21
New technology and GIS

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GIS is in the vanguard of a sea change in the meaning of technology. GIS technologies mainly comprise software rather than hardware but data and organisational design increasingly form part of this wider perspective. In this chapter, we trace the evolution of this technology, specifically focusing upon the emergence of desktop GIS, the development of GIS across networks, and the move to interfaces based on virtual reality systems which link 2-dimensional mapping to 3-dimensional visualisations. We conclude by noting that GIS itself, like many contemporary software technologies, is diffusing into the very infrastructure of the systems to which it is applied, thus posing radical opportunities for this technology to be central to the real-time management and organisation of postindustrial society.

1 ABOUT TECHNOLOGY

Our common conception of technology is still based on machines developed a century or more ago in a bygone age. Hofstadter (1985: 492) illustrates the point quite cogently when he says: '. . .we all have a holdover image from the Industrial Revolution that sees machines as clunky iron contraptions, gawkily moving under the power of some loudly chugging engine'. GIS technology however is very different in that increasingly it no longer refers to the material world – the computational hardware – but to software and its engineering, and more recently to its application in diverse contexts. GIS technology clearly involves software but it also includes the data which comprise applications and the kinds of organisation in which GIS is embedded. Hardware, software, 'dataware,' and 'orgware' thus comprise this technology but there is another spin to this technology in sight. As digital information comes to dominate more and more activities of everyday life, GIS is fast becoming part of the infrastructure of society itself. In this chapter, we will extend our image of this technology into the very infrastructure which is often the subject of GIS applications themselves, thus posing a conundrum of usage which is the hallmark of late twentieth-century technology. No longer hard but soft, no longer material but ethereal: in this sense, GIS is at the vanguard of what technology will come to portray in the twenty-first century which is a very different conception from that on which modern science was founded.

Before we discuss the characteristic technology, it is also worth noting the longstanding distinction between science and technology and how this relates to GIS. Commentators on the history of science and technology have frequently made the point that technologies often develop quite independently from the science which they imply and they point to the age of steam which developed in parallel to the physics and mechanics which provides its theoretical justification. In one sense, the development of GIS mirrors the same kinds of disjunction in that although the software technologies depend upon computer hardwares which would never have been invented but for breakthroughs in the most esoteric of science, GIS software owes something to developments in computational science, particularly to database theory, but not much, so far, to geographic theory per se. In fact, as we run headlong towards postindustrial society, the traditional distinctions between science and technology seem increasingly irrelevant and in themselves may be only appropriate to past times. As Metropolis (1993: 121), one of the founders of atomic physics, has recently said it is in computer science '. . . that real scientific progress is nowadays to be found. Computer science . . . has changed and continues to change the face of the world more thoroughly and more drastically than did any of the great discoveries in theoretical physics'.

What has never been understood in any broad sense throughout the entire history of computing is that digital computation is universal. The inventors of the field such as Turing and von Neumann only barely perceived the point that when everything can be reduced to bits, everything can be subject to computation and therefore the technology will ultimately manifest itself in every form of media (Negroponte 1995). Over the last half century this point has been driven home by successive waves of hardware developments: miniaturisation enabled the earliest forms of numerical computation to be swamped first by text-based, then graphics-based applications, and then by multimedia systems and entire computer environments such as those based on virtual reality which now represent the cutting edge (Neves and Câmara, Chapter 39). Computing is characterised by many layers of activity, each developing and evolving different manifestations of digital technology. Mainframes gave way to minicomputers, thence to micros and workstations at one level while super and parallel computers have evolved at another (see Openshaw and Alvanides, Chapter 18). Handheld digital devices from cameras to palmtop organisers are emerging at the grass roots embodying much of the software such as spreadsheets and even simple GIS which were evolved at higher levels. In another dimension, computing and telecommunications have rapidly converged, first from the need to interact directly with machines over distance, but more recently, with computation itself becoming embodied within networks themselves.

For GIS, which essentially began as part of the 1980s wave of graphical computing, the key technological issue has until recently revolved around miniaturisation. Ever faster graphics processing has enabled GIS software to move from remote systems to the desktop. Only a decade ago, this technology was essentially remote in that users, although networked, largely used such technology in non-interactive or non-immediate form. Miniaturisation has enabled GIS computing to move to the more personal domain, from collectively- to individually-based computation (Batty 1995). Current changes in these technologies are emphasising applications across the Internet with dramatic consequences for all aspects of GIS computing. And last but not least, GIS technology is beginning to leak into the very infrastructure which GIS seeks to understand and describe, as the technology begins to find uses in much more routine applications, such as in-vehicle navigation, the delivery of local services, gazetteers, real estate use, and so on (Graham and Marvin 1996).

The rest of this chapter will review four key aspects of this technology. We will sketch the evolution of GIS through the hardware and software revolutions, and then describe the move to the desktop. This represents the state-of-the-art, but the cutting edge is very different. The move of these technologies to the Internet, and the idea of urban infrastructure embodying GIS represent dramatic changes in the nature of these technologies and we have only just begun to see the prospects ahead. In the previous edition of this book (published in 1991), there was hardly any mention of networks (see Coleman, Chapter 22), and certainly no sense that GIS was part of the very infrastructure it is designed to understand and monitor (see also Waters, Chapters 59). Desktop GIS (see Elshaw Thrall and Thrall, Chapter 23) had not come of age, for the state-of-the-art was based on workstation applications and the technology was much less diffuse. Needless to say, we can barely anticipate what is in store in the next decade although real-time applications with real-time data inputs are likely to dominate the future, as the gap between actual systems and the software used to understand them narrows. Before we speculate on the future, however, we must trace the evolution of GIS through its hardware and software revolutions.

2 GIS THROUGH THE HARDWARE AND SOFTWARE REVOLUTIONS

Inevitably, any general discussion of GIS requires some definition. Here we see the technology as embodying the representation of geographical phenomena in digital form where the data can be visualised in at least two different ways or 'views'. The traditional distinction is between cartographic visualisation, and the manipulation of spatial data in a form that exploits its spatial nature. Cartographic visualisation by itself defines computer cartography while spatial data analysis per se is rarely considered as GIS. Normally it is the intersection of these different forms of analysis which defines GIS as software with the ability to look at spatial data through two or more views (see also Longley et al, Chapter 1). In its early history, computer cartography was somewhat separate from spatial data analysis but towards the end of the mainframe era of computing, various efforts were made (particularly at the Harvard Laboratory for Computer Graphics, and at the Royal College of Art) to integrate the visual with the mathematical analysis of spatial data (Chrisman 1988). The logic of this was based on the notion that spatial data have their own unique form which is essential to the analysis of deep geographical structure but is also essential to its 'correct' visualisation and mapping.

It took a long time to put these ideas together, but during the 1970s work on spatial data analysis slowly proceeded, drawing on developments in spatial statistics and emergent database theory. Developments in spatial analysis in this area were orientated towards geometric operations involving points, lines and polygons, interpolation, contouring, and point-in-polygon algorithms such as those found elsewhere in this book (e.g. Dowman, Chapter 31; Martin, Chapter 6). It was not until computer hardware really got to grips with graphics in the 1980s that GIS came to be defined as it is conceived in this book. Data analysis of the geometric attributes of space was independent of its visualisation, which in the 1960s and 1970s was through computer cartography and computer draughting. Almost as soon as computers were developed in the 1940s, graphics were invoked, first as a by-product of monitoring the working of the machine using oscilloscopes, but mainly in the 1950s and 1960s using line plotters where the computer drawing was carried out off-line from the computation itself. What marked the late 1960s in the emergent field of GIS was the use of the normal output device attached to mainframe and minicomputers – the line printer – for mapping in which the resolution of the device was the size of the characters themselves. Some remarkably good thematic maps were displayed in this form using ingenious forms of overprinting but true GIS had to await the development of the more personalised technologies of the 1980s.

The graphics technology which was cutting edge in the 1970s was a development of the oscilloscope – the vector graphics device – in which each line, and each point in any filled area of the drawing was swept out on the light sensitive surface of the scope – the phosphor – by an electron beam. This technology was not used very much for computer cartography, where the emphasis was upon the kind of precision more akin to line plotting, but it was widely used in scientific visualisation and it was thus a surprise when the technology changed so dramatically after the invention of the microprocessor. Miniaturisation began almost as soon as computers were conceived with the invention of the transistor at Bell Laboratories in 1948, the integrated circuit in 1957, and the microprocessor or 'computer on a chip' in 1971 at Intel. Many anticipated that computers would get ever smaller but few realised that graphic images could be directly associated with computer memory or that computers would pervade society in the way they have done. In fact, each great wave of computing has been unforeseen by the establishment. The remote computing industry represented by IBM and DEC did not foresee personal computing (indeed they positively resisted it), while none foresaw the amazing rise of the Internet, network computing and the drift of computation into the ether. In the 1980s, it was cheap computer memory that made better graphics achievable and this led directly to better graphics interfaces as well as improved image processing, of which GIS was a direct beneficiary. The desktop environment has followed as personal computers have become ever more powerful and as workstations have moved to the desktop.

The 1980s was the time when computer cartography finally merged with spatial data analysis. Early versions of proprietary software such as ARC/INFO did make use of plotter devices for visual outputs, but it was the advent of cheap raster graphics devices in the early 1980s that made interactive use a possibility. GIS then began to take off. In terms of data input, digitisers gradually came into use, although many cartographic data were input through the keyboard. With the advent of raster graphics, scanners have become widely used, as have remotely-sensed images. However, the current distinction between vector- and raster-based GIS does not reflect the earlier distinction between vector and graphics devices. Most GIS now deal with data which can be represented in either raster or vector form, but whether raster or vector, the usual way that data are visualised is on a raster device. This distinction is beginning to blur as new algorithms are being developed to translate raster into vector and vice versa, although the distinction remains, largely because of the type of data and the way they are input rather than the way they are output (see also Martin, Chapter 6).

GIS software however remained quite rudimentary during this period. In essence, operations on cartographic data represented most of the functionality of the software. The most significant functions were those which pertained to geometry with the concept of layers and overlay central to the operations known as spatial modelling. Models pertaining to the attributes of the geographical system being represented remained separate from GIS, for its logic is related to spatial geometry rather than to any system model based on the functioning of those attributes. This is a tension within the field. GIS is a generic technology and thus its functions must be applicable to different types of system. Modelling, analysis, and design usually pertain to specific systems to which GIS must be applied and insofar as this technology can embrace the relevant functionality pertaining to different systems of interest, it is through connecting the technology to other software (Batty and Xie 1994). Programming of GIS software systems has reflected the development of programming per se with early versions being in FORTRAN or more structured languages such as Pascal, later ones in C and its variants. Of late, new systems such as Smallworld make use of object-orientation (OO: see Worboys, Chapter 26) while recent desktop packages such as ArcView embody OO scripting languages which enable their interfaces to be customised and some new functionality to be programmed in.

3 THE MOVE TO THE DESKTOP

The state-of-the-art in GIS technology when the first edition of this book was produced was workstation GIS, usually networked in client-server or file-server mode, where spatial data was usually viewed using raster graphics devices but with minimal customisation in terms of graphical interfaces. Windows systems were first introduced on workstations in the mid 1980s based on MIT's X standard although the Apple Macintosh broke the mould in personal computing around the same time in its adoption of the interface developed at Xerox-Parc. However, GIS technologies still tended to output graphics either in a single window – virtually offline from the main processing – or for final print on line plotters. There was some ability to customise the interface (see Maguire, Chapter 25), and a typical plot frame using the ArcPlot window from ARC/INFO (circa 1991) is illustrated in Plate 15 (Batty 1994). Some customisation of the output was possible using rudimentary drawing functions in the package through the Arc Macro Language (AML).

Desktop GIS (see Elshaw Thrall and Thrall, Chapter 23) emerged rapidly following the introduction of Windows 3.1 as the replacement to DOS in the late 1980s. Prior to that, desktop GIS such as PC-ARC/INFO was usually based on stripped-down versions of workstation or even mainframe/mini packages or rather crude graphics interfaces built on top of DOS such as early versions of the educational raster-based GIS Idrisi (see Eastman, Chapter 35 for more recent use of this software). The main feature of desktop GIS is in fact integrated functionality based on the WYSIWYG principle (What You See Is What You Get). This will be illustrated with the package MapInfo which began life as a desktop mapping package and has rapidly moved 'upscale' in acquiring ever more functionality, thus now approaching the capability of workstation GIS but with everything on the desktop. Figure 1 shows a thematic map output from a simple GIS based on the 32 boroughs comprising Greater London. On the screen are the three main windows or views which MapInfo offers – the map window, the browser which is the table containing the attribute data for each borough, and a graph of data which in this case are 1991 populations. Also shown are two buttonpads which provide the user with short cuts to the various functions within the package, and to basic drawing tools which can be used for editing the map geometry and for presentation. Like most desktop GIS, MapInfo has a structured query function (see Egenhofer and Kuhn, Chapter 28) which enables the user to search for various combinations of attributes and to highlight these as spatial objects in any of the open windows (through hotlinking) and as a short cut to information in the browser stored as an information function on the main buttonpad and activated using point and click. In MapInfo, apart from the usual notion of structuring the data in layers and seeing the data as map layers, there are the usual thematic mapping capabilities which can be used to combine and derive new layers. Unlike Idrisi or ArcView, there is no

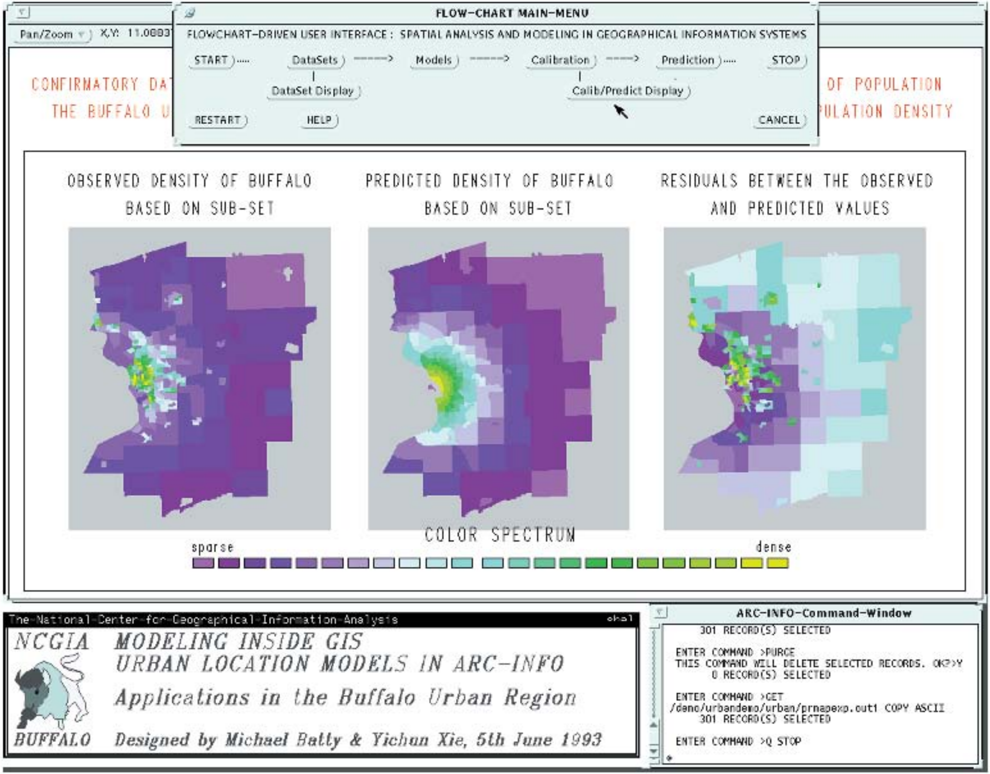

Plate 15

A typical interface from workstation GIS.

elaborate overlay capability as such, thus betraying the program's origins in thematic mapping. But like all desktop GIS, newer releases are incorporating ever more sophisticated functions only found hitherto in workstation GIS.

Other developments involve workstation GIS acquiring desktop features with new user-friendly front-ends being developed (see also Schiffer, Chapter 52). ArcView was originally intended to be such a front-end to ARC/INFO although the package now exists in its own right. Desktop GIS is now open to other kinds of software through dynamic data and other exchange mechanisms, and through the addition of programming languages within the GIS which opens it to other software on the same machine or network. Furthermore, what were once very different software packages are beginning to converge. Spreadsheets are adding map capability and it is only a matter of time before wordprocessing packages add GIS-like functions – drawing and animation functions are already a part of such software. But perhaps the most interesting development is the further move down the hardware hierarchy to putting GIS on handheld devices such as personal digital assistants like the Apple Newton. The package Local Expert, essentially GIS software for navigating or streetfinding in different cities for use by tourists or local residents, is an example. Local Expert, typical output from which is illustrated in Figure 2 for London, enables the user to find information on restaurants, places of historic interest, and so on using a particularly bulletproof user interface. Much of its functionality is similar to that found in more professional desktop GIS, although the emphasis at this level is upon structured query language (SQL)-type interrogation, route finding and the measurement of shortest paths. Nevertheless, it is clear that by the time the next edition of this book is written, this kind of application will be widespread.

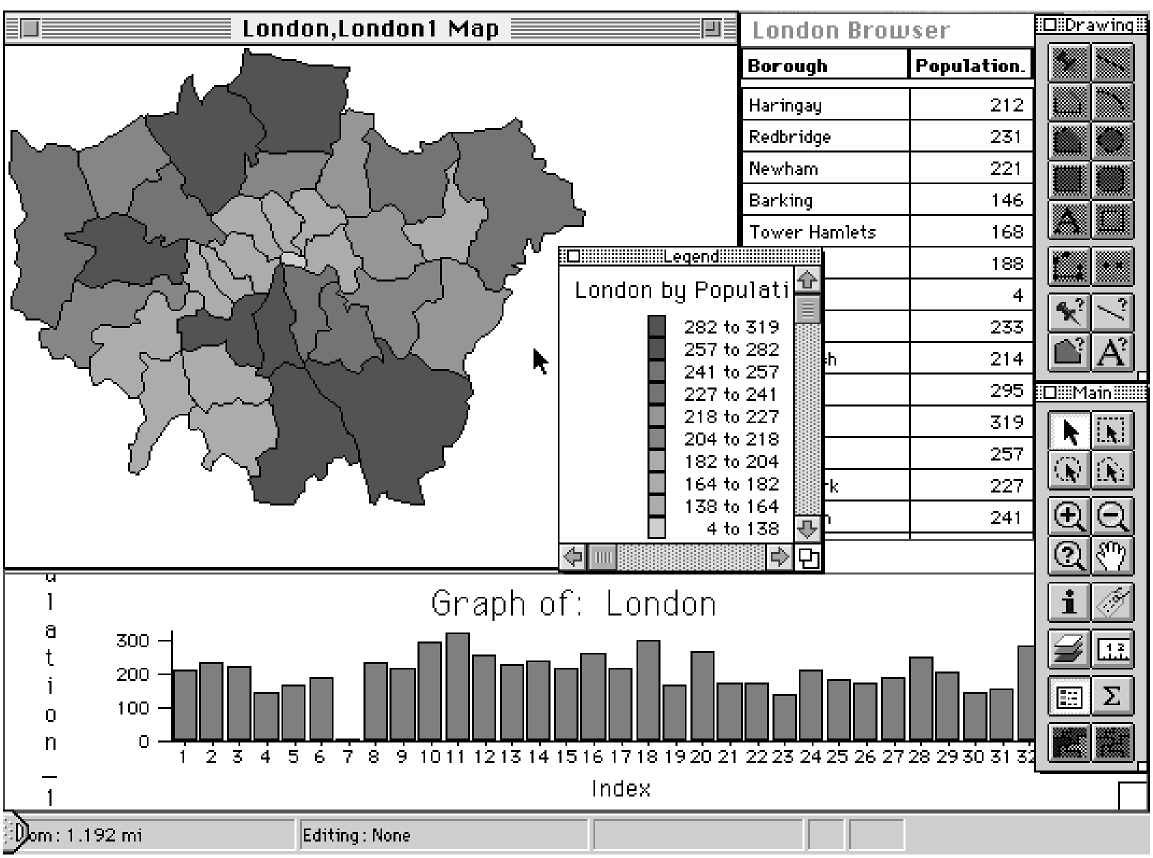

Fig 1. Mapper, browser, and graph windows in desktop GIS.

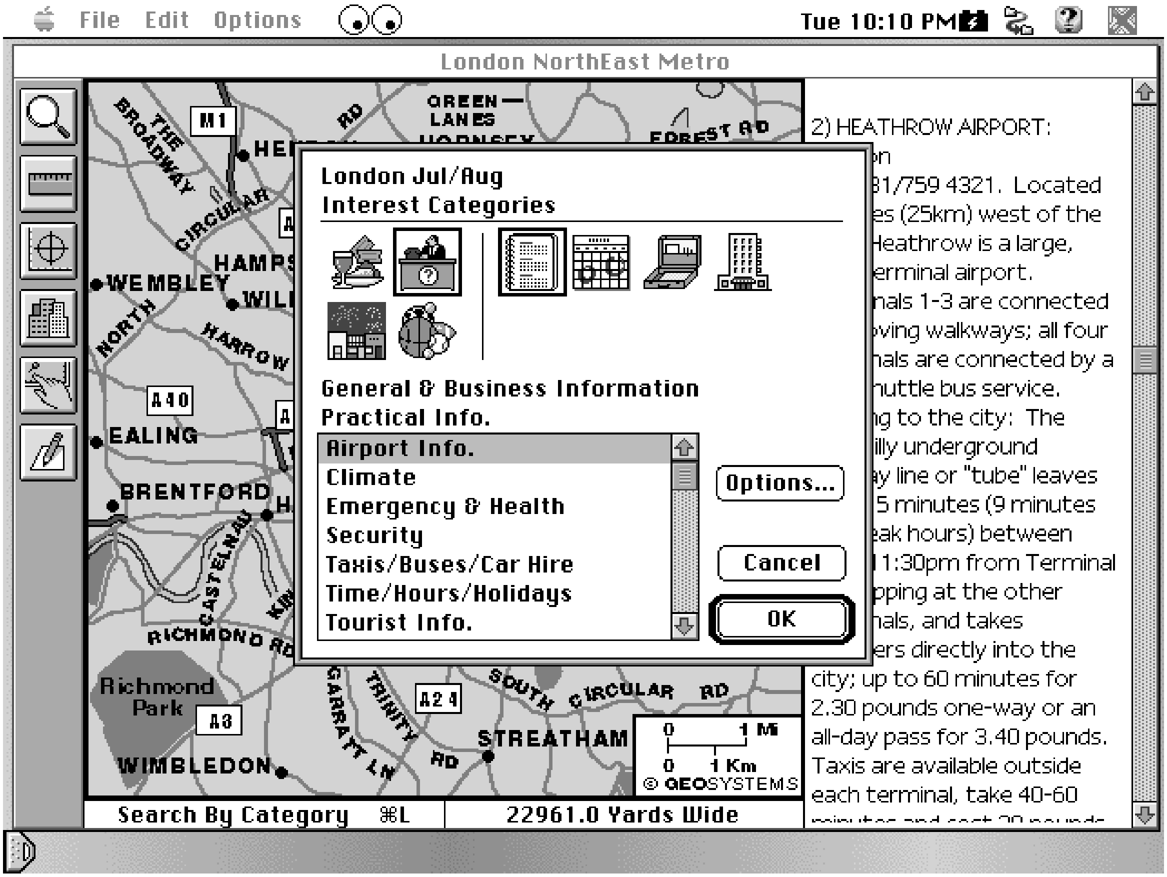

Fig 2. Information and street finders based on low cost GIS.

4 THE MOVE TO THE INTERNET

The convergence of computers and telecommunications was anticipated as a means of linking computers and their users remotely, but what was never anticipated was the extent to which computation itself would fuse with communications (see also Coleman, Chapter 22). The movement of software to the World Wide Web (WWW), for example, is a startling and unexpected development which was deemed unlikely even five years ago. At one level, what is currently happening is simply an extension of the opening of software on the desktop to other software across the Internet. With the costs of memory still dropping fast, and new memory still soaking up ever more graphics, this trend has migrated to networks. The fact that the Internet has been effectively free to users in educational environments, and low cost to others, has fostered a massive increase in shareware of a very high quality. What is amazing is the high quality 3-dimensional and multimedia software which now exists in the public domain and this is threatening quite well-established vendors of proprietary software. Three-dimensional graphics is being particularly taxed by these developments with the advent of virtual reality software over the Internet, but GIS shareware is on the horizon as a variety of developers is beginning to develop graphical interfaces to locational data in the form of virtual reality interfaces such as animated maps.

These developments are so fundamental that hardware itself is beginning to change. Several hardware-software companies have announced the ‘NC’ or network computer which will function with no more software than a web browser and some communications protocols (e.g. see Dale and McLaren, Chapter 61; Sugarbaker, Chapter 43). The implication is that all the software ever required will be available on the Internet to be downloaded to the user or leased in some form. What goes for software also goes for data. Archives of data in the public domain are appearing such as the US Population Census archive at the Lawrence Berkeley Laboratory (*http://cedr.lbl.gov/cdrom/lookup/*) and already there are applications which take such public domain data and explore it using appropriate GIS shareware. Animated maps are appearing. For example, the BigBook 3D browser is an experimental animated map query system to the Yellow Pages which will display 3-dimensional visualisations of city blocks from queries made in terms of the 2-dimensional map (*http://vrml.bigbook.com/bb3d/*).

These developments in network computing when coupled with developments in 3-dimensional computing and multimedia, specifically in virtual reality systems, provide dramatic possibilities for GIS technologies. Powerful 3-dimensional and animation software coupled with digital video provides the raw material to creating 3-dimensional interfaces to the kinds of 2-dimensional databases which are central to GIS. At University College London, a group has created a virtual interface to an information system of buildings in the college. This system was created for programming and making inventories of room use. An animated interface was constructed as an interactive Quick Time movie based on sequences of digital video of college buildings. This was made operational within Hypercard. The essence of the Hypercard stack is the use of hotlinks to access other software such as various types of GIS used to portray the data. Once the system had been constructed, the various links within the software were exploited, first to open the system to other software on the desktop. For example, the local software was linked to electronic atlases as well as more local map software. An example of the interface is illustrated in Plate 16, where the AUTOCAD model of the college gives the entry points to the video which accesses the building information system from which an electronic atlas and other GIS can be accessed.

However, what can exist on the desktop can also exist on the net, and the system has now been extended to the web where the Virtual Reality Markup/Modelling Language (VRML) has been used to provide an interactive model of the college based on the AUTOCAD model. If you have the correct version of the Netscape browser and plugins such as 3D Live, then you can use the model to access data and other WWW pages associated with departments in the college from anywhere in the world. If you log onto *http://www.ge.ucl.ac.uk/* then there are several options to run the interface under QT, VRML, and other graphics interfaces. With the most basic of browsers, some animation is possible. An illustration of the VRML model is given in Plate 17 where the façades of the college buildings have been texture mapped. The intention is to extend this kind of interface to a much bigger model of Central London and the City to provide a virtual interface to GIS data.

Finally, the Internet introduces yet another dimension to GIS. Most software is written for individual users. Applications may involve some team work or group problem-solving, but the notion of using software collectively is a very recent idea in GIS at least. Networks provide the means for such interactive use. In the design sciences and the arts, the idea of the virtual design studio is well advanced where users engage in group design using common software but also use common repositories and archives for various solutions or designs (Day 1994; Wojtowicz 1995). The idea of the digital pinboard is central to such developments. The same kinds of use might be envisaged for GIS at the level of the construction of a GIS, its use in analysis, and where appropriate its use in problem solving, design, and decision making. The use of GIS in this context is encapsulated in spatial decision support systems and their extension in a collaborative mode is under way (Batty and Densham 1996; Densham 1991). The immediate future is likely to see substantial developments of these ideas especially where the hardware is an NC, and the software and data are available over the Internet.

5 GIS AS URBAN INFRASTRUCTURE

The brief history of GIS has involved a rapid broadening of the technology, from hardware and software to data and organisational design, and from individual to collective use across networks. The diffusion of the technology has also changed its nature, and this diffusion has now reached the point where many routine functions which make society work on a day-to-day basis are being endowed with some GIS functionality. This is what we mean by GIS leaking out into the social infrastructure in parallel to many other software technologies. It is the passage of GIS from professional use to lower level routine use that changes this balance. In one sense, all science is part of the infrastructure

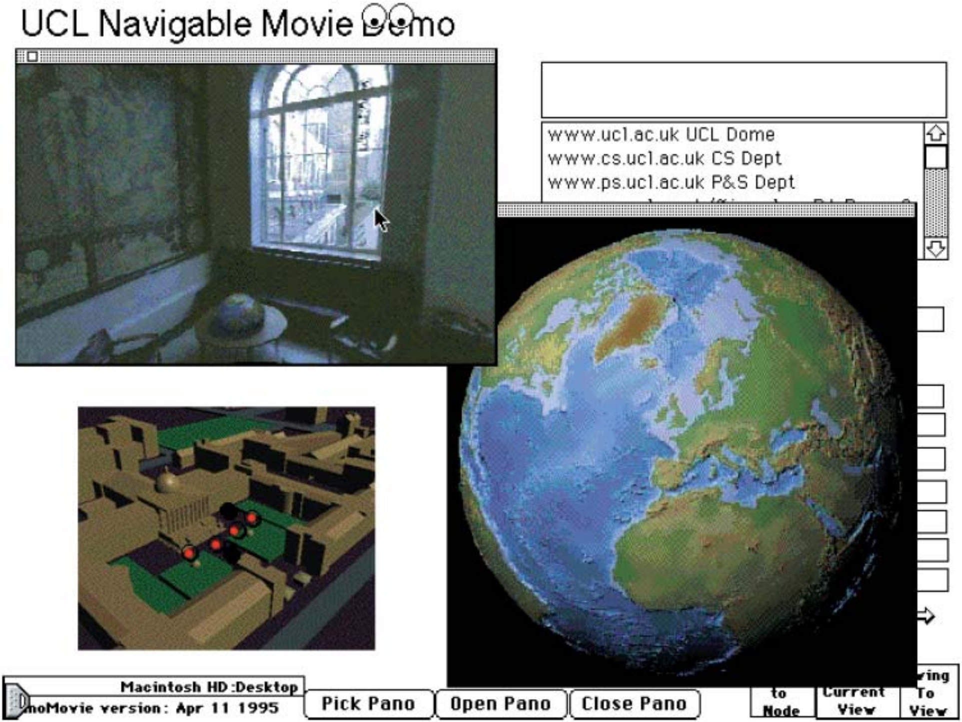

Plate 16

Visual interfaces to GIS incorporating animation and 3D.

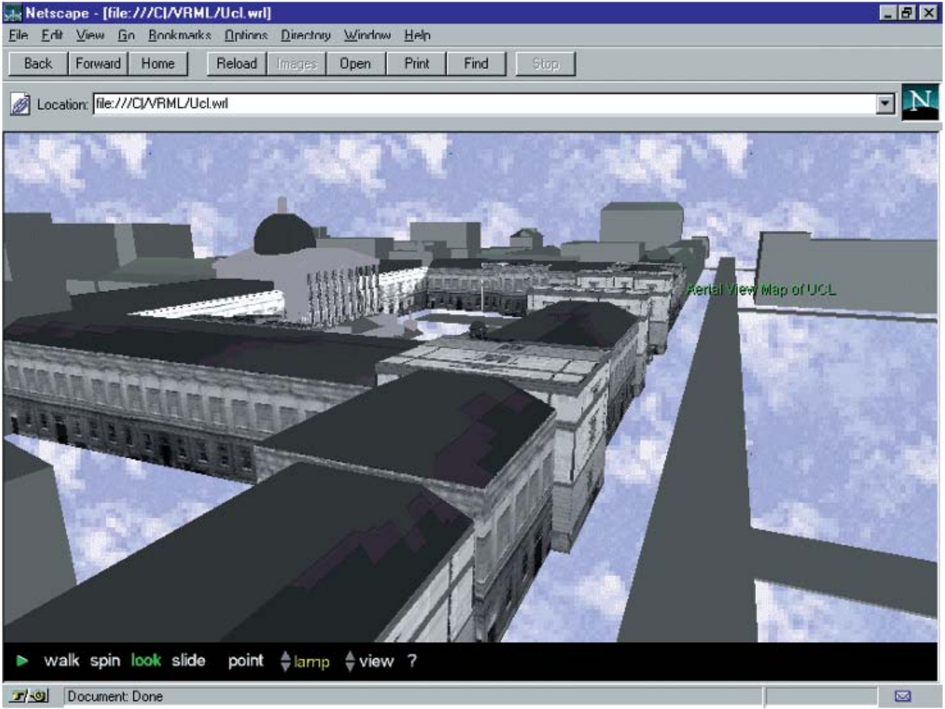

Plate 17
A VRML interface to GIS on the WWW.

although it forms such a small proportion of everyday activity and is concentrated in such a small elite that the notion of science being affected by the very activity of science itself still remains an alien one. However, the idea that GIS is being affected by the wider all-pervasive activity of GIS is clearer. Networking is central to this in that the kinds of inputs and outputs to GIS are beginning to be available in real-time.

In Figure 3, we show how GIS is becoming part of the infrastructure through the kinds of links which are being formed between hitherto disparate activities. The real-time delivery of data makes real-time GIS a feasible proposition for appropriate uses such as traffic management, emergency services, even just-in-time geodemographics for marketing. Very basic uses such as navigation and information finding within cities by individuals is also on the horizon, as the data used by handheld devices can be updated through wireless technology. In fact, the entire continuum of GIS usage from the most immediate and the most routine to the most remote and long term is being integrated though network and wireless technologies. All kind of devices and networks – cable, TV, telephone, computer – are merging and this is making software technologies in any one of these accessible and relevant to the others (Graham and Marvin 1996).

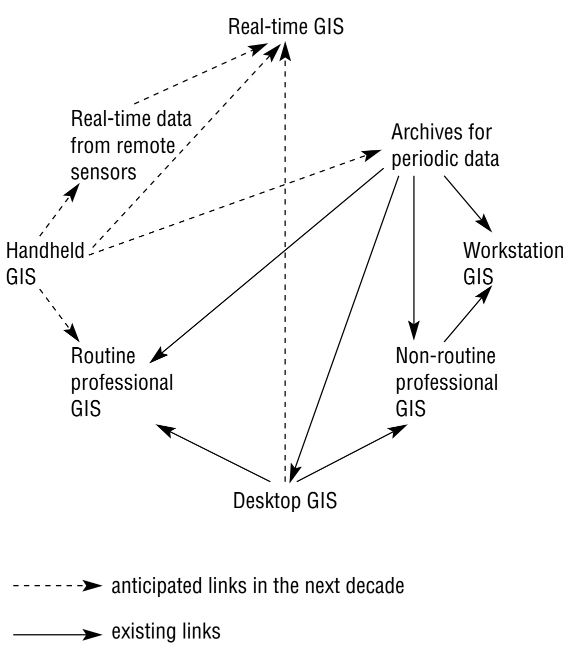

Fig 3. The evolution of GIS technologies.

A major impact of new computer technologies on cities is the fact that patterns of use, location, and movement are beginning to change. In a global economy, patterns of accessibility in cities are becoming very different from those on which much geographical theory and some GIS applications are based. GIS itself is fuelling these changes as the software is being used for all kinds of navigation, for the delivery of local services, for welfare provision, for real estate acquisition, and so on. Electronic commerce and geodemographics in business is a direct user of GIS, which in turn is changing the data for GIS and even the functions which are embodied within GIS. Such immediacy from applications has for long characterised those technologies of the industrial age, but a new mindset is required to understand similar kinds of change associated with software technologies. This kind of complexity marks out the postindustrial world from any hitherto, and in extending technology in this fashion to embrace the city, society and economy, it heralds a redefinition of the meaning of technology itself.

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