# 23
# Desktop GIS software

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This chapter reviews the emergence of desktop GIS, which is defined as products which may have begun as features of workstation GIS but which have been spun off to create new and useful niche market products. As such, desktop GIS is seen to include: digital atlases; interactive street displays and route finding software; mapping on the Internet; spreadsheet and database mapping; clip art and readymade maps; thematic maps; and so-called 'true' desktop GIS. Geographically-enabled programming languages are also considered from the standpoint of add-ons to desktop GIS.

## 1 INTRODUCTION

GIS keeps getting bigger, encompassing more as technology develops and our knowledge base increases. As GIS grows, so pieces of what had previously been viewed as exclusively the territory of GIS are being sliced away to become market niches in their own right. Those who use new market niche products may even be unaware of the background GIS technology from which it developed and may have no need ever to be directly involved with GIS per se (see also Batty, Chapter 21).

What, then, is 'desktop GIS'? There are a number of ways in which to answer this question. From one viewpoint, desktop GIS is simply that part of the newly emergent desktop computer market that is not developing for any specific market niche. From this perspective, desktop GIS is no more than a software and technology marketing term. And yet in order to understand desktop GIS trends a second, more analytical perspective is required. In this chapter, we choose to define desktop GIS as inclusive of those products that may have begun as features within workstation or desktop GIS software programs and technology, but which have been spun off to create more useful products within new market niches.

How is the market for desktop GIS developing? Thrall, interviewed for the industry magazine *Geo Info Systems* in 1996, made the following five year forecast:

> 'I expect mainstream [desktop] GIS will be mainstream application software. GIS will lose its distinguishable identity in the market-place. If a map makes sense in an application, then a map will be in that application. If GIS functionality makes sense in an application, then that application will contain GIS functionality. GIS will become application niche software and application niche software will seamlessly include GIS. Customers will expect it. In five years, only us old-timers will remember when GIS was a technology with a culture separate and distinct from mainstream software.' (Thrall and Trudeau 1996: 12)

From the vantage point of the general software user, GIS will be all-pervasive and unrecognisable as a unique technology with a unique history. From the vantage point of the academic, the software developer, and the more sophisticated user, understanding of the development of desktop GIS technology will be one means of distinguishing between casual users and experts.

In this chapter we present an overview of desktop GIS. Our broad definition of desktop GIS will enable us to discern the market trends more readily. Our purpose is to present a categorisation of desktop GIS, and to provide examples of each. This will contribute towards clarification of what desktop GIS is today and how it is distinguished from previous GIS technology. Table 1 presents eight categories of desktop GIS, in increasing order of complexity. As new markets emerge, so new categories will be added: as technology and the markets change, so the ordering of the categories will change.

**Table 1 Categories of desktop GIS technology.**

| | | |
|---|---|---|
| Least complex ↓ | Most users ↑ | Digital atlas |
| | | Interactive street display and route finding software |
| | | Mapping on the Internet |
| | | Spreadsheet and database mapping |
| | | Clip art and readymade maps |
| | | Thematic mapping |
| | | 'True' desktop GIS |
| Most complex | Least users | Geographically enabled programming |

Novice users of desktop GIS might consider any software that fits within any of the categories of Table 1 to be 'GIS'. Conversely, novices may believe that their requirements can only be met by what we refer to as 'true' GIS software; or, because they are producing thematic maps they may believe that they are working within a 'true GIS environment'. Such differences in part reflect the rapidity of development of the field: what may once have been a central component of desktop GIS may have evolved into a niche which is peripheral to 'true' GIS, but which is nevertheless an important emerging new market segment. For example, GIS functionality and geographical data have been key to increasing the productivity of those who need customised maps: however, the new category of readymade maps (which includes no GIS functionality) may now better suit the needs of this user group. The core components of each of the classes of geography software identified in Table 1 will now be discussed in turn.

## 2 THE DIGITAL ATLAS

The digital atlas has developed from its traditional analogue counterpart using GIS technology (see also Salgé, Chapter 50). Today the digital atlas is typically distributed on CD-ROM. The illustrative products included in Table 2 serve the same purpose as printed atlases. In terms of production costs, the first (master) copy of the digital version may cost as much or more than the first master copy of its printed version counterpart. However, the marginal cost of producing each additional digital atlas, especially when very large mass-market volumes are considered, becomes insignificant. The digital atlas has further advantages over its printed counterpart by virtue of being compact and lightweight – so that, for example, information can even be accessed with a CD-ROM-equipped laptop computer. The digital atlas may also include a computer-automated 'find' feature: printed atlases require one to go to an index, read cryptic references to the page and row and column that a map feature may be found on, and then – armed with such information – the atlas reader must locate the feature on the map. The digital atlas will find the feature for the user and show the user where the feature is on the appropriate map. Digital street atlases like those discussed below may even allow the user to enter an address and the digital version will then zoom into the likely location of the address. It is traditional for the printed atlas to include some thematic maps and charts. The digital version may allow the user to select from more themes, and to vary the manner in which the theme is displayed.

**Table 2 Simple mapping products and digital atlases.**

| | |
|---|---|
| *Small Blue Planet* | Now What Software |
| *Maps 'n' Facts* | Broderbund |
| *Picture Atlas of the World* | National Geographic |
| *Expert Maps Gold* | Expert Software |
| *World Atlas* | Software Toolworks |

To sum up, the digital geographical technology offers advantages over traditional printed technology in terms of convenience of use, reduced size and weight, and lower cost. The lower marginal production cost is likely to mean that the product is more frequently updated: by contrast, the traditional atlas in a library may previously only have been replaced when its pages became worn from years of use.

## 3 INTERACTIVE STREET DISPLAY AND ROUTE FINDING

Interactive street and route finding software is a variation on the digital atlas that is a separate and new emerging technology. Several of the products that are available in the USA, for example, are listed in Table 3. DeLorme has become dominant in the

US market with this type of product because it entered the market early, its street maps are attractively designed and easy to read, it is inexpensive, and (very important for a product of this type) it uses data compression technology to include the software and the geographical data on a single CD-ROM.

**Table 3 Interactive street display and route finding.**

| | | |
|---|---|---|
| Global Explorer | DeLorme | multimedia with photographic images |
| Map 'n' Go | DeLorme | includes route finding |
| Street Atlas USA | DeLorme | based on US Census TIGER/Line |

Beyond the basic functions of street display and route finding, there are also products (e.g. those of Sony Inc.) that combine features from Table 3 with hardware. The hardware is ergonomically designed for ease of use in an automobile. These products may include Global Positioning Systems (GPS) technology (see Lange and Gilbert, Chapter 33) with interactive voice, whereby the device will select the best route based upon current traffic conditions and will audibly inform the driver where to turn (see also Waters, Chapter 59).

## 4 MAPPING ON THE INTERNET

Simple descriptive maps have also become a feature used to measure user access, also known as 'hits', to World Wide Web (WWW) sites on the Internet. Users may access these 'Where is it?' maps in either of two ways. First, the user utilises a 'find' feature to locate an Internet address, using a similar procedure to that used to interrogate a CD-ROM street atlas. Advertisers will often pay to have their logo and universal reference locator (URL) jump to their site prominently displayed alongside a 'Where is it?' map. Second, the 'Where is it?' map feature may be part of a WWW page that provides the user with a street map so that some desired destination can be found (Figure 1).

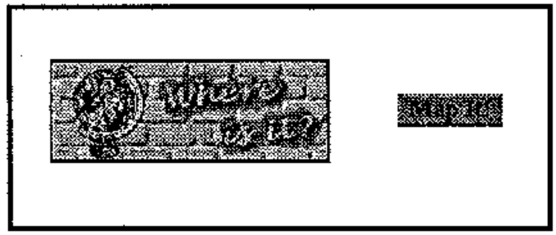

**Fig 1. 'Where is it?' map feature from a WWW page.**

'Where is it?' maps can be downloaded or printed thereby making available to the user custom atlas type features. An example of two kinds of 'Where is it?' map is provided in Table 4. The Vicinity site uses Etak Corporation geographical data and software to create the maps; the maps are used as a draw to their site for the display of advertising. Union Street Links uses on-line maps to inform the user of business locations in order to encourage patronage.

The ability to locate point addresses on a map is considered a standard feature of GIS software; the 'Where is it?' map separates out this feature from the general purpose GIS, allowing the user to display the location of an address or object. As discussed below, to be 'true GIS' the software must be capable of transforming and manipulating the data thereby effectively creating new data. 'Where is it?' maps are highly valuable but are limited to the display of stored geographical information. At the same time, if the program user's needs require only 'Where is it?' capability, then there is no need to use any more complex GIS software. Table 5 includes a list of software vendors that provide the capability to program WWW sites to include GIS features such as the 'Where is it?' capability.

A second type of mapping on the Internet is analogous to placing the geographical and attribute data and GIS software in a client/server configuration. The actual software and the data reside on a server which the user accesses via the Internet. The users (clients) request maps and the information is returned to them. Many of the GIS user tasks, such as opening tables and formatting the

**Table 4 Examples of 'Where is it?' maps on the Internet.**

| *Name of* | *Owner* | *Description* | *URL* | *WWW site* |
|---|---|---|---|---|
| Vector | Vicinity Inc. | Address locator on demand | | http:/www.vicinity.com |
| Union St Links | G&S Thrall | Displays location of business | | http://www.afn.org/~links/ |

**Table 5 Vendors of Internet enabled mapping software.**

| | |
|---|---|
| Caliper | http://www.caliper.com |
| ESRI | http://www.esri.com |
| MapInfo | http://www.mapinfo.com |
| Sylvan Ascent | http://www.sylvanmaps.com |

*Note*: see authors' Web page for sample list of URLs using Internet enabled mapping software: http://www.afn.org/~thrall/gitwebs.htm

layers, are performed by the server. Proper software design is imperative, because many of those that access such Internet sites will be novices to geographical technology.

## 5 GEOGRAPHICALLY-ENABLED SPREADSHEETS

The thematic mapping capability has become mainstream with its introduction as an adjunct to mass consumer market spreadsheets (Thrall 1996d). For example, in the mid 1990s the alliance between Microsoft Corporation and MapInfo Corporation provided users of the Microsoft Excel spreadsheet software with the capability to generate simple thematic maps (Table 6). Similar products are available from Autodesk and Intergraph. While highly limited in terms of numbers of mapping features and options, the Excel/MapInfo product is a good example of how a mapping software program can be designed to be highly user friendly (see also Birkin et al, Chapter 51). The product also includes a limited amount of coarse resolution geographical boundaries, including those of the major land forms, many nations (e.g. the USA, Canada, Mexico, Western Europe, Australia), states and provinces of North America, and US counties. Excel does not include smaller boundary files like census tracts or zip codes.

With Microsoft's Excel, the user selects a range of cells to map. One of the columns of selected cells in the range enables the data to be linked to a geographical object such as a US county. For the attribute data to be geographically enabled, the field with the geographical identifier must follow a rigid standardised convention. The other columns in the selected range contain the attribute data to be used to provide values to the mapped themes. All mapping is done by linking attribute data to polygon map objects. Excel cannot map with user-specified latitude and longitude coordinates. Excel does not allow the user to customise polygon boundaries, and polygons may not be joined or buffered. As such, the polygon areas that can be mapped with Excel are highly limited. Yet these very limitations, which make it simple for the novice to use, in combination with its widespread distribution by Microsoft, have created a lucrative market for GIS data vendors. A variety of boundary files and attribute data can be purchased separately and then used within Excel.

**Table 6 Geographically-enabled spreadsheets.**

| | | |
|---|---|---|
| Borland | *Quattro Pro* | Strategic Mapping Inc. |
| Lotus 1-2-3 | *Lotus 1-2-3* | Strategic Mapping Inc. |
| Microsoft | *Excel* | MapInfo Inc. |

*Note*: In 1996, Strategic Mapping Inc. was purchased by ESRI (Environmental Systems Research Institute)

Wessex Inc. has released an 'after market' product designed to extend the range of attribute data easily accessible by a mapping program to include the entire US Census of Population and US Census of Housing. Geographical boundary files for census tracts are provided with the Wessex product. Wessex's products include ProFiler (the US Census of Population data), a set of TIGER/Line files (the US Census boundary files in MapInfo format), First Map (for desktop mapping with Excel), and First Street (ArcView Software from ESRI (Environmental Systems Research Institute), Wessex's ProFiler, and Wessex's boundary files in ArcView format).

Lotus Corporation has also linked with a GIS software vendor to provide mapping capability similar to that described above for the Excel/MapInfo product. The choice of Lotus to have aligned with Strategic Mapping Incorporated (SMI) may have been unfortunate since SMI has subsequently ceased to exist and has sold its geographical software division to ESRI – best known for the GIS program ARC/INFO. However, what may appear to have been a mistake for Lotus – to align itself with a troubled GIS software vendor (SMI) – may in the final analysis appear to be fortuitous given the quality and strength of product offered by ESRI. For more discussion on ESRI's takeover of SMI see Thrall (1996a) and see Longley et al (Chapter 1; Chapter 72) for a discussion of rationalisation and change in the GIS software industry.

The mapping capabilities of spreadsheet programs are highly user friendly, but primitive in mapping capability. Prior to the introduction of mapping in spreadsheet software there were perhaps 100 000 users of geographical mapping software in the world, with varying skills and interests. Now with geographical technology included in mass market spreadsheet products the numbers of persons becoming familiar with geographic technology may exceed 20 million. As those high numbers of users proceed through the learning curve they will demand a greater variety of mapping operations, together with the ability to manipulate geographically enabled data. The scene is thus set for GIS to become part of the mainstream mass market computer software industry, in contrast to its past which appears increasingly esoteric and peripheral in comparison. At the time of writing, several database vendors including ORACLE, Informix, Computer Associates, Sybase, and IBM have already announced planned products that will allow the user to work with spatial data (Sonnen 1996).

## 6 CLIP ART AND READYMADE MAPS

In this section we will discuss clip art maps and a newly emerging product that we refer to here as 'readymade maps'. In Table 1 they could have been listed as two separate product categories. They share a number of common characteristics and are both based upon a newly emergent technology in a highly dynamic market. Indeed, the vendors of what we call readymade maps advertise their products as clip art maps. However, the authors of this chapter believe that once the consumers understand the capabilities of the mapping products, readymade maps will be identified as a new product category (see Thrall and McLean 1997).

Readymade maps combine the technology of clip art imagery with GIS. Clip art has long been a common feature of desktop publishing where the digital artist may begin to construct a computer image by importing an image from a catalogue of images. Clip art usually allows simple manipulation of the image such as changing the colour or deleting a part of the image. Clip art may also stand alone without modification and is used extensively in the design of brochures and other forms of advertising. Clip art maps allow simple editing of a map by exporting it to a graphics program which is used to manipulate it.

The readymade map is a more-powerful variation of the standard clip art map. Readymade maps differ from clip art maps in the magnitude of the file size and in the complexity of the data file. Clip art is typically one layer of information while readymade maps typically have many layers. Clip art images are typically small while readymade maps can require as many as 64 megabytes of RAM memory just for their editing. Clip art is designed to be brought into a text document – for example as an image in a Microsoft Word text file. Readymade maps, by contrast, generally must be imported into a graphics program to be edited. Most readymade maps are distributed as an ensemble of geographical data and a software program to display them. Readymade map software can also often allow the geographical data to be exported in a variety of formats for subsequent editing.

With readymade maps, the user can do much more than change the colour or insert a map into text. With readymade maps, the user can use advanced features such as masks which allow the addition of boundaries, physical features such as rivers and mountains, graticules, scale bars, shadowing, and so on. Readymade maps can also be edited at a 'sub-image' level using a product like Macromedia's Freehand which allows the map to be edited in layers. Some readymade maps allow the importation of multiple files that automatically register to one another at the same scale and in the correct location without manual manipulation. For example, if a file of a country is opened, then other imported countries will align correctly and at the same scale as the original opened country. Table 7 gives examples of some readymade map vendors.

Usually the quality of readymade maps requires the highest quality printer and a desktop computer specifically configured for high resolution graphics production. These are truly maps ready to publish and bear comparison with the finest maps published anywhere today.

**Table 7 Some readymade map vendors and their products.**

| | | |
|---|---|---|
| *Mountain High Maps* | Digital Wisdom | High resolution relief maps of countries of the world |
| *Cool Maps* | Digital Wisdom | Relief maps for desktop publishing produced using visually exciting colours and projections |
| *Globe Shots* | Digital Wisdom | Views of the earth from space: many of the earth images are animated for easy inclusion in multimedia |

*Note*: Based upon Thrall and McLean (1997)

Clip art maps and readymade maps provide basic descriptive geography for the publisher and graphics artist/cartographer. The fundamental characteristic that differentiates clip art maps and their more powerful cousin, readymade maps, from, say, a digital atlas is that the digital atlas is targeted towards the end or final consumer whereas clip art maps and readymade maps are intended to be modified using the map program itself or by using a program such as Adobe Photoshop or Macromedia Freelance to prepare the map for the enduser. The finished map may remain in digital form. Macromedia includes the ability to distribute electronic images produced within its software program on diskette. With Macromedia Director comes the ability to produce multimedia productions and to distribute the results over the Internet. By acquiring the desktop GIS capability to edit maps, clipart maps and readymade maps have established a market niche for themselves.

## 7 THEMATIC MAPPING

Thematic mapping begins one small step beyond the categories of the digital atlas, 'Where is it?' maps, and readymade maps. Thematic mapping software can be quite complex and sophisticated in its data manipulation functionality. Many 'true' desktop GIS software programs include thematic mapping capabilities; however, these capabilities are generally highly limited. 'True' desktop GIS software has greater focus upon the manipulation of spatial data while thematic mapping software has greater focus toward the display of spatial data. Software specialising in thematic mapping generally offers a much greater range of thematic mapping features than is available from desktop GIS software programs. Thus users of GIS who desire more complex thematic mapping capability may process and manipulate their data within the GIS, and then transfer the results of analysis to a thematic mapping program for presentation.

Thematic mapping capability includes the ability to produce shaded choropleth maps where the data ranges are represented by different colours, shading, hatching patterns or dot densities, or by graduated symbols. In dot density maps, dots are randomly scattered within polygons, although the total number of dots represents the number of observations. In graduated symbol maps, the symbol size is proportional to the value of the observation (see Martin 1996; and Kraak, Chapter 11, for a general discussion of digital symbolisation). Some thematic mapping software also includes the ability to construct isoline and 3-dimensional shaded relief maps, or prism maps in which a polygon can be extended 3-dimensionally above the surface – the height above the surface being proportional to some attribute data value. Thematic mapping software may also allow the mapping of two variables as bivariate maps. However, even though some software allows a virtually unlimited number of themes to be simultaneously displayed, it should be recognised that a map generally loses interpretability when more than two themes are displayed. Each of these types of maps is discussed in fuller detail below in the GIS software section.

Thematic mapping software often requires data input in a very rigid data format and field layout. Thematic mapping software programs also generally have very limited capability for modification of the data. Thus while many GIS software programs include a variety of thematic mapping functionalities, most thematic software programs cannot be classified as true GIS software. Table 8 gives some examples of thematic mapping products.

**Table 8 Some thematic mapping products.**

| *Product* | *Manufacturer* | *Description* |
|---|---|---|
| Surfer | Golden Software | Processes the user's data into isolines or contour lines. Provides a robust variety of spatial interpolation features as well as a reasonable set of default options for the novice. For a review and further discussion of Surfer see Thrall (1995a). |
| Map Viewer | Golden Software | Allows the user's data to be associated with US county and US state boundary files for the display of 3-dimensional prism maps as well as other forms of thematic map that are popular among endusers. Program users may provide their own boundary files. (See Elshaw Thrall 1997.) |

## 8 'TRUE' DESKTOP GIS

'True' desktop GIS software programs include features which allow the user to achieve similar results to all of the above desktop technologies, but also include additional capabilities. True desktop

GIS software programs allow the user to access information using spatial logic, to modify geographically-enabled data, and to visualise the results as a map. This category of desktop software allows the user to query data and map objects using enhanced structured query language (SQL: see Egenhofer and Kuhn, Chapter 28) database operations. The user can also query individual map objects.

It is routine for desktop GIS software to include the capabilities for the input of textual spatial queries, including SQL queries, polygon joins, point-in-polygon operations, and buffering. Each of these uses is discussed in detail below. Table 9 identifies some of the leading desktop GIS software programs.

Who are the users of feature-rich desktop geographical software technology? The user of desktop GIS today is quite a different kind of individual to the user who is reliant upon mainframe and workstation GIS. Large GIS platforms like ARC/INFO or Intergraph are now used primarily by governmental organisations and large research universities. Governmental organisations have not traditionally been highly price sensitive or high productivity-motivated, and therefore they have been able to afford the high expense of large platform software and hardware, as well as the high learning curve required of highly technically trained specialised workers. ESRI, which produces ARC/INFO, has suggested that the learning curve to become fully proficient in ARC/INFO is roughly three years (Thrall 1995b; Thrall et al 1995). Thus GIS such as the mainframe systems of ARC/INFO and Intergraph have traditionally been used by the public sector.

Private businesses are generally unwilling to allocate the high level of expenditure necessary to establish mainframe and workstation GIS. Businesses are also generally unwilling to commit themselves to adding employees who require years of training in a software program which can only indirectly enhance their decision making. In short, businesses are unwilling to become hostage to an exotic technology operated by irreplaceable workers. The negatives of the mainframe and workstation environments make private businesses the primary audience for desktop GIS since, other than the ubiquitous desktop computer, there are no special hardware requirements. Moreover, powerful GIS software of unprecedented user-friendliness can be obtained at prices similar to those of bundled business office software (wordprocessing, spreadsheet, database management, presentation designers, etc.) from major manufacturers. Inexpensive GIS software now comes as standard with the basic geographically-enabled data required for most business decisions (see also Coleman, Chapter 22; Sugarbaker, Chapter 43).

Private businesses will not readily adopt research frontier technology, yet until quite recently GIS has resided within this realm. However, with mapping now included with conventional spreadsheet software, businesses no longer perceive mapping and geographical technology as being the research frontier. Most businesses which do adopt GIS perceive it as an aid in what Thrall has referred to as the first stage of GIS reasoning; namely, the employment of GIS technology to represent spatial phenomena for descriptive purposes (Thrall 1995c). Businesses may understand the need for spatial data visualisation. They may also use GIS for fast manipulation of large volumes of spatial data. For them GIS saves the many weeks or years that might be needed to organise and visualise their own data in association with data that describe their market. Prior to the innovation of desktop GIS, the cost and complexity of such descriptive representations made all but a few businesses stay away from the technology. Desktop GIS has changed all that, so now having this information is considered to be a necessary input for proper business decisions.

Some businesses which better understand geographical concepts may have proceeded to Thrall's second and third stages of GIS reasoning,

**Table 9 Leading desktop GIS software programs.**

| | | |
|---|---|---|
| ArcView 3 | ESRI (Environmental Systems Research Incorporated) | Redlands, USA |
| Atlas GIS* | ESRI (Environmental Systems Research Incorporated) | Redlands, USA |
| Autodesk World | Autodesk Corporation | San Rafael, USA |
| GeoMedia | Intergraph Corporation | Huntsville, USA |
| MapInfo | MapInfo Corporation | Troy New York |
| Maptitude | Capliper Corporation | Newton, USA |

* Note that Atlas GIS orginally published by Strategic Mapping Incorporated is now under the ownership of ESRI so the future of Atlas GIS is doubtful.

namely using GIS for explanation and prediction. The ability to visualise large amounts of geographical data has made it easier for businesses to understand correlation and causality. In order to enhance explanation and prediction, mathematical constructs such as gravity models (Haynes and Fotheringham 1984) have been programmed to use data that have been spatially summarised or modified using desktop GIS software (see Birkin et al, Chapter 51; Waters, Chapter 59). Geographical prediction with desktop GIS software is akin to 'what-if' scenarios performed with conventional spreadsheet software. Forecasts of spatial trends and processes, such as the changing market for a business firm, can be created with the desktop GIS software. It is in this context that Thrall (1995c) has written that 'relevance and marketability are key to understanding market-driven GIS today . . .'.

Business utilisation of desktop GIS software has not substantially gone beyond descriptive applications. There has been very little documented use of GIS to enhance business judgement and decision strategy. Business remains largely unaware of the contemporary capabilities of geographical technology and methodology. Today it is essentially the sizzle and pizzazz of a descriptive map that sells GIS. Given that the use to which GIS is put by business has been highly limited, the cost of implementation of GIS in a business environment must be low, in order to overcome the perceived limitations of the technology. As awareness of capabilities increases, business will demand more geographical capability from their GIS software and employees. As a consequence, we anticipate bright prospects for appropriately trained economic geographers. However, knowing the commands of the GIS software does not geographically enable the personnel using the software. By analogy, knowing the software features of a spreadsheet program does not by itself make one an expert in finance or accounting. The need for personnel who are trained in geographical reasoning is a prerequisite for the continued expansion of the desktop GIS industry.

Business requirements for high productivity that accompany inexpensive and user-friendly turnkey GIS solutions translates into a demand for prepackaged GIS data. And the market can respond by offering commercial business data because the volume is high and in the USA at least the production costs are very low (but see Rhind, Chapter 56). Free availability of high quality geographical and geographically enabled attribute data (Smith and Rhind, Chapter 47) has given the USA a competitive edge over those countries where access to similar data is highly restrictive or very costly.

Businesses have not adopted GIS in the same way that governments and related large public institutions have. Still, the chronology of the adoption by business of geographical technology mirrors the earlier process of adoption by government. Outside of military applications (see Swann, Chapter 63), those government agencies and divisions that were the first to adopt GIS were in the fields of natural resources or physical geography (e.g. Hutchinson and Gallant, Chapter 9). Only later did government agencies and divisions concerned with human geography applications adopt GIS. Similarly, those businesses in the natural and earth resources industries, such as forestry, were the first to adopt geographical technology, including desktop GIS. It has been a recent phenomenon that businesses have adopted GIS for use within the fields related to human geography; examples include real estate appraisal and investment, market analysis for retail outlets, and banking (see Birkin et al, Chapter 51; Longley and Clarke 1995).

## 8.1 True desktop GIS features and functions

Desktop GIS can be used to perform a variety of operations, though many of these operations are not unique to GIS. For example, adding new street line segments to a base map is a feature shared between GIS (computer assisted drawing), and software designed for and limited to digitising. In this section we discuss those features and operations that differentiate desktop GIS software from other software. These features include generating thematic maps, performing spatial queries or selections, joining polygons, performing point-in-polygon operations, and buffering (see Thrall and Marks 1994).

A fundamental application of desktop GIS software is the creation of thematic maps. Although thematic mapping is but one facet to the visualisation capabilities of GIS (see Kraak, Chapter 11), the thematic mapping feature is one that has been carved out from the GIS technology and sold on the market place as a separate product (as described in section 7 above). The advantage of separate smaller products is simplicity of software design, cost of software production and support maintenance, and a quicker learning curve for the program user; the disadvantage is that the product is much more limited in scope.

The GIS thematic map presents an underlying motif of data in spatial form. Data that can be mapped can be numeric or nominal. Nominal data are data with no numeric value that are described by name (Star and Estes 1990: 28): for example, various types of crimes (murder, assault, rape, robbery), or various types of underground cables (electric lines, cable television lines, fibre optic cables). The thematic maps that can be generated on desktop computers fall into several general categories: maps of individual values, choropleth maps, dot density maps, and graduated symbol maps. Another type combines two data themes in the same map and is referred to as a bivariate map. Some thematic mapping programs specialise in isoline, wire frame, and prism maps (see also Beard and Buttenfield, Chapter 15; Kraak, Chapter 11).

Individual value maps show different colours for each unique value of the data. Individual value maps are used primarily for the display of nominal data. A different colour or pattern is used to represent each data value. The attribute data can be associated with any form of geographic object, namely points, lines, or polygons. For example, a crime occurrence has a location and a classification; the colour of a point being red may indicate the crime as murder; likewise, assault could be represented by a brown dot, or a fibre optic cable line can be represented by a blue line and electrical lines represented by black lines. Individual value maps can also present numeric data, though often a map of this type suffers from loss of interpretability. Consider a map of Europe where the colours represent unique population density figures of the countries; each country would then have a different colour since while countries may have similar population density, no two countries will have identical population density values.

Choropleth maps (see Figure 2) are used to present ranges of values by colour or shading or hatching. Appropriate data ranges can usually be

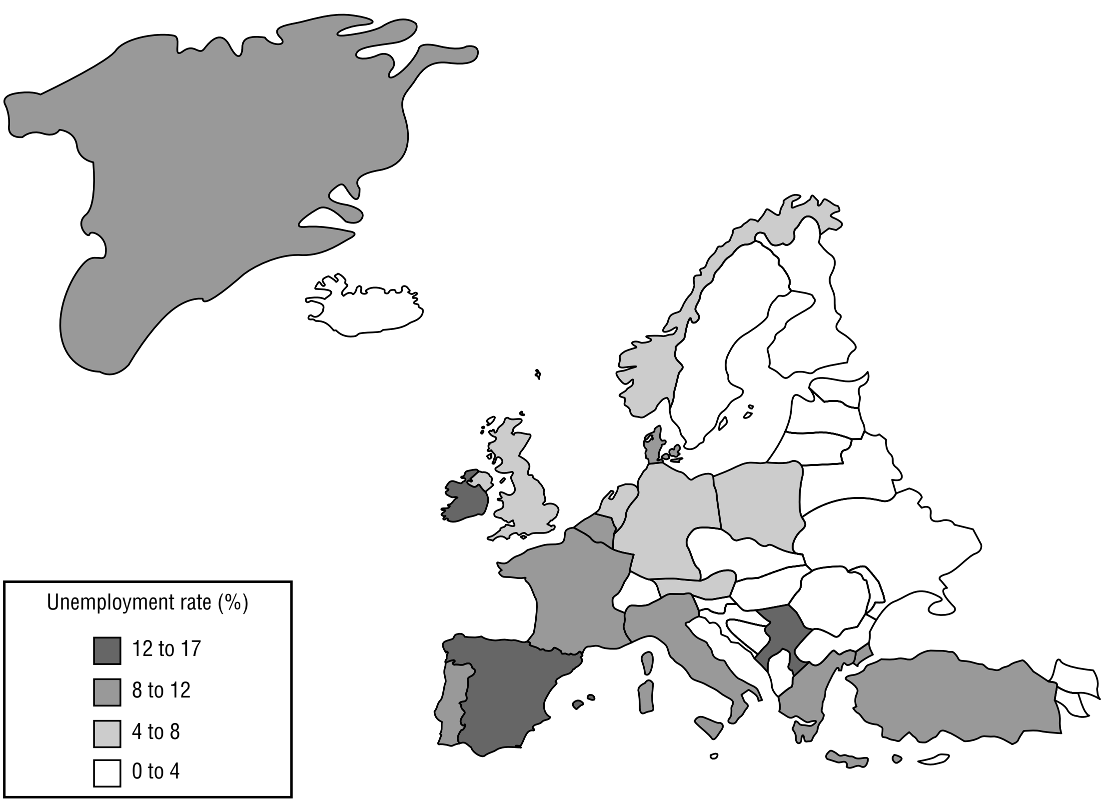


**Fig 2. An illustrative choropleth range map.**

identified by the user where: there are the same number of observations in each range; the ranges themselves are of the same size; or the user can customise the ranges to any convenient values. Each value range then is represented by a particular colour, and successive ranges are denoted using lighter or darker shading of the same colour, or by a different hatching pattern.

Dot density maps (see Figure 3) represent raw data values that reside within a polygon. With a dot density map the software assigns one point for each incremental range of data values, such as one point for every 1000 people in a state or province or county. Desktop GIS software generally displays the dots as being randomly scattered as opposed to clustered where the density of observations might be the greatest.

Finally, the graduated symbol map (see Figure 4) displays a symbol of varying size where size represents the magnitude of the attribute data value. For example, a large aeroplane symbol could represent a major regional airport while a small aeroplane symbol could represent a minor local private airport. The size of symbol could be graded by thousands of passengers served.

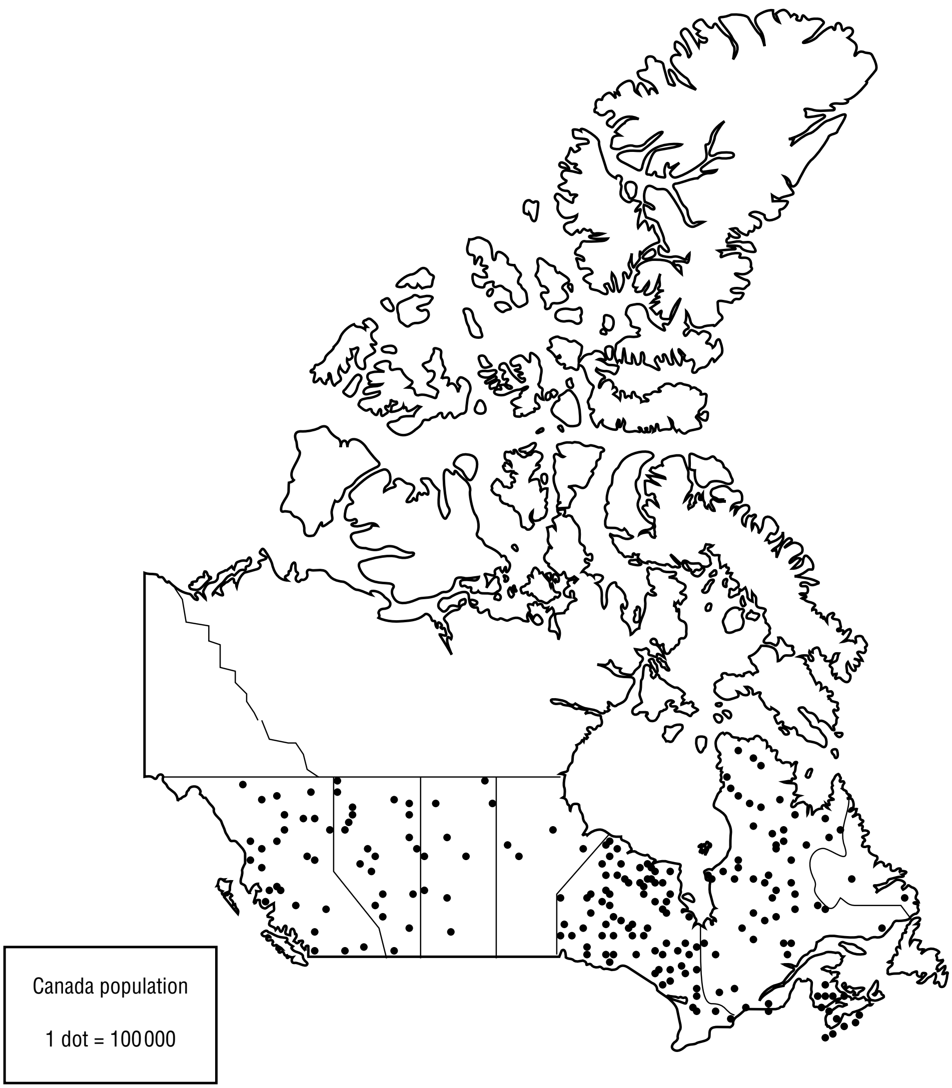


**Fig 3. Dot density map of Canadian population 1990.**

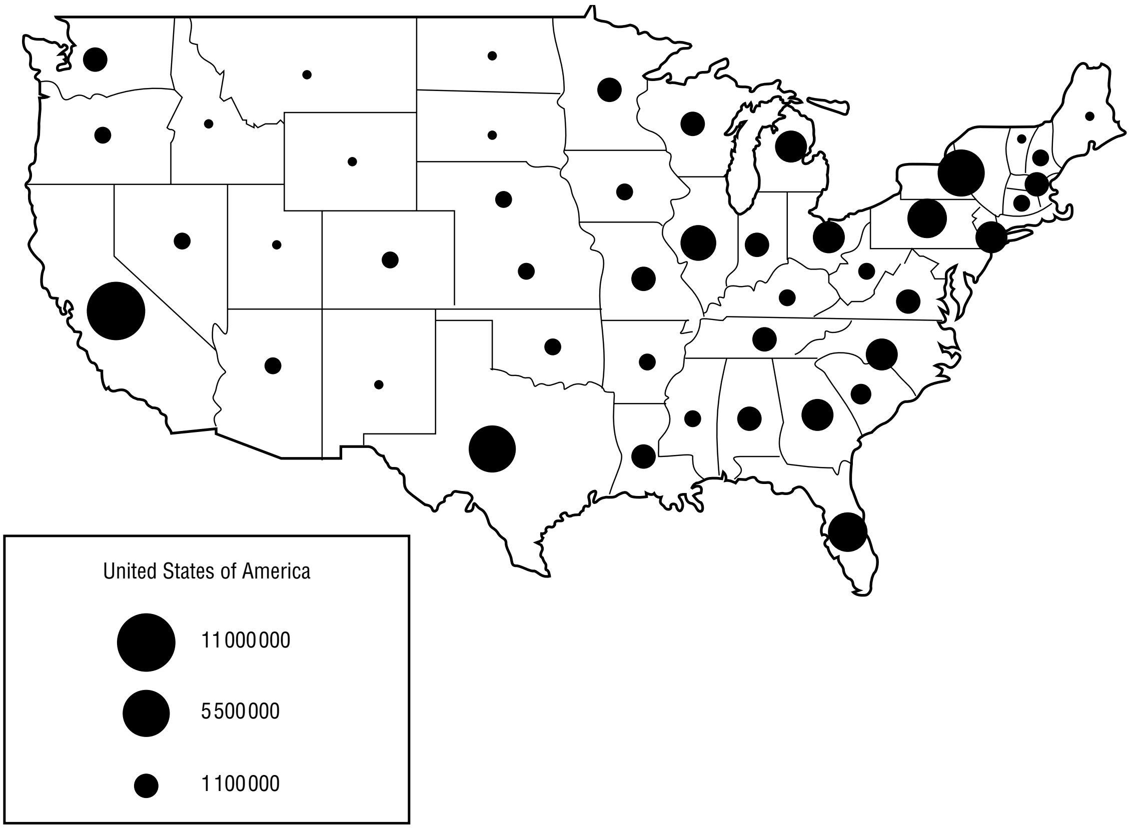


**Fig 4. Graduated symbol map of number of housing units per US State 1990.**

A bivariate map displays two themes, or two data variables. For example a map may have different symbols representing the type of crop grown in an area (like a corn stalk for corn or wheat shaft for wheat) and then the size of the symbol can represent the amount of yield for the particular crop. Bivariate maps typically use a combination of different symbols with different colours or sizes or the same symbol showing different sizes and colours to represent the two themes. Bar chart maps and pie chart maps are variations on the theme of bivariate maps. With bar chart or pie chart maps the user can have different bars or pie slices represent different fields for each record.

Isoline maps show varying data ranges by means of lines. For example, an isotherm map may show temperature ranges. The lines are labelled with the data value they represent. From these isoline maps, 3-dimensional wire frames can be mathematically interpolated and drawn. Some mapping programs can generate wire frame maps (see Figure 5) also offer features of sun inclination showing on the wire frame, perhaps with a solid or shaded drape over the frame, to give a more realistic 3-dimensional effect (Thrall 1995a; Dowman, Chapter 31).

Another form of GIS produced thematic map, known as a prism map (see Figure 6), is a variation of a bar chart map. The height of the bar (prism) is proportional to the attribute value being mapped. But the prism itself is more than a plain rectangular 2-dimensional or 3-dimensional bar; it is in the form of the polygon with which the attribute is associated. The effect is to generate a map of varying plateaux or elevations in the shape of the polygons comprising the map.

## 8.2 True desktop GIS spatial selections

All true desktop GIS software programs include the capability to perform spatial operations. A spatial operation is a database query that is performed on spatial data using spatial criteria (see also Martin, Chapter 6). For example, a regular aspatial query

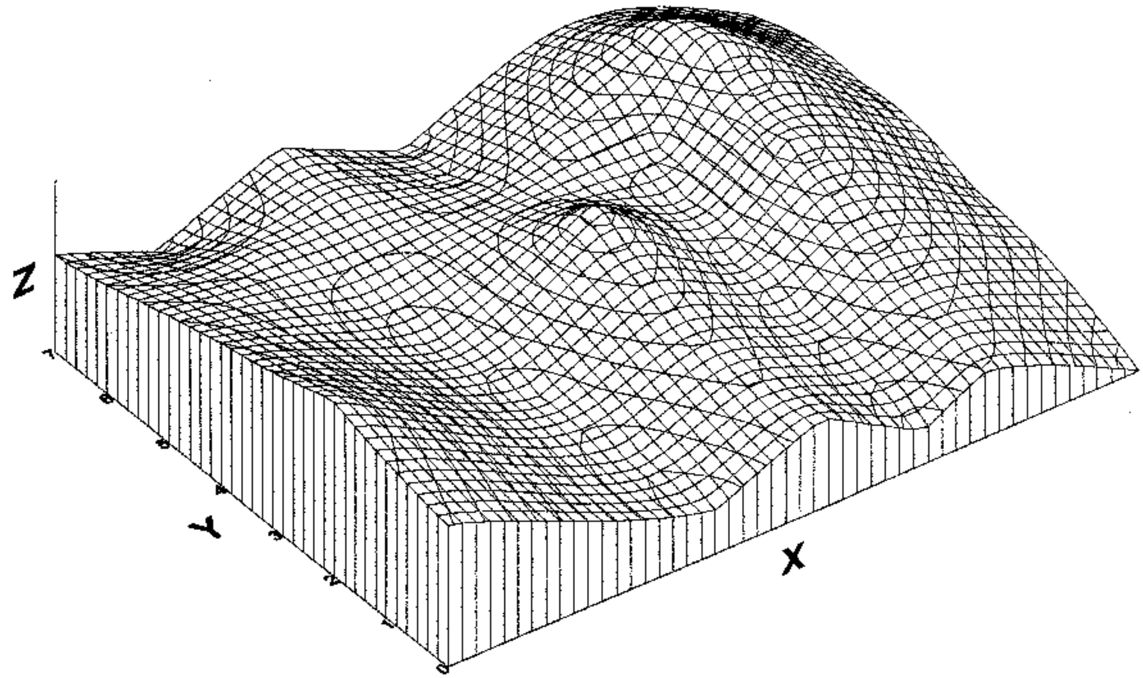


**Fig 5. A wire frame map.**

might be to select those home sales records for which the value of the sale is above a certain amount. A spatial query might be to select those homes for sale which are within a five kilometre radius of a given school. Again, by itself the capability to perform this operation does not distinguish true GIS from some GIS niche products.

Spatial selections in GIS are usually accomplished using tools selected using a toolbox icon, or via typed queries entered using a dialogue box. Tools for spatial queries using desktop GIS fall into three general categories: selection or pointer-like tools; circular or 'radius select' tools; and polygon (non-circular area) tools. The selection or

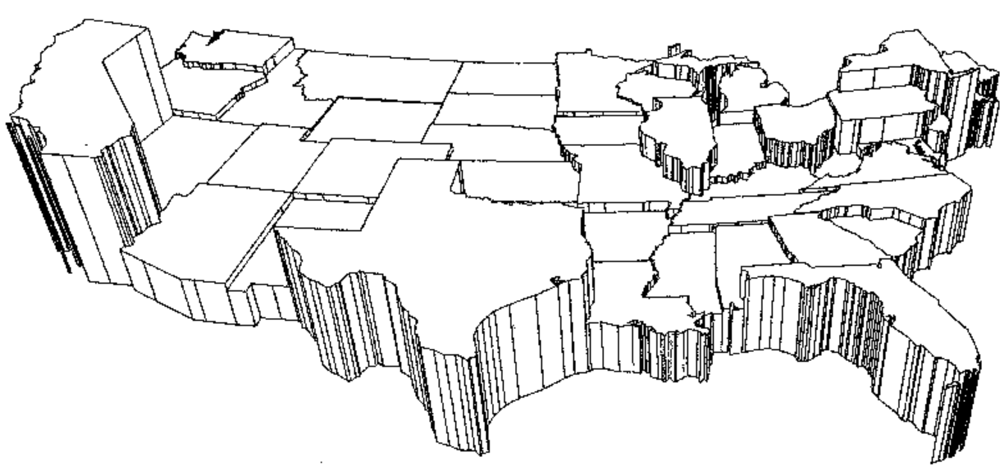

**Fig 6. A prism map depicting the relative population sizes of the contiguous United States.**

pointer tool is typically in the shape of an arrow head (and is a normal tool found, for example, in windows-based wordprocessors). It is used to point at map objects, and by clicking the main mouse button the user may select items. In a true desktop GIS, the items selected are spatial objects, namely points, lines and polygons, and the associated labels. Generally, the layer that includes the item being selected must be active. Many true desktop GIS software programs allow only one map layer to be active at a time.

The radius selection tool allows the user to draw circular areas around a point such that all records falling within a circle are selected. For example, in order to find all major cities in a database that fall within a 100-km radius of New York City, the software user would click on the central point of the City and drag a radius of 100 km from it. All records falling within the circle defined by the radial distance would be selected (but see Birkin et al, Chapter 51, for a discussion of the limitations of such tools).

The polygon selection tool is similar to the radius selection tool in that it allows the user to draw polygons around areas and to select those records that fall within the polygon. The polygon tool does not limit the user to a circular area, but rather allows the user to construct any regular or irregular closed shape.

Spatial queries can be performed using logic and words as well as pointing and selecting with a tool. Spatial querying using words is known as 'word query'. All regular database queries in true desktop GIS can be performed using word queries, including simple queries using the relational operators (less than, less than or equal to, greater than, etc.) and complex compound queries using the logical operators (and, or, not). In addition to these standard database operators, true desktop GIS software programs include geographic operators such as 'contains', 'falls within', and 'intersects'. 'Contains' is an operator where one object contains another, such as a circle inside of a square. 'Falls within' is an operator where one object falls spatially within another object such as a point residing within a circle. 'Intersects' is an operator where part of one object overlaps or intersects part of another object such as a line that passes through a circle.

Structured query language (SQL) word queries allow the user to perform selection operations which are more complex than simply pointing and clicking with a mouse (see also Egenhofer and Kuhn, Chapter 28). SQL is a standard database query language. When using a regular word query with the geographical operators, the operators work on fields that are actually in the database. SQL queries can work on fields that are not explicitly in the database, but which can be implicitly calculated from fields and spatial information in the database. For example, a regular word query can be performed on the population of the countries of the world (e.g. 'select countries whose population exceeds 50 million'). A SQL query can be performed on any field so long as that field can be created using a combination of information from other fields. Thus, for example, queries can be made about population density, even though population density is not one of the fields in the database, since population is known and a desktop GIS can calculate the area of a county polygon. The desktop GIS software will create a new data field – population density – which can subsequently be saved to the database. For extended discussions of this and related topics, see Oosterom (Chapter 27) and Worboys (Chapter 26).

## 8.3 True desktop GIS polygon joins

Another common use of desktop GIS is to join polygons. New polygons in the same or in a new layer are created by joining existing polygons – for example, county polygons might be joined to create sales territories for a sales force, and the newly created layer saved as the 'sales territories' layer. Each map object normally has attribute data assigned to it, such as the population of a county. When joining polygons, the user can choose to discard the attribute data or to save them after modification using a mathematical operator – for example, the user may require the software to add the population of each county that is joined to form a new attribute, the 'population of the sales territory'. For further details see Thrall (1992) and Martin (Chapter 6).

## 8.4 True desktop GIS point-in-polygon operations

The term 'point-in-polygon search' was originally coined to describe the geometrical operations used to locate points relative to vectorised line boundaries. Point-in-polygon operations also involve performing mathematical operations on attribute data fields, for points that fall within the same polygon. For example, if crimes are identified as points on a map, then the number of crimes within a census tract (polygon) can be measured by commanding the software to count the number of points by polygon. If the crime is burglary and the value loss from the burglary is included as an attribute field, then the software can be used to calculate the total loss from burglary within a census tract. Standard mathematical forms of aggregation include performing counts, averaging, multiplying, calculating standard deviations or variance, and so on.

### 8.5 True desktop GIS buffering

Buffering is the creation of polygons that surround other points, lines, or polygons. Individual buffers can be created around individual objects, or multiple objects can be buffered to act as one buffer area. The user may wish to create buffers to exclude a certain amount of area around a point, line, or polygon, or to include only the buffer area in a study. For example, in using GIS to help determine the possible sites for a new water well, the location of chemical factories may have a 10-km buffer drawn around them so that these buffered areas are excluded in the list of possible sites. The user of desktop GIS can indicate how many line segments are to be used to make up the boundary of the buffer, thereby controlling the accuracy of the buffer boundary. Buffering of points is performed in a way analogous to the 'radius select' or 'polygon select' tools described above. Buffering of lines and polygons can be accomplished by using the buffer function in the desktop GIS program.

### 8.6 True desktop GIS programming

GIS is foremost a *spatial* database management tool. One of the uses of database management is application development through the use of the programming language feature of the database management program. General purpose GIS programs are seen by many business managers as being too difficult to learn. They want push-button GIS capability in the software where no special knowledge on how to use a GIS is required. Special purpose GIS or niche GIS is being demanded by those without the knowledge or time to proceed up a steep GIS learning curve. Niche GIS programs are programmed using either true desktop GIS, or written using a geographically-enabled software language.

True desktop GIS software has language capabilities that allow the development of specific or niche applications. As a variation on this theme, the many true desktop GIS software vendors offer the capability to add GIS functionality to programs written in languages such as Visual Basic and C++, or written in database management languages such as PowerBuilder, Visual Fox Pro or Access.

## 9 GEOGRAPHICALLY-ENABLED PROGRAMMING LANGUAGES

Some desktop GIS have add-on products that allow the user to program with a language embedded within the GIS software. This capability generally requires a fee in addition to the price of the true desktop GIS software. Also, if copies of the resulting program are distributed to other users, additional fees are generally payable.

MapInfo Corporation sells a programming language known as MapBASIC. MapBASIC is similar to the generic BASIC with the addition of geographical operators such as 'is located within' that are used for the distinct geographical operations. Caliper Corporation also offers a stand alone geographically enabled language known as the 'geographic information systems developers kit' (GISDK).

Other true desktop GIS software programs allow the programming of modules using standard programming languages such as Visual C++ or Visual Basic. They permit the use of the generic languages to write modules that can be used in conjunction with the GIS. The modules are called from the GIS as standard dynamic link libraries (DLLs) or using object linking and embedding (OLE). Often, however, communicating with DLLs or using OLE requires knowledge of advanced programming procedures.

If the applications programmer is not starting with a pre-existing GIS program, but is writing a program that will have GIS capabilities, a language such as Visual Basic or C++ will probably be used for the primary program. A commercial off-the-shelf add-on module can then be used to write the GIS component of the program. Standard components called VBXs (16 bit components) or OCXs (32 bit components) exist that allow functions to be added to the Visual Basic or C++ program. Examples of functionality added to software programs include the capabilities of drawing and charting, spreadsheets, wordprocessing, database management, telecommunications, and so on. These add-on modules, called custom controls, save the programmer the time needed to program them from scratch, and are usually moderately priced and very easy to use. The VBX or OCX feature is thus an added tool in the programmer's toolbox. The programmer can add the feature to the program with a click of a mouse on the tool. For further discussion on the role of GIS programming tools and the impact on the GIS industry see Thrall (1996b, 1996c).

## 10 CONCLUSION

Desktop GIS has changed immeasurably since its inception as a province of desktop computing. It has grown to include many new features and capabilities. The start-up costs of learning 'traditional' GIS software have never been small and with added features and functionality comes a steeper learning curve. Yet users of spatial software have increasingly demanded more user-friendliness. The response to these demands has been that parts of what has always been considered GIS are being spun off into new market niche software. Thus while 'traditional' GIS has been growing in capabilities, its stature is at the same time being eroded by niche software and other generic spreadsheets and databases – as vendors discover that these are symbiotic with certain GIS features. GIS software vendors are finding opportunities to form cooperative ventures with generic software vendors, and those that fail to form such cooperative ventures may in time find their own market lost to niche software vendors.

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