CHAPTER 1

Geographical Information Systems and Geographical Information

Society is now so dependent on computers and computerized information that we scarcely notice when an action or activity makes use of them. Over the past few decades we have developed extremely complex systems for handling and processing data represented in the only form acceptable to computers: strings of zeros and ones, or bits (binary digits). Yet is has proved possible to represent not only numbers and letters, but sound, images, and even the contents of maps in this simple, universal form. Indeed, it might be impossible to tell whether the bits passing at high speed down a phone line, or stored in minute detail on a CD-ROM (compact disk-read-only memory) represent a concerto by Mozart or the latest share prices. Unlike most of its predecessors, computer technology for processing information succeeds in part because of its ability to store, transmit, and process an extremely wide range of information types in a generalized way

Computerization has opened a vast new potential in the way we communicate, analyze our surroundings, and make decisions. Data representing the real world can be stored and processed so that they can be presented later in simplified forms to suit specific needs. Many of our decisions depend on the details of our immediate surroundings, and require information about specific places on the Earth's surface. Such information is called *geographical* because it helps us to distinguish one place from another and to make decisions for one place that are appropriate for that location. Geographical information allows us to apply general principles to the specific conditions of each location, allows us to track what is happening at any place, and helps us to understand how one place differs from another (Figure 1.1). Geographical information, then, is essential for effective planning and decision making.

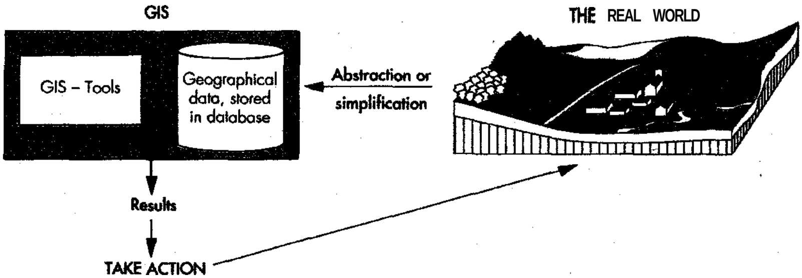

Figure 1.1
GIS is intended to be a means of improving everyday life. It is therefore important that the information that results from data processing be applied to guide the real world in the right direction.

We are used to thinking about geographical information in the form of maps, photos taken from aircraft, and images collected from satellites, so it may be difficult at first to understand how such information can be represented in digital form as strings of zeros and ones. That problem is one of the central issues of this book, and the fact that many alternatives exist is one of the reasons why this book is as long as it is. If we can express the contents of a map or image in digital form, the power of the computer opens an enormous range of possibilities for communication, analysis, modeling, and accurate decision making (Figure 1.2). At the same time, we must constantly be aware of the fact that the digital representation of geography is not equal to the geography itself-any digital representation involves some degree of approximation.

Since the mid-1970s, specialized computer systems have been developed to process geographical information in various ways. These include:

- Techniques to input geographical information, converting the information to digital form
- Techniques for storing such information in compact format on computer disks, compact disks (CDs), and other digital storage media
- Methods for automated analysis of geographical data, to search for patterns, combine different kinds of data, make measurements, find optimum sites or routes, and a host of other tasks
- Methods to predict the outcome of various scenarios, such as the effects of climate change on vegetation
- Techniques for display of data in the form of maps, images, and other kinds of displays
- Capabilities for output of results in the form of numbers and tables.

The collective name for *such* systems is *geographical information systems*, (GISs). The acronym GIS has come to signify much more than a software system that processes, stores, and analyzes geographical

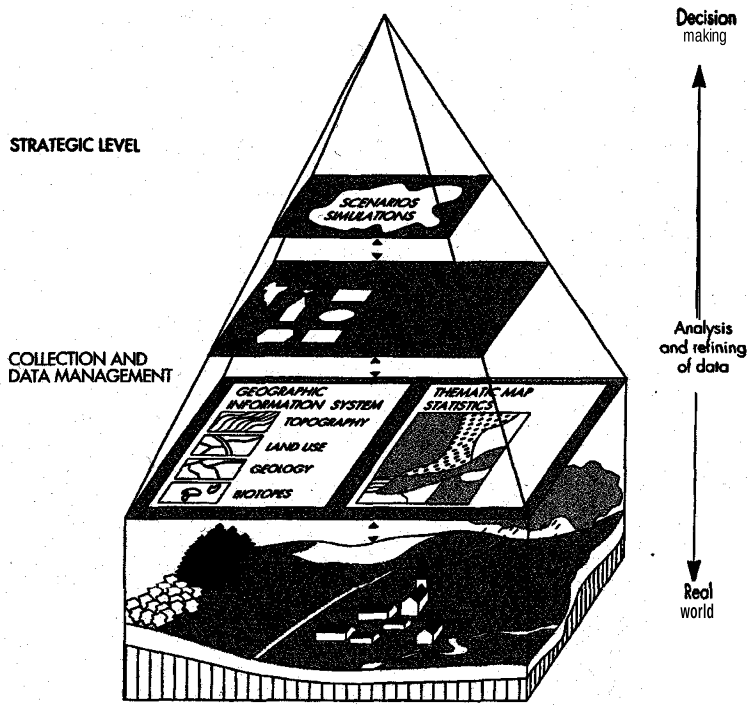

Figure 1.2
By use of geographical information systems, a simplified world can be brought into the computer. Different techniques can be applied to analyze and simplify the data, and the foundation is laid for the decision-making pyramid. Today, geographical information systems are in the process of filling the upper half of the pyramid. (Figure freely adapted from Grossman 1983.)

data. GIS is a "hot" application area for digital technology. Its software industry has been growing at more than 20% a year for many years, and recent figures for total annual sales of GIS software exceed $500 million. The term 'GIS' has come to be associated with any activity involving digital geographical data; we now talk about GIS data, GIS decisions, and even GIS systems.

Although it is very easy to purchase the constituent parts of a GIS (the computer hardware and basic software), the system functions only when the requisite expertise is available, the data are compiled, the necessary routines are organized, and the programs are modified to suit the application. A computer system can function at what may appear to be lightning speed, yet the entire time span of a GIS project can stretch to months and even years. These facets of an overall GIS are interlinked (Figure 1.3). In general, procurement of the computer hardware and software is vital but straightforward. The expertise required is often underestimated, the compilation of data is ex-

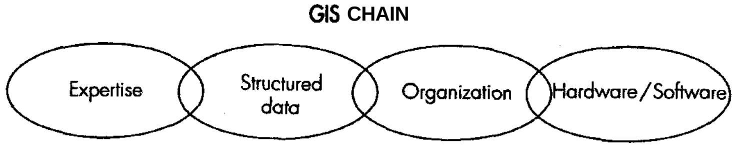

Figure 1.3
A GIS system cannot be bought off the shelf. The system has to be built up within an organization. When planning to introduce GIS, it is important that equal attention be given to all four links in the GIS chain.

pensive and time consuming, and the organizational problems can be most vexing. These facets of an overall GIS are discussed in detail later.

Traditionally, geographical data are presented on maps using symbols, lines, and colors. Most maps have a legend in which these elements are listed and explained—a thick black line for main roads, a thin black line for other roads, and so on. Dissimilar data can be superimposed on a common coordinate system. Consequently, a map is both an effective medium for presentation and a bank for storing geographical data. But herein lies a limitation. The stored information is processed and presented in a particular way, usually for a particular purpose. Altering the presentation is seldom easy. A map provides a static picture of geography that is almost always a compromise between many differing user needs. Nevertheless, maps are a substantial public asset. Surveys conducted in Norway indicate that the benefit accrued from the use of maps is three times the total cost of their production.

Compared to maps, GIS has the inherent advantage that data storage and data presentation are separate. As a result, data may be presented and viewed in various ways. Once they are stored in a computer, we can zoom into or out of a map, display selected areas, make calculations of the distance between places, present tables showing details of features shown on the map, superimpose the map on other information, even search for the best locations for retail stores! In effect, we can produce many useful products from a single data source (Figure 1.4).

GIS defined

The term geographical *information system* (GIS) is now used generically for any computer-based capability for the manipulation of geographical data. A GIS computer-based capability for the manipulation of geographical data. A GIS includes not only hardware and software, but also the special devices used to input maps and to create map products, together with the communication systems needed to link various elements. The hardware and software functions of a GIS include:

- Acquistion and verification
- Compilation

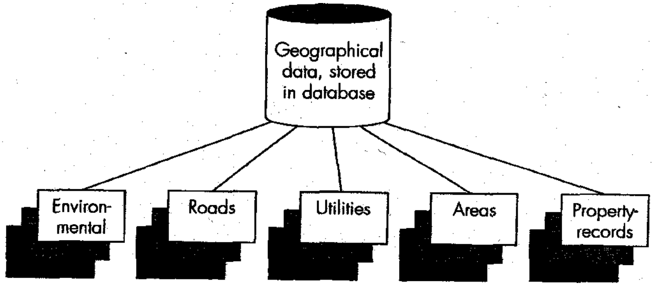

Figure 1.4
A map can be both a presentation medium and a storage medium, with resulting limitations. With GIS, storage and presentation are separated, thereby enabling a wide variety of products to be created from the same basic data.

- Storage
- Updating and changing
- Management and exchange
- Manipulation
- Retrieval and presentation
- Analysis and combination

All of these actions and operations are applied by a GIS to the geographical data that form its database.

All of the data in a GIS are georeferenced, that is, linked to a specific location on the surface of the Earth through a system of coordinates. One of the commonest coordinate systems is that of latitude and longitude; in this system location is specified relative to the equator and the line of zero longitude through Greenwich, England. But many other systems exist, and any GIS must be capable of transforming its georeferences from one system to another.

Geographical information attaches a variety of qualities and characteristics to geographical locations (Figure 1.5). These qualities may be physical parameters such as ground elevation, soil moisture level, or atmospheric temperature, as well as classifications according to the type of vegetation, ownership of land, zoning, and so on. Such occurrences as accidents, floods, or landslides may also be included. We use the general term *attributes* to refer to the qualities or characteristics of places, and think of them as one of the two basic elements of geographical information, along with locations.

In some cases, qualities are attached to points, but in other cases they refer to more complex features, either lines or areas, located on the Earth's surface; in such cases the GIS must store the entire mapped shape of the feature rather than a simple coordinate location. Examples of commonly mapped features are lakes, cities, counties, rivers, and streets, each with its set of useful attributes. When a feature is used as a. reporting zone for statistical purposes, a vast amount of in-

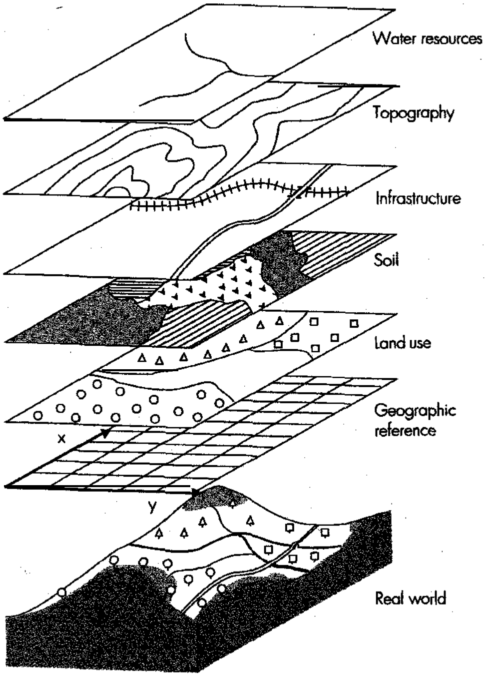

Figure 1.5
One can visualize the data stored as theme layers in the computer, with each layer linked to a common georeferencing system.

formation may be available to be used as attributes for the zone in GIS. In market research, for example, it is common for postal codes to be used as the basis for reports on demographics, purchasing habits, and housing markets.

The relationships between geographical features often provide vital information. For example, the connections of a water supply pipe network may be critical for firefighters, who need to know which valves to close in order to increase water pressure while extinguishing a fire. The details of properties bordering a road are necessary if all property owners affected by roadwork are to be properly notified. Connections between streets are important in using a GIS to assist drivers in navigating around an unfamiliar city. The ability of a GIS to store relationships between features in addition to feature locations and attributes is one of the most important sources of the power and flexibility of this technology. Some GISs can even store flows and other measures of interaction between features, to support applications in transportation, demography, communication, and hydrology, among other areas.

Stored data may be processed in a GIS for presentation in the form of maps, tables, or special formats (Figure 1.6). One major GIS strength

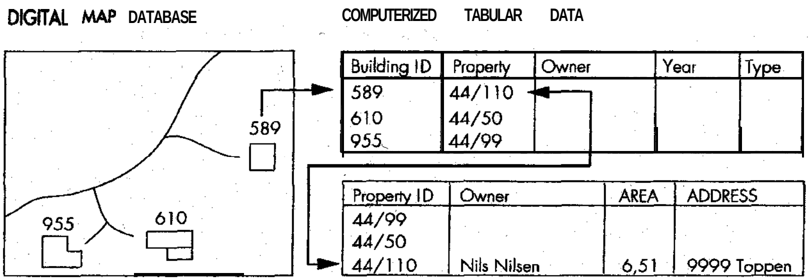

Figure 1.6
How GIS functions, based on the interaction between a digital map database and computerized tabular data.

is that geographical location can be used to link information from widely scattered sources. Because the geographical location of every item of information in a GIS database is known, GIS technology makes it possible to relate the quality of groundwater at a site with the health of its inhabitants, to predict how the vegetation in an area will change as the climate warms, or to compare development proposals with restrictions on land use. This ability to overlay gives GIS unique power in helping us to make decisions about places and to predict the outcomes of those decisions. The only requirement is that the geographical information from each source be expressed in compatible georeferencing systems.

A GIS can process georeferenced data and provide answers to questions involving, say, the particulars of a given location, the distribution of selected phenomena, the changes that have occurred since a previous analysis, the impact of a specific event, or the relationships and systematic patterns of a region. It can perform analyses of georeferenced data to determine the quickest driving route between two points and help resolve conflicts in planning by calculating the suitability of land for particular uses.

Many recent GISs can process data from a wide range of sources, including data obtained from maps, images of the Earth obtained from space satellites, videofilm of the Earth taken from low-flying aircraft, statistical data from published tables, photographs, data from computer-assisted design (CAD) systems, and data obtained from archives by electronic transmission over the Internet and other networks. Data integration is one of the most valuable functions of a GIS, and the data that are integrated are more and more likely to be obtained from several distinct media-multimedia is an active area for research and development in GISs (Figure 1.7).

Technically, a GIS organizes and exploits digital geographical data stored in databases. As we have already seen, the data include information on locations, attributes, and relationships between features.

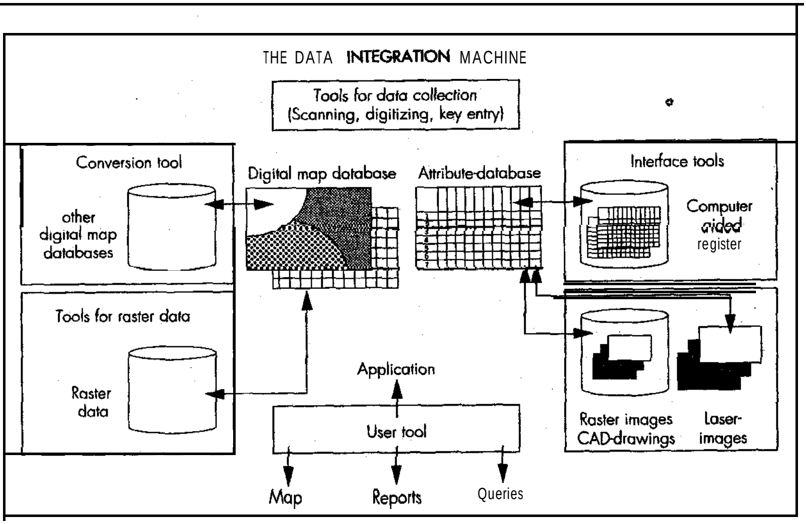

Figure 1.7
GIS is in the process of becoming a typical data integration machine. Some modern systems can receive, process, and transmit data of widely varying origin. (Figure freely adapted from ESRI.)

But a database can only approximate the real world, since the storage capacity of a database is minuscule in comparison with the complexity of the real world, and the cost of building a database is directly related to its complexity. The contents of a book of 100,000 words can be stored in digital form in roughly 1 million bytes (the common unit of computer storage is a byte, defined as 8 bits; 1 megabyte is slightly more than 1 million bytes). The information on a topographic map is comparatively dense, and it commonly takes 100 megabytes to capture it in digital form. A single scene from an Earth observing satellite might contain 300 megabytes, the information content of 300 books. Thus even crude approximations to the complexity of real-world geography can rapidly overtake the capacity of our digital storage devices.

Although we often think of the contents of a GIS database as equivalent to a map, there are important differences. On a map, a geographical feature such as a road or a power line is shown as a symbol, using a graphic that will readily be understood by the map reader (Figure 1.8). In a geographical database a road or power line will be represented by a single sequence of points connected by straight lines, and its symbolization will be reattached when it is displayed. A windmill will be represented by a single point, with the attribute "windmill", and will be replaced by a symbol when displayed. This approach is economical, since the geometric form of the windmill symbol will be

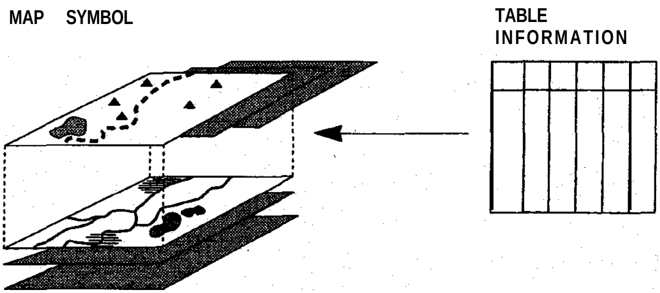

Figure 1.8
For presentation purposes, the table information is translated into map symbols, which are then superimposed on existing map data.

stored only once rather than repeated at each windmill location, and it also allows analysis to be more effective.

Databases are vital in all geographical information systems, since they allow us to store geographical data in a structured manner that can serve many purposes. Many GISs impose further structure by using a database management system (DBMS) to store and manage part or all of the data in a largely independent subsystem under the GIS itself (Figure 1.9). A DBMS is a general-purpose software product, and GISs that use this approach are often able to function in conjunction with a wide range of DBMS products.

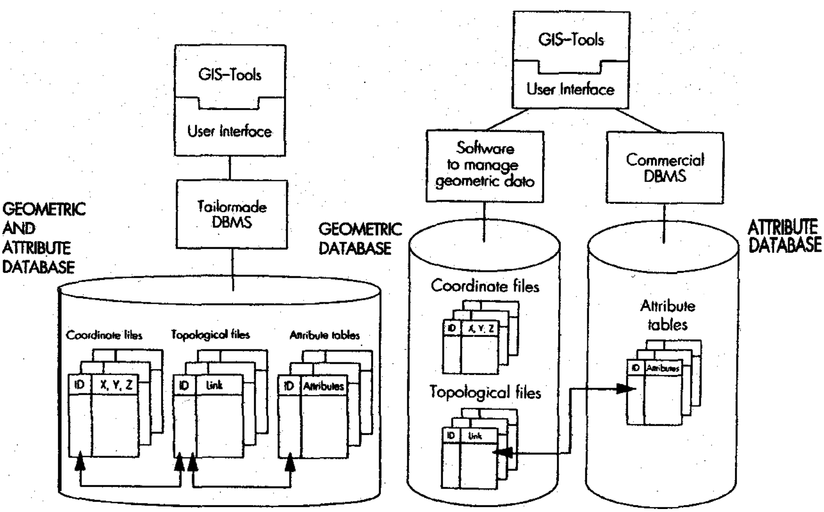

Figure 1.9
Alternative DBMS solution for GIS.

The database underlying a GIS achieves many objectives. It ensures that data are:

- Stored and maintained in one place
- Stored in a uniform, structured, and controlled manner than can be documented
- Accessible to many users at once, each of whom has the same understanding of the database's contents
- Easily updated with new data

This contrasts with the traditional way of organizing and storing data on paper in filing cabinets, in which data are often:

- Stored in ways that are understandable to one person only
- Easily corrupted by use, or edited in ways that are meaningful only to the editor
- Inaccessible to anyone other than the creator of the system
- Stored in formats and at scales that are so diverse that they cannot be compared or collated
- Difficult to update

The constituent parts and modes of operation of GISs are discussed in detail in Chapter 3.

GIS diversity

Although the general definition of GIS given here is quite valid, in practice the diversity of GIS has spawned various definitions. First, users have contrived working definitions suited to their own specific uses. Thus they may vary according to whether operators are planners, water-supply and sewage engineers, support service personnel, or perhaps professional and public administrators or Earth scientists. Second, those with a more theoretical approach, such as research workers, software developers or sales and training staff, may use definitions that are different from those used in practical applications. Systems can be tailor-made by assembling them from available software tool kits of semi-independent modules, assorted computer hardware components, and other interoperable devices. Many applications can be addressed by acquiring a single, generic GIS product and a standard configuration of hardware. There are many views of GISs, including:

- A data processing system designed for map production or visualization
- A data analysis system for examining conflicts over plans or optimiring the design of transport systems
- An information system for responding to queries about land ownership or soil type
- A management system to support the operations of a utility company, helping it to maintain its distribution network of pipes or cables

- A planning system to aid the design of road systems, excavations, or forest harvest operations
- An electronic navigation system for use in land or sea transport.

GISs are often designated according to application. When used to manage land records they are often called land information systems (LISs); in municipal and natural resource applications they are important components of urban information systems (UISs) and natural resource information systems (NRISs) respectively. The terms *spatial* and *geospatial* are often used almost interchangeably with *geographical*, although *spatial* is also used to refer more generally to any two- or three-dimensional data whether or not it relates directly to the surface of the Earth. The term *automatic mapping/facility management (AM/FM)* is frequently used by utility companies, transportation agencies, and local governments for systems dedicated to the operation and maintenance of networks. Nonetheless, GIS is now accepted internationally as an umbrella term for all digital systems designed to process geographical data, and is, used in that sense in this book.

As befits this breadth of applications, the field of GIS involves many disciplines, applications, types of data, and end users, examples of which are:

- *Disciplines:* computer sciences, cartography, photogrammetry, surveying, remote sensing, geography, hydrography, statistics, information sciences, planning
- *Applications:* operation and maintenance of networks and other facilities, management of natural resources, real estate management, road planning, map production
- *Data*: digital maps, digital imaging of scanned maps and photos, satellite data, ground truth data, video images, tabular data, text data
- Users: water supply and sewage engineers, planners, biologists and cartographers, surveyors

The software capabilities required for a GIS often overlap those needed by other computer applications, particularly image processing and computer-assisted design (CAD). Image processing systems are designed to perform a wide range of operations, on the images captured by videocameras, still cameras, and remote-sensing satellites. Today, the distinction between image processing and GIS is becoming increasingly blurred as images become more and more important sources of GIS data. Broadly, though, it is convenient to think about image processing systems as concerned primarily with the extraction of information from images, and GIS as concerned with the analysis of that information.

CAD systems have been developed to support design applications in engineering, architecture, and related fields. Broadly, CAD systems emphasize design over analysis and often lack the capabilities needed to process the complex attributes and information of georeferenced data or to integrate georeferenced data from many sources. Nevertheless, the distinction between CAD and GIS has become increasingly blurred in recent years; by adding appropriate features, many former vendors of CAD systems are now able to compete effectively in the GIS market.

1.2 Socioeconomic Challenges

Various surveys have been conducted to determine the importance of geographical data by assessing the proportion of all data that are geographical, as defined above. In local government bodies and in utility companies the proportion is often over 80%; in mapping agencies it may come very close to 100%. These surveys have also shown that major users of geographical data-the construction sector, public administration, agriculture, forestry and other resource management, telecommunications, electricity supply, transportation-spend 1.5% to 2% of their annual budgets acquiring geographical data. In relation to gross national product (GNP), annual expenditures average 0.5% in industrialized countries and 0.1% in developing countries. In the United States, a 1993 survey by the Office of Management and Budget found annual expenditures on geographical information in federal agencies totaling over $4 billion, suggesting that the total in all areas of U.S. society is well over $10 billion. The major challenges to system developers and users alike are now very different, and related to the comparative ease of use of the technology, the problems of finding and accessing suitable data, and the lack of trained personnel able to exploit the technology's potential to its full.

Our complex society

Modem societies are now so complex, and their activities so interwoven, that no problem can be considered in isolation or without regard for the full range of its interconnections. For example, a new housing development will affect the local school system. Altered age distribution in a village will affect health and social expenditure. The volume of city traffic will put constraints on the maintenance of buried pipe networks, affecting health. Street excavations may drastically *reduce* the turnover of local retail shops. Traffic noise from a new road or motorway may well drive people from their homes. The actions needed to solve such problems are best taken on the basis of standardized information that can be combined in many ways to serve many users (Figure 1.10). GISs have this capability.

Populations are now extremely mobile; changing jobs and moving to another location have become commonplace. When key personnel leave a company, they take their expertise with them; if that expertise

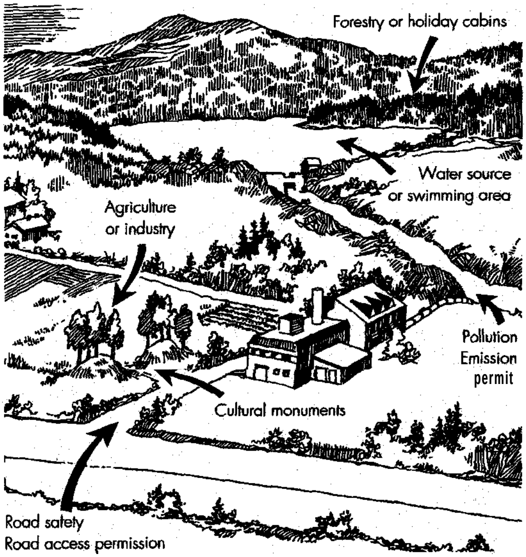

Figure 1.10
Today's society has a growing need for information. Conflicts of interest have to be brought out into the open and information has to be made available to the parties concerned. It has been shown that at least 50% of the public administration sector needs geographical data in one form or other. (Courtesy of the Norwegian Cartographers Union et al.)

involves specific knowledge of, say, the water supply and sewage network of a community, the loss can be serious if the information is otherwise inadequately documented. Here, too, GIS has an advantage in that it can act as an effective filing system for dissimilar sectors of a complex society

Operation and maintenance

Another aspect of developed industrial societies is that emphasis has shifted from the planning and development of infrastructure to its operation and maintenance, particularly for such facilities as buried pipes and cables, and transportation systems. As we approach the twenty-first century the infrastructure of many industrial societies is deteriorating and the costs of maintenance are increasing accordingly (Figure 1.11). It is estimated that the average age of the water supply pipes of many cities of eastern North America is now over 100 years, and some 20% to 30% of the water supplied to these systems is now lost through leakage. The costs of replacing this aging infrastructure over the next decades will be truly astronomical. In Sweden, too, costs of operation and maintenance of the water supply system in the 1990s are double those of the 1980s.

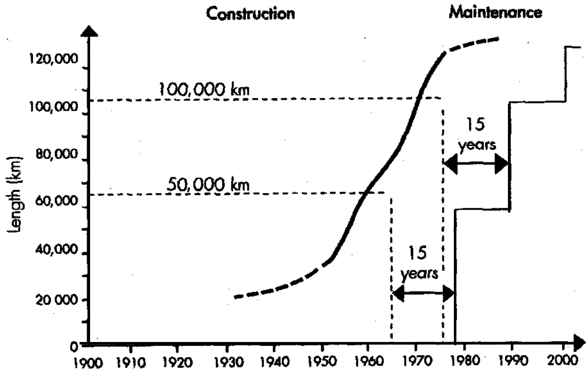

Figure 1.11
Total length of the water and sewerage system in Sweden from 1935 to date. Maintenance is normally carried out about 15 years after the pipes have been laid. This means that maintenance costs in the 1990s are double those of the 1980s.

In Norway in 1990, municipal budgets for operation and maintenance were nine times those allocated to building new facilities. The large sums involved indicate that even minor gains in efficiency in this area can result in considerable savings. Yet more efficient operation and maintenance is possible only when full information is available on a facility's location, condition, age, construction material(s), and service record.

As many as 35 different types of piping and cable may be buried beneath the surface of a major city street. These include telecommunications and optical cables, high-voltage, local power, signal, heating, and TV cables, as well as piping for water supplies, sewerage, gas, and remote heating (Figure 1.12). Indeed, such is the confusion of pipes and cables that it is impossible to include all the relevant information on an ordinary map. Since the mid-1970s, therefore, piping and cable data have increasingly been computerized.

Computerization is the only realistic way of systematizing and standardizing the enormous amounts of data involved. For instance, even in a small city (population 500,000) there may be several million meters of buried pipes and cables. Even though the cities of industrialized countries have long had such problems, the overall picture seems equally serious in the cities of developing countries. In some cases, construction workers have been electrocuted when high-voltage cables whose locations were not pinpointed have been cut accidentally. The situation with water supply and sewage networks is equally adverse. Far too many human tragedies may be ascribed to an inadequate, leaky water supply, deplorable sewerage, lack of maintenance, and lack of knowledge of the networks involved. The prime requirement for the information involved is, of course, that it must be manageable. This means that now and in the future, it must be computer based.

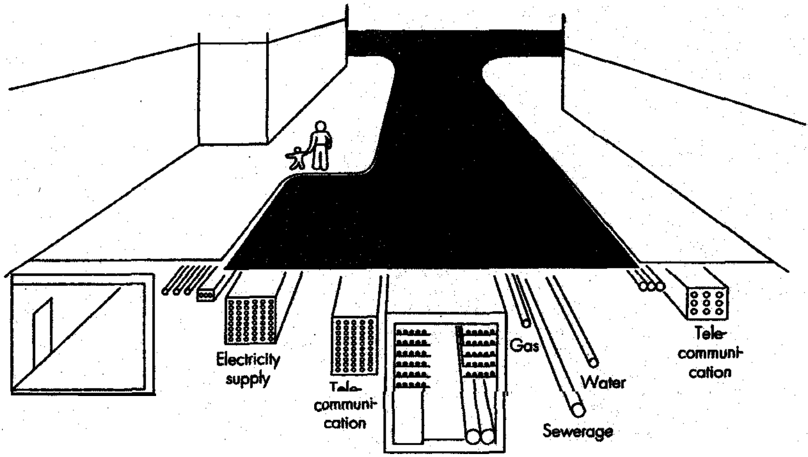

Figure 1.12
Complexity of the systems under a city street. There can be up to 35 different utility systems under a single street (standard specifications for piping·cartography).

Environmental and resource management

Decision making is becoming increasingly complex as dwindling natural resources and more demanding economic priorities diminish the chances of today's decision being right tomorrow. Furthermore, environmental awareness is constantly increasing among the general public, particularly among the younger generation. The pressing global challenges are now;

- Uncontrolled desertification
- Erosion, particularly of productive agricultural soils
- Monoculture, particularly in areas devoted to cereal production such as the American Midwest, and its associated pollution and soil deterioration
- Loss of endangered animal and plant species
- Acid rain and associated deterioration of forest-and aquatic environments
- Pollution of rivers, lakes, and oceans
- Environmentally related illnesses
- Contaminated groundwater and other environmentally related stresses
- The greenhouse effect and resultant climatic change
- Reduction in the ozone layer
- Repeated environmental catastrophes, such as oil spills, poison leaks, and radioactive releases

Despite many comprehensive studies, the global environment is still not well understood, because nature is complex and most effects are

Figure 1.13
Today the world's natural resources are under great pressure and it is important to ensure sustainable development built on a strong foundation. GIS can be instrumental in initiating such a process.

interrelated. For example: a small decrease in the atmospheric ozone layer permits more ultraviolet radiation to reach the surface of the Earth; this kills the marine algae on which fish feed. Fish populations dwindle, which reduces catches, and threatens the economy of fishing villages in major coastal areas. To help us map and monitor such changes, and plan appropriate responses that take account of the complex interactions of the Earth system, many countries now have comprehensive programs to capture and archive information on existing natural resources and known sources of pollution, using technologies such as satellite remote sensing and GIS (Figure 1.13). Worldwide databases have been established by agencies such as the United Nations Environmental Program, whose GRID program makes such data available to a wide range of users in GIS format.

Environmental data may be used both to expose conflicts and to examine environmental impacts. Impact analyses and simulated alternatives will probably become increasingly important. GIS is playing a key role in:

- Monitoring and documenting natural conditions and detecting change
- Documenting the suitability of resources and land areas for various uses
- Exposing conflicts and conflicting interests
- Revealing cause-effect relationships
- Modelling the interaction of various components of the Earth's environment to predict the effects of changes: for example, the ef-

fects of continued burning of fossil fuels on atmospheric carbon dioxide, or the effects of global climate change on forests and agriculture

Addressing environmental problems is complicated by a sparsity of information. Even the data that have been compiled are of limited use in decision making because of non uniform storage and filing, lack of verification, lack of a systematic approach to data acquisition, and even obsolescence. GIS techniques and databases are ideally suited for the optimal manipulation of such environmental data.

Planning and development

As discussed above, the planning and development of new housing, roads, and industrial facilities requires data on the terrain and other geographical information. Development often involves building on marginal terrain, increasing the density of building in areas already built up, or both. Yet the new structures must fit within the existing technical infrastructure; here computerization is a great aid. For example, when Stockholm's Central Railway Station was expanded, between 1986 and 1989, all technical infrastructure facilities above and below ground were registered, and the entire project managed with the use of computers and GIS. In the United States, GIS has been used to plan and manage the massive Inner Relief Project in Boston, Massachusetts. One of the benefits GIS holds for such projects is a minimalization of disruption to the existing infrastructure (Figure 1.14).

Escalating construction costs have made the optimizing of building and road location extremely important. Minimizing blasting and earthmoving are significant aspects of minimizing costs. Flexibility is vital: plans should be amenable to rapid change as decisions are made. The influence of special-interest groups and of individual citizens require that initial plans be presented efficiently and in a manner that is easily understood. Simplified, visualized plans are instrumental in conveying both the content of a scheme and the nature of any likely impact on those concerned.

Management and public services

In modern societies, decisions should be made quickly, using reliable data, even though there may be many differing viewpoints to consider and a large amount of information to process. Today, the impact of development decisions is ever greater, involving conflicts between society and individuals, or between development and preservation Information must therefore be readily available to decision makers; the majority of such information is likely to be geographical in nature, and best handled using GIS.

Figure 1.14
Today's requirements for physical planning are stringent. Projects that involve encroachments on nature have to be carried out in the most environmentally friendly, yet economical way. (Courtesy of Asplan Viak.)

Overviews of administrative units and properties are crucial in the development of both virgin terrain and built-up areas, in both developing and developed nations. In many countries, property registration is extensive: even in smaller states, 2 or 3 million properties may be involved. Moreover, property is also an economic factor in taxation and as security for loans, so comprehensive overviews are essential to a well-ordered society. Computerized registers based on GIS technology are now well established in many countries. They are playing a vital role in restructuring the system of land ownership of former communist countries and in modernizing land records in developing countries.

Safety at sea

In many waters, the volume of shipping has increased considerably Offshore oil rigs and other fixed facilities have been erected in customary shipping channels. As alterations along channels often affect navigation, there is an urgent need in shipping circles for up-to-date information. Today, a ship sailing in international waters may carry as many as 2,000 navigational charts, each of which may need updating as often as weekly (Figure 1.15).

Technology now permits the sending of information to mariners via public telecommunications networks, while electronic charts may

Figure 1.15
A prerequisite for safe navigation at sea is rapid access to relevant navigational data. The risk of collisionat sea is enhanced by the increasing speed of vessels and complexity of shipping lanes. Electronic sea chart systems function in the same way as GIS at sea and improve safety.

be combined with positioning and radar displays on a ship's bridge. This means that ships can now sail more safely and at greater speeds in hazardous waters. Computers are now widely used for the production of traditional paper charts as well as for the production of updates.

Land transportation

In many countries, the greater part of transportation has shifted from rail and water to roads; at the same time, the use of private cars has greatly increased. These developments have created traffic problems, which cause loss of time and money Large (and sometimes hazardous) goods are now transported by road. In most countries the annual costs of traffic accidents have become extremely high.

The transportation sector has always been a major consumer of maps and geographical data, so new technologies may realize considerable savings. The automobile industry is now investing heavily in the development of driver information systems (Figure 1.16), and several systems are now on the market. In principle, all of them involve

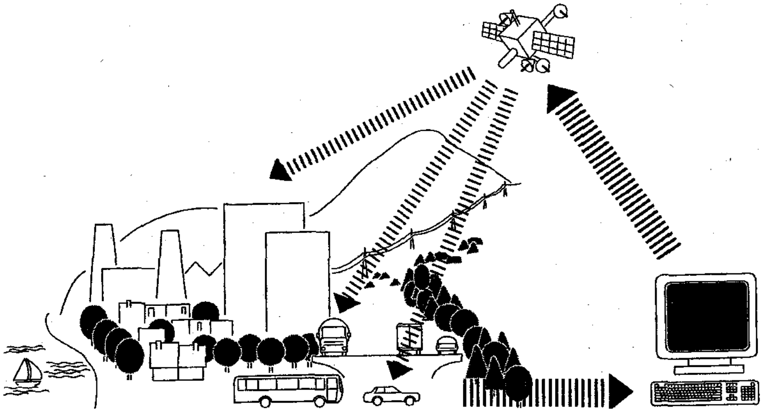

Figure 1.16
The transport sector has always made extensive use of geographical data. The introduction of new technology has opened a new range of applications in the fields of transport planning and traffic information.

simple GIS functions with digital maps and supplementary information. In many urban areas, where traffic is complex, increased driver information can ease congestion and improve safety. Such innovative programs to address problems of traffic congestion, known collectively as *intelligent transportation systems* (ITSs), are the subject of much research, particularly in the United States and Europe. They rely heavily on database representations of road networks and related information of importance to drivers and travelers, and on GIS.

Military uses

Modern military planning, training, and warfare are extensively computerized. In many ways, military computer systems include GIS functions. Digital data representing the form of the land surface are used in flight simulators and as the basis of automatic navigation and targeting in many weapons systems, such as the Cruise missile. Digital information on shorelines, water depth, land cover, and roads is now widely used by the military, and is processed using military forms of GIS technology.

The global positioning system (GPS) is another increasingly useful form of geographical information technology, initially developed by the U.S. military but now widely used for both military and civilian applications around the world, often in conjunction with-GIS. It consists of a constellation of 24 satellites whose signals can be analyzed by a very simple hand-held device to determine position on the Earth's surface. A single receiver, available at a retail price of less than $300, can provide positioning in civilian applications to about 100 m, and in military applications to about 40 m. By using a combination of a roving receiver and a base station it is possible to achieve much higher accuracy, down to the centimetre level. An investment of $10,000 in a base station and receiver will yield positional accuracy relative to the base station of better than 1 m.

The importance of geographical data and information technologies in the Gulf War was such that it was described on more than one occasion as the "first GIS war". The implications for the GIS community of such statements, and of the role of GIS in warfare in general, have been the subject of comment. As a rule, military operations are relatively independent of civilian activities. However, the increasingly demanding military specifications pertaining to equipment and data access will undoubtedly benefit civilian GIS in due course, and trends in modern warfare indicate that military GIS activities can be expected to increase.

Conclusions

This is the age of information, and information technologies such as GIS and GPS will have increasing impact on our lives. GIS technology can be used to build detailed information databases on individual citizens, and thus threaten individual privacy, and it can be used to improve our monitoring of the global environment and the decisions we make about the future of the planet. It can be used to make either reliable decisions based on good data, or unreliable decisions based on bad data or inappropriate methodsof analysis. In such issues the computer itself is no more than a mechanical processor. The responsibility for wise use lies entirely with the user and with those who provide its data, develop its software, and build its hardware. The technology has enormous potential, both for use and abuse, both conscious and unconscious. There is 'sometimes a tendency to give computer results more credibility than they deserve, and the wise use of a powerful technology like GIS often requires more responsibility on the part of its users than did the earlier techniques of map use and analysis.

Benefits of Computerizing Information

Almost all aspects of modern society use digital information, and the total amount that flows through our communication networks daily is truly staggering. GIS offers its users the ability to process quantities of data far beyond the capacities of manual systems (Figure 1.17). Data in GIS are stored in a uniform, structured manner, as opposed to manual systems in which data are stored in archives and files, in agencies, on file cards, on maps, or in long reports. Data may be retrieved from GIS databases and manipulated far more rapidly and reliably than data in manual systems. In addition, data are quickly compiled into docu-

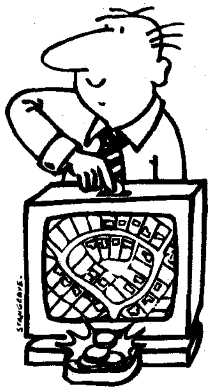

Figure 1.17
There are considerable gains to be made by converting to computerized information. However, unlike with slot machines, the winnings are not based on chance.

ments using techniques that include automatic mapmaking and direct report printouts. The potential gains from switching from manually prepared maps and ordinary files to computerized GIS are considerable, in both the public and private sectors.

A joint Nordic research project (Nordic KVANTIF) has evaluated the gains realized by implementing GIS through studies of its use in 50 to 60 organizations in the United States, Canada, Italy, and the five Nordic countries-Norway, Sweden, Denmark, Finland, and Iceland. The study showed that considerable benefits may be achieved, provided that the strategy used to implement GIS is suitably chosen. The study also showed that benefits are often related to objectives and that the following benefit/cost ratios may be attained by introducing GIS (Figure 1.18):

1. If computerized GIS is used for automated production and maintenance of maps, the benefit/cost ratio is 1: 1.
2. If the system is also used for other internal tasks such as work manipulation and planning, the benefit/cost ratio may be 2: 1.
3. The full benefit of the system is first realized when information is shared among various users. The benefit/cost ratio may then be 4:1.

The benefit/cost ratios quoted above refer to municipal services. Studies have shown that corresponding ratios for nationwide uses are somewhat lower, up to 2: 1 to 3: 1. Nonetheless, it is obvious that investment in GIS is at least as productive as investment in other sectors. These benefits are not automatic. They depend largely on proper choice of an acquisition and implementation strategy, following care-

Objective level	Map production	Map production and internal use of data	Map production, internal use of data and shared use of data
Tasks	• storage • manipulation • maintenance • presentation	• map production • planning • facility maintenance • project management	• map production • project • planning • facility maintenance • coordination • general service • facility management • economic planning • service and information
Benefit/cost ratio:	1:1	2:1	4:1

Figure 1.18
The benefit/cost ratio of transferring to GIS depends on how the system and information are applied. The ratio will normally be 1: 1 for pure map production; 2: 1 for other applciations such as planning, and as much as 4: 1 for a multiple-user information system.

ful study of the objectives and requirements of GIS investment, and careful selection of the appropriate system. Without these safeguards, many GIS projects eventually fail to deliver the promised benefits and may eventually fail entirely, at considerable cost to the institution. Even with a carefully selected strategy it is difficult to estimate benefits precisely The ratios discussed above are average over many projects varying widely in scale and scope. Some figures, however, are impressive, with benefit/cost ratios of up to 8 to 10:1 or more. Detroit Edison, a public/electric company in the United States, cut production time for a particular type of map overview from 75 hours to 1½ minutes. The city of Burnaby in Canada experienced costs that exceeded benefits by $1 million for the first three years of the project, but after seven years achieved an annual benefit of $400,000 dollars.

Some benefit/cost ratios for various sectors and activities are (Tveitdal 1987).

National data	
Forestry	2.0:1
Transportation	4.0:1
Environmental data	1.8 : 1
Documentation	2.0:1
Municipal data	
Map production	1:1
Agency uses	2:1
Joint uses	4:1

A number of GIS projects have been terminated because benefits did not meet expectations; in other cases, a project might not have been terminated had benefits been evaluated in a rigorous, objective manner. The Nordic KVANTIF study showed that GIS projects almost always involve high financial risk but that successful projects often results in benefits greater than anticipated.

Benefits are a function of many factors, including the goals and objectives of the project, the strategy adopted in its implementation, and the structure of the system built to serve the objectives (Figure 1.19). Systematic planning and implementation often set profitable GIS projects apart from those that are unprofitable. Projects based on carefully estimated cost and benefit calculations are often more profitable than projects driven by pure technology. Profitable projects are user oriented rather than production oriented. Profitable projects start by being defined so clearly and convincingly that they are funded outside the ordinary operating budget.

The measurable benefits of GIS are usually expressed as gains in efficiency in terms of time saved, but there are also many cases of direct increases in income and reductions in costs. Measurable benefits may include:

- Improved efficiency due to more work being performed by the same staff, or the same work performed by a smaller staff
- Reduction in direct operating costs through better bases for financial management, less costly maintenance of facilities, and joint uses of available data
- Increases in income due to increased sales, or sales of new products and services

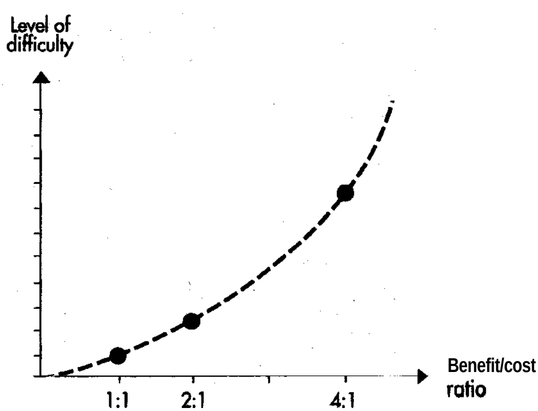

Figure 1.19
High benefit/cost ratio figures are not easy to achieve, and the level of difficulty of the project tends to cause the ratio to increase proportionately.

Experience indicates that when GIS makes some traditional jobs superfluous, staff are not made redundant but instead put to tasks in the GIS environment that create more value.

Intangible benefits may also accrue. They cannot be expressed directly in monetary terms, but attempts should always be made to include them when benefits are evaluated. Intangible benefits may include:

- Improved public and private decision making in administration, planning, and operations
- Improved information and service to the public
- Increased safety, and reduction in the impact of disasters through better planned evacuation and more efficient management of emergency services
- An improved environment for future generations
- Better presentation of plans and their associated effects
- Improved decisions regarding new development, and better analysis of market and site conditions

The greatest long-range global benefits of GISs are probably in the sectors where decisions have an environmental impact. The environment and the natural relationships within it are complex and not yet fully understood. It is, however, widely known that environmental degradation is implicated in the causes of many modem illnesses, such as asthma and cancer, the annual costs of which are enormous.

Increases in safety at sea are associated with the introduction of electronic navigation systems, such as the *electronic chart display and information system* (ECDIS). The benefits realized can best be appreciated by considering what the ECDIS might help prevent. Among the more serious environmental disasters are oil spills from tankers that run aground. Subsequent cleanups have cost from $40 per kilogram of oil to totals of up to $2 billion. If improved navigation using ECDIS can prevent one such disaster per year, the benefits are considerable, albeit difficult to assess directly

1.4 Users of GIS

In this chapter we have reviewed some of the basic concepts of GIS and some of the issues that arise it its use. Today, the widespread acquisition of digital computers by businesses, schools, and households has allowed technologies such as GIS to penetrate many aspects of our lives. Nevertheless, computer processing of geographical data remains problematic, and GIS are widely regarded as difficult to learn about and to use. We hope that subsequent chapters of this book will provide a conceptual and technical understanding of GIS that will allow readers to make effective use of its capabilities in one or more of the many areas of its application.

Users of GIS naturally fall into two groups. Some are professional operators of GIS, who spend much of their lives working with the technology in their jobs. They are well trained in the particular software they use and am well aware of its capabilities. In many cases they do not use the results of their work themselves, but pass them to end users. The results may be maps, designed and produced by the GIS operator, results of analysis to be used in planning harvesting of trees, or work orders for maintenance staff in a major utility company.

The second group of users spend a relatively small proportion of their lives using GIS. They may maintain a GIS capability on their personal workstation in order to produce an occasional map, to find a restaurant in an unfamiliar city, to plan a driving route for a vacation, or to carry out analysis of map data in connection with a research project. In these cases the opportunities for lengthy training are much less, so the GIS must be simple and easy to use.

This second group also comprises end users and primary users who make professional decisions based on GIS products. The group includes:

- Operation and maintenance engineers; a typical decision may be whether to replace or repair a damaged water main.
- Regional planners; characteristic tasks involve presentations of plans to municipal authorities in a realistic, varied, visual manner.
- Building authority functionaries; representative jobs include processing building permit applications involving access roads, water supply, or sewage.
- Revenue officials, typically dealing with tax assessment and taxpayer addresses.
- Road engineers, whose responsibilities include locating new roads to minimize cut-and-fill operations.
- Information officers; information produced may include complete packages to newly established firms with details on industrial areas, schools, and transportation.
- Local officials, who may require updated overviews on the effects of effluents on water quality at public beaches or the effects of zoning on school capacities.
- Fire brigades, for whom rapid, reliable information on the locations of fires and the presence of hazards such as explosives would be invaluable.
- Forest managers planning harvest operations, computing volumes of annual growths, estimating road costs and identifying sensitive wildlife areas.

- Bank officials, perhaps wishing to verify ownership of properties offered as collateral.
- Oil tanker captains maneuvring a ship in hazardous waters.
- Truck drivers seeking to minimize the problems of transporting an extrawide load between two points.

Such a list could be endless; only imagination sets a limit. Indeed, GIS may spawn information technologies applicable to completely new sectors, such as optimum warehousing or, even, brain mapping.

Geographic Information Systems

An Introduction

Second Edition

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