson 1980), but this appears to have had relatively little impact on GIS. The potential significance of applications of computer-based handling of data was, however, increasingly recognized. The Royal Town Planning Institute established a committee on the topic in the early 1970s, a British equivalent of the Urban and Regional Information Systems Association (BURISA) was established in 1970 and the National Computing Centre attempted to promote interest in this field. Nevertheless, the practical results of such interests were small, although these developments no doubt assisted the explosion of interest which occurred in the late 1980s.

As in North America, initiatives by central and local government were sometimes undertaken through the agency of university researchers, with the Universities of Durham, Edinburgh and London among the main foci of such work. The staff of such universities were also involved in a number of initiatives in computer mapping; in particular, T. C. Waugh (1980) developed his widely used GIMMS package at Edinburgh from 1970 onwards. Other initiatives were undertaken by researchers in the Institute of Terrestrial Ecology (ITE), where national databases of environmental and land use data were developed (Brown and Norris 1988).

Despite the late start, the single most important influence on GIS in the United Kingdom in recent years has probably been the growth in use by utilities of digital mapping data in conjunction with records of their own plant. Indeed, they are now the main driving force behind the acceleration of the digitizing of the coverage of OS digital maps. Since this is very recent, currently involves no major methodological advance in GIS and is described by Sowton (1991) and by Mahoney (1991) in this volume, no more will be said here except to stress its importance in providing data which are also useful for other purposes.

Official inquiries relating to GIS

A distinguishing characteristic of the United Kingdom in the decade between 1978 and 1987 is the series of inquiries carried out by the British Government or Parliament into geographical data and its use (see Chorley and Buxton 1991 in this volume). These demonstrate a shift in emphasis in successive inquiries. The first of these was the Ordnance Survey Review Committee, appointed in 1978 to advise on long-term policy for the OS. It paid considerable attention to the adoption of digital mapping, recommending that – if it was proved (as the Committee expected it would be) that digital mapping was cost effective – the OS should accelerate conversion from manual methods to provide digital coverage at the 1 : 50 000 scale by 1982–83 and at the basic (i.e. primary mapping) scales (of 1 : 1250, 1 : 2500 and 1 : 10 000) by 1992–93; it made no reference to GIS as such. This report, then, considered OS very much in terms of its role as a traditional map producer, but producing the paper maps in future by digital means.

The Report of the House of Lords Select Committee on Science and Technology (House of Lords 1984; see also Rhind 1986) investigated both digital mapping and remote sensing. It was much more appreciative of the potential benefits of digital data as such and, among its many recommendations were several on the need to accelerate the OS digitizing programme and the manner in which this should be done. In addition, it recognized the pervasive nature of geographical data and the many interrelationships and dependencies being built up, principally with regard to OS data. Therefore, it recommended the establishment of a Committee of Enquiry into the handling of geographical data. Such a Committee was established under the chairmanship of Lord Chorley and found widespread interest in such data; a large part of its

Report (DoE 1987; Rhind and Mounsey 1989; Chorley and Buxton 1991 in this volume) was devoted to the role of the OS in providing a digital map framework. In addition, however, it strongly emphasized the role of GIS, examined the value of standards for spatial referencing, noted that the lack of 'awareness' of what is possible and what is already going on in other areas was a major impediment to the widespread use of GIS, and recommended the establishment of a centre for coordination and advice on the handling of geographic data. Some of the recommendations were acted upon speedily: thus considerable resources have since been put into GIS research in the United Kingdom by the Natural Environment and the Economic and Social Research Councils (Goodchild and Rhind 1990). More significantly, there has been a move away from maps as products in themselves towards the view that they are only one of many sources providing geographical data for use in GIS. In essence, a database approach is now firmly established in British government thinking and, because of the highly centralized nature of the state in comparison to that of the United States and the existence of a ubiquitously used and country wide spatial referencing framework (the National Grid), this approach may be expected to permeate most organizations quite quickly.

Yet, despite this initiative to study what should be done in the national interest, the commitment by government departments to making geographical data generally available has been less than had been hoped. This is significant because data are not 'in the public domain' in the United Kingdom; government sees itself as entirely justified in charging for its data and, indeed, OS receives over one-third of its budget from cost recovery – a figure which will certainly rise (Rhind 1990). The military have marketed (through OS) Digital Elevation Models at 50 m resolution derived from the OS 1 : 50 000 scale contours and the Census offices have agreed to code each 1991 Census household response with a postcode (1.3 million of which exist for the country, so a multiplicity of small area data sets could be constructed for particular purposes). A significant factor is that income generated by sales of data by government departments does not generally accrue to them but reverts to the Treasury; since no part of their budget is provided for making data available and since to do so demands resources, little incentive exists for data to be provided. However, recent relaxations in rules as some departments are converted into executive agencies may alter the situation.

If activity in the United Kingdom in GIS was disappointingly small in the 1970s and early 1980s after the pioneer work of the ECU and OS, it expanded greatly in the late 1980s, stimulated by the publication of the Chorley Report. As already pointed out, much of the funding to stimulate action has come from the utilities, which need large-scale digital databases for the efficient management of the networks they control (NJUG 1987); their pressure has been influential in simplifying the specification for digitizing OS maps and in accelerating that programme. Local authorities, too, are showing a keener interest and, along with the utilities, have been major actors in the establishment in 1989 of the Association for Geographic Information (AGI), a national umbrella organization which involves vendors, chartered surveyors, geographers, educationalists, users in commerce and industry, software houses, learned societies and many others: its primary roles are to ensure the dissemination of knowledge, promote standards and advance the field. Commercial interest, which had been notably lacking in the 1970s, also rapidly developed, particularly in relation to market research (see Beaumont 1991 in this volume), plant location, local planning and traffic guidance systems, and is exemplified by the formation of Pinpoint Analysis Ltd which, in collaboration with the OS, has prepared a national database of centroid references of all properties in Britain (Rhind 1988). Finally, an exceptional contribution has been the creation of GIS demonstrators (Green 1987) and tutors (Raper and Green 1989) which have served to instruct and inform a world-wide audience.

DEVELOPMENTS ELSEWHERE IN THE WORLD

It is obvious that developments elsewhere cannot be covered in the same detail as for North America and the United Kingdom. None the less, several important distinctions need to be made. Developments elsewhere in Europe appear, apart from any military interest, to be associated primarily with national mapping agencies and with the maintenance of cadastral records of property. In respect of the latter, one of the most interesting developments has been that of the Swedish Land Databank System (SLDS), initiated in the early 1970s by a decision of the Swedish Parliament to replace the earlier manual system of property and land registration by an electronic system. An agency, the Central Bureau for Real Estate Data (CBRED), was created to establish and maintain this system. A pilot system was introduced in Uppsala County and operated under legal authority from 1976, and the system was progressively implemented, half the country having been covered by 1986 (Andersson 1987). It had a much wider application than solely in the field of property (see Dale 1991 in this volume; also Ottoson and Rystedt 1991 in this volume) and is being combined with statistics on housing and population (routinely available in Sweden on the basis of individual properties) as an input to urban and regional planning and to throw light on policy issues of various kinds, such as nuclear emergencies, civil defence and second homes.

Many applications elsewhere in the world are more recent than those in the United States. In Australia, initiatives have come primarily from two sources, cadastral mapping (a state responsibility) and applied scientific research (O'Callaghan and Garner 1991 in this volume). The handling of land records is now well established in all Australian states, having begun very early in South Australia, and is indeed internationally regarded as a major Australian success. GIS in the science area has been developed mostly through the Commonwealth Scientific and Industrial Research Organization (Cocks, Walker and Parvey 1988), where a continental-scale GIS, the Australia Resources Information System (ARIS), was begun in the late 1970s. It arose from an initial need seen in the mid-1970s for the production of maps of local government data and was stimulated by the availability of digital files of local government boundaries from the Division of National Mapping. By 1982, a wide variety of natural and socio-economic data were available. This system is essentially a research tool which has been used in a number of applications, from the location of new cities, through the identification of areas that should be withdrawn from pastoral use and of other ungrazed areas that might be devoted to this purpose, to the representativeness of National Parks. It remains a prototype, produced on a limited budget, which might serve as a model for an operational system at some future date.

Despite its immense commitment to the electronics industry, Japan showed little interest in the 1960s and 1970s in GIS, although here too interest in GIS developed very rapidly in the 1980s (Kubo 1987; see also Kubo 1991 in this volume). The only related activity in the 1970s appears to have been the production of digital land data by the Geographical Survey Institute using a 1 km grid; but no indigenous software was available to process the data and their use was accordingly very limited. The recent surge of interest has apparently been encouraged by the commercial survey and computing industries, which are very keen to acquire new business, and by central government agencies wishing to extend their control.

It is unclear from the account by Koshkariov, Tikunov and Trofimov (1989) at what stage interest in GIS occurred in the Soviet Union, although the immense challenges which that country faces in the management of natural resources throughout its vast territory seem to cry out for use of such systems; the impression is that not much had happened before 1980. By 1983, the Institute of Geography in the USSR Academy of Sciences was holding a conference on the problems of GIS science and, in the same year, the first of a series of schools and seminars for young scientists was held in the Far Eastern Research Centre on cartographic modelling and GIS. The main emphasis generally seems to have been on developing systems of automated mapping and on the preparation of cartographic databases, rather than in GIS *per se*. In this regard, the Soviets seem to be following the same path undertaken by the United States and the United Kingdom a decade or more earlier.

The history of GIS in developing countries is, in the main, similarly restricted to the 1980s when, partly through the initiatives of aid groups, a number of systems was established (see Taylor 1991 in this volume). For example, the Jamaica GIS (JAMGIS) was begun in 1981, funded by the US Agency for International Development using Michigan State University's Comprehensive Resource Inventory and Evaluation System (CRIES) as the basis (Eyre 1989), and a Land Titling Project was begun in Thailand in 1985 through a World Bank loan and technical assistance from the

Australian International Development Assistance Bureau (Angus-Leppan 1989). The latter has highlighted the importance of the staff of the host country being intimately involved in the work, of using familiar concepts and terms wherever possible, of providing comprehensive training and education, and of the role of persuasion by adequately briefed advisers.

Not all developments in such countries, however, are dependent on outside support. In the People's Republic of China, where work on digital mapping had begun in 1972 and tapes of satellite imagery had been acquired by 1975, a conference at the Academia Sinica in 1980 led to the establishment of a working group on GIS and to a number of regional initiatives. Chen Shupeng (1987) has summarized the numerous developments since then, mostly related to environmental hazard prediction and management, and carried out on microcomputers.

For completeness, reference should be made to the attempts at multinational and global GIS. Of course, the problems of developing and implementing GIS across national boundaries reflect, in exaggerated form, experiences within each country (notoriously those within the United States) of a lack of correspondence between mapping systems, data collection and the like. The European Commission (EC) has sought to develop a coordinated system of environmental mapping for the whole community. The main emphasis to date has been on the collation and evaluation of comparable data for the constituent countries and on software to handle them (Wiggins *et al.* 1987). At a global level, the availability of data from satellites, an increasing concern for the global environment and experience with such cartographic databases as World DataBank II have led to increasing interest in the possibility of world wide systems, a view that has led to initiatives to develop a topographic framework for such databases, initially through the activities of D. P. Bickmore, Chairman of a Commission of the International Cartographic Association (ICA) on a World Digital Database for Environmental Science from 1987 until 1990. Mounsey and Tomlinson (1988) have chronicled the progress of GIS in managing and exploiting global databases; it is clear from their book that such developments are still embryonic but are developing rapidly (see Clark, Hastings and Kinneman 1991 in this volume; also Townshend 1991 in this volume).

CONCLUSIONS

A history of GIS is necessarily piecemeal and partial. Inevitably, events are duplicated in different countries at different times. But, despite the unsatisfactory nature of the evidence and the fact that such conclusions are necessarily approximations to reality, four overlapping phases may be distinguished in the development of GIS in the more advanced countries. The first is the pioneer or 'research frontier' period, from the 1950s to about 1975 in the United States and the United Kingdom. This was characterized by individual – even idiosyncratic – developments, limited international contacts, little data in machine-readable form and ambitions which far out-ran the computing resources of the day. Individual personalities greatly influenced events. The second phase was that in which formal experiment and government-funded research was the norm, stretching from about 1973 to the early 1980s; the role of individuals was diminished somewhat in the international and national arenas except for strong-minded heads of national mapping agencies, but at the local level the effect of individuals persisted strongly. Rapidly replacing this phase was the commercial phase commencing *circa* 1982 which, in the light of strong competition among vendors, is now giving way to a phase of user dominance. The last two phases can also be characterized as ones in which systems handling individual data sets on isolated machines (latterly workstations) gave way to those dealing with corporate and distributed databases, accessed across networks and increasingly integrated into the other non-spatial databases of the organization. A vital characteristic of both the latter phases is that these activities became routine: in earlier phases, skilled 'fixers' were required to be on hand to cope with problems in the software, data or hardware.

What particularly emerges from this chapter is the dominant contribution of North America to the development and implementation of GIS up to the mid- and late-1980s, a function of the persuasive power of key individual pioneers, the size of the internal market, the leading role of the United States in the development of computer hardware and software and – above all – an increasing appreciation by many North American users of the need for efficient, speedy and cost-effective means of handling large quantities of geographical data. It is that perception of need which led potential users to seek GIS solutions and has encouraged commercial providers to develop and offer turnkey systems to convert that perceived need into a reality. What is not clear from the piecemeal evidence, however, is the ratio of failures to successes or how many operational systems are fully used and living up to their promises. A federal system of government, where large bureaucracies have considerable powers to take initiatives on their own account and where states are often as large as many independent countries, are no doubt important features, as is the large area of public land to be managed directly by federal and state agencies. Being continental in scale faces both Canada and the United States with particular problems, but it also helps to create an awareness of the importance of GIS to policy. Even so, CGIS remains unique in its scale, comprehensiveness and ambition at a time of inadequate technology.

Developments elsewhere in GIS were more limited until late in the 1980s, although those in Japan, the United Kingdom and several other countries in mainland Europe seem in rapid evolution. Land registration promises to make GIS a globally used technology from the 'bottom up' while earth monitoring from satellites promises to achieve global use 'top down'. It is a reasonable expectation that routine (and often boring, if valuable) use of GIS will be nearly ubiquitous over the next 20 years. This is the end of the beginning of GIS.

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