CHAPTER 1

Introduction to Digital Geography

LEARNING OBJECTIVES

When you are finished with this chapter you should be able to:

1. Provide a complete definition of geographic information systems (GIS).
2. Explain why the definition of GIS as merely a software system is incomplete.
3. Explain the parallels between the evolution of geographic thought and the advent of GIS.
4. Explain the initial impetus for the development of GIS.
5. Describe some of the difficulties encountered during the early development of GIS.
6. Describe the relationships among a GIS, computer-assisted cartography (CAC), and computer-assisted drafting (CAD).
7. Describe some basic analytical capabilities of a modern GIS.
8. Suggest possible users of a GIS and how it might benefit them.

GEOGRAPHIC INFORMATION SYSTEMS DEFINED

While many consider geographic information systems (GIS) to be software programs that manipulate spatial data, this definition is very restrictive. As the name implies, geographic information systems are systems designed to input, store, edit, retrieve, analyze, and output geographic data and information (DeMers 2005). Like all systems (e.g., ecosystems, digestive systems, ventilation systems, etc.), the GIS is composed of an orchestrated set of parts that allow it to perform its many interrelated tasks. These parts include computer hardware...
and software, space and organizations within which these reside, personnel who use the system in a number of levels and capacities, data and information upon which the system operates, clients who obtain and use the products, vendors who supply the hardware and software, and other systems (financial, institutional, and legal) within which the GIS functions (Figure 1.1). While the software component of GIS is most often what we think of when we hear the term, its scope is far bigger and more comprehensive than that. Initially we will focus our discussion on the computer programs themselves—the technology component—and revisit the other components later in this book as appropriate.

The primary task of a GIS is to analyze spatially referenced data and information. To perform meaningful analysis requires that the software be able to perform many other tasks, such as input, editing, retrieval, and output. Still, analysis is the strength of GIS. There are many ways of classifying the analytical and modeling capabilities of GIS because many of these capabilities interact. Ultimately, the software most certainly contains algorithms and computer code specifically designed to (1) organize geographic data within appropriate referencing systems, (2) selectively query those data and aggregate them for easy understanding, (3) count and measure both individual objects and collections of objects, (4) classify and reclassify objects based on user specified properties, (5) overlay related thematic map data, and ultimately (6) be able to combine these individual techniques into ordered sequences of operations designed to simulate some natural or anthropogenic activities for decision making. All of these tasks tend to involve, either directly or indirectly, some form of mapped data.

To understand how this works, imagine how you currently read, analyze, and interpret the analog equivalent of GIS—maps. Many first-time GIS students, even those who do not regularly refer to maps, are surprised when they discover that they are already GIS practitioners when using road maps to find routes from one place to another. This activity requires us to select portions of the road map for analysis (query), to find the shortest route from place to place (measurement), and to mark that route with a highlighter pen (classification). We use a special-purpose digital GIS when we use online map services such
Geographic Information Systems Defined

Figure 1.2 MapQuest output for a query showing directions from Las Cruces, NM to Tucson, AZ. Most people who use this service are unaware that they are actually using a rudimentary GIS.

as MapQuest to perform this same task for us (Figure 1.2). Some of us have onboard global positioning system (GPS)/GIS components in our automobiles such as OnStar (Figure 1.3) that not only tell us where we are and give us routing information, but also connect us to emergency services through wireless telecommunication. Both of these examples deal with the movement along networks and demonstrate relatively simple applications of the existing technology.

We become more sophisticated in our GIS skill set when we begin looking for places to buy or build a home. Whether we directly employ maps or not we most certainly employ what geographers call mental maps (mental perceptions of our spatial environment) when we do this. To perform this task we frequently develop spatial queries by defining the criteria we employ in selecting our candidate locations. For example, we may tell a real estate agent that we wish to buy a home that is in a new development (a query of our geographic data), costs less than $150,000 (another query), “near” our workplace (a measurement combined with a query), and within a particular school district (a form of overlay that we will later call point-in-polygon). These operations can readily be implemented by a digital GIS and are commonplace within commercial GIS software. Some real estate firms already employ GIS on a regular basis. So from these simple illustrations you can see that you already possess some of the skills necessary to perform GIS analysis. You only need to expand your concept of how space can be examined, measured, and compared, and then envision how the geographic objects you wish to examine might be encoded (input), stored, retrieved, and manipulated inside the computer.

The last example illustrates the analytical power of the GIS. Some people believe, for example, that there is no difference between computer-assisted cartography (CAC), computer aided drafting (CAD), and GIS. Because the graphic display from these three systems can look identical to both casual and trained observers, it is easy to assume that they are, with minor differences, the same thing. Anyone attempting to analyze maps will discover, however, that CAC systems, computer systems designed to create maps from graphical objects combined with descriptive attributes, are excellent for display but
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How OnStar Works

1. A GPS receiver in the vehicle picks up signals from Global Positioning System (GPS) satellites and calculates the location of the vehicle. That location information is stored in the vehicle's OnStar hardware.

2. When the driver pushes the blue OnStar button, red Emergency button, or an air bag deploys, OnStar places an embedded cellular call to the OnStar Center. Vehicle and GPS location data is sent at the beginning of the call.

3. The cellular call is received by a cellular tower and routed to the land line phone system.

4. The OnStar switch sends the call to the first available advisor, who has the location of the vehicle and the customer's information on her computer screen.

Figure 1.3 OnStar system at work.

generally lack the analytical capabilities of a GIS. Likewise, for pure mapping purposes it is highly desirable to use a CAC system developed specifically for the input, design, and output of mappable data rather than working through the myriad analytics of the GIS to produce a simple map. CAD—a computer system developed to produce graphic images but not normally tied to external descriptive data files—is excellent software for architects, speeding the process of producing architectural drawings and simplifying the editing process. It would not be as easy to use for producing maps as would CAC, nor would it be capable of analyzing maps—generally the primary task assigned to the GIS (Cowen, 1988). As each of these three technologies matures, however, we are finding a large crossover of techniques and capabilities, thus blurring the definitional lines among them.
A BRIEF HISTORY OF GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems are the result of over twenty-five hundred years of geographic research and exploration. As such, they reflect the culmination of that evolutionary process from exploration to description to explanation and finally prediction. The earliest stage of geographic thought was relatively simple, focusing on exploration of unknown lands, their inhabitants, and other phenomena. Its primary outcome was one of discovery. Later, as writing and graphic tools became available, the geographer’s craft began to systematically describe the observed lands, people, and other objects. Among the most powerful of such descriptions involved the preparation of maps showing not just locations but, eventually, distributions of phenomena. This phase led to the need to explain what these distributions might mean. Geographers began to look for both natural and anthropogenic explanations for different types of distributions. A natural outcome of pattern explanation was that of predicting new distributions based on those explanations and, ultimately, to exploit those predictions for planning. It is this need to exploit our knowledge of our resources for planning and management that led to the eventual development of what is now known as GIS. The following situation closely parallels the evolution of geographic thought and demonstrates how this process ultimately led to the development of the GIS toolkit.

In the early 1960s the Department of Forestry and Rural Development of Canada decided to pursue a large-scale project to manage the resources for much of their territory (Tomlinson, 1984). Among the initial tasks was the inventory (exploration and discovery) and mapping (description) of the available forest and mineral resources, wildlife habitat requirements, and water availability and quality to list just a few. The inventory was meant as a first step in a larger endeavor to compare the maps to each other to explain their patterns and finally to predict the longevity of the resource base. The goal of this proposal was to develop a management strategy to ensure the long-term availability of both renewable and nonrenewable resources without damaging the environment.

The mission just outlined was a daunting one, requiring enormous amounts of data gathering, compilation, evaluation, analysis, and modeling. Yet this is often the very task that faces natural resource managers. Immediately it became obvious that maps of the resources would permit viewing the extent, quality, and current rate of use at a single glance. The manual production of such very helpful maps covering an entire country, especially a large one, would call for the employment of perhaps hundreds of cartographers and considerable amounts of time and money. Many of you are painfully aware of the limited coverage and variable quality of topographic, vegetation, and soil maps for your own region or nation. Depending on the size of your area, it is entirely possible that long before such a task is completed the resources themselves will have disappeared, leaving the environment despoiled and the local residents up in arms.

A chance meeting between Roger Tomlinson, the director of the Department of Forestry and Rural Development, and an IBM executive resulted in a suggested application of the emerging computer technology to the problem. What was needed was a GIS for Canada. Thus the then newly instituted Regional Planning Information Systems Division, funded by the Canadian government, was
assigned to produce what was to become the first fully operational geographic information system ever built—the Canada Geographic Information System (CGIS). Its initial task was to classify and map the land resources of Canada, but more advanced uses were envisioned as these maps became available for analysis.

Before any of this could be accomplished there were substantial hurdles that needed to be negotiated. Because Canada encompasses such a large area of land, the first problem the CGIS developers encountered was how to input such vast amounts of data into the computer without using clear plastic grids and cell-by-cell input. This required the refinement of the rather crude digitizers of the day to a large (48" × 48") pencil-following cartographic digitizing table to input point data. At the same time a large format (48" × 48") cartographic-quality drum scanner was also invented to replace manual line tracing. In tandem with the development of the digitizer, and because graphic displays were not available, Tomlinson’s team was forced to developed computational versions of topology—a branch of mathematics dealing with spatial properties and their conditions upon deformation—to detect input errors (e.g., closure of polygons).

Related to the large data volume problem was the limitation of the computers available in the early 1960s. In 1962 neither laptop nor desktop computers existed. Moreover, even the largest mainframe computers had very little core memory (kilobytes, not megabytes nor gigabytes). The IBM 1401, for example, had 16K of memory and the 1964 IBM 360/65 had 512K of core memory. There was no such thing as random access memory (RAM), so all the data had to be kept on tape. Imagine trying to build a geographic information system with a computer that has less core memory than one of today’s simplest hand calculators. A simple text file with the three characters Hi would take up nearly 1/3 of the core memory of most computers of the time (Figure 1.4). One major solution to the memory limitation was the development of the Morton Matrix,
the first of today’s facet or tile data structures. It provided a method of splitting up the database into small portions called tiles (Guy Morton’s idea). This “tiling” approach to dividing large spatial databases into manageable portions is still used today.

A third major problem needing a solution was that of finding a way to store and to link the locational data (points, lines, and polygons) with their nonspatial descriptions—a storage and editing problem. On analog maps this is done through the legend, a graphical device interpreted by the map reader, but the computer required that these be explicitly defined and linked. The spatial database management system that was developed was called a retrieval monitor and consisted of two separate databases—one for the locational data and one for the descriptions—linked by software pointers. The retrieval monitor also contained a language structure that allowed users to reclassify attribute data, dissolve lines, merge polygons, measure cartographic objects, change scale, generate circles, generate new polygons, search attributes, create lists and reports, and carry out polygon overlay operations. This was the essence of the analytical portion of a GIS and is still the core of modern GIS software.

One additional problem to overcome was the need to build a complex spatial software package using (pre-PL1) computer languages that were not designed for graphics or for the complex nature of geographic data. Moreover, nearly all the programmers at that time either worked for computer companies or for very centralized governmental service bureaus. None of these programmers were trained in digital spatial data handling. This required rethinking the training of computer scientists to understand the nature of spatial (geographic) data and the training of geographers in computer science.

GIS AS A GROWTH INDUSTRY

As with the Regional Planning Information Systems Division in 1960s Canada, today there is an ever increasing recognition of the need to perform large-scale mapping and map analysis operations for a wide variety of traditionally manual tasks. Foresters wanting to keep an up-to-date inventory of their timber resources see GIS as an efficient management tool for their day-to-day operations. Fire departments need GIS to enhance their routing capabilities to ensure rapid response in emergencies. The military uses GIS to determine appropriate battle plans and to organize troop movements. Cellular phone companies, wanting to provide the best service for a mobile customer base, employ GIS to site their transmission towers to avoid conflicts with neighbors and while still allowing clear line-of-sight for signal transmission. Local governments employ GIS to develop growth and development plans and to modify zoning regulations to account for increasing population pressures. Businesses are using GIS to market products and even to develop mailing lists based on selected spatial criteria. Real estate companies are using GIS to isolate available housing on the basis of customer criteria such as proximity to schools, type of neighborhood, or access to highways. Police departments are currently using GIS to compile information to characterize the movements and operational settings of
suspected serial killers. Academic disciplines such as geography, biology, geology, landscape architecture, range science, and wildlife management now have the capability to employ the technology to develop and test hypotheses concerning patterns of natural phenomena on the earth. Even social science and scientific researchers are increasingly adopting GIS technology, although their numbers are small by comparison with many other groups. The potential users of GIS are nearly limitless, and their types and numbers are growing at a logarithmic pace.

This growth is indicative of the nature of GIS as an empowering technology. It is not unlike the development of the printing press, the creation of the first telephone, the replacement of the horse and buggy with the automobile, or the introduction of the first computer. All these innovations had a profound impact on the way in which we communicated, the way we moved from place to place, and the way we solved problems—even on the nature of the problems we solved. Modern GIS enhanced the utility of the map by replacing a single map with a large number of interrelated thematic maps. These maps could be automatically analyzed, and their themes combined to give meaningful answers for decision makers. GIS has changed the way we do things with maps, the way we think about geographic information, even the way in which geographic data are collected and compiled. Tasks that were impossible with traditional maps are now commonplace.

A decade or more ago, market trends for GIS and related technology indicated that it would be a major growth industry, far outstripping many others, even during recession years (U.S. News & World Report, 1995). In early 2004, Directions Magazine estimated that there would be over $2 billion in GIS software sales alone by the end of that year, with additional billions spent for services, hardware, and related activities (www.directionsmag.com/press.releases/?duty=Show&id=10412; accessed 6/20/06). As more organizations become dependent on GIS, the need to become familiar with its basic principles will grow as well. There will also be an increase in the demand for people knowledgeable about the concepts behind the technology. We will examine these concepts here, with an aim toward understanding how spatial phenomena can be manipulated and how the technology can help us in an increasingly complex world.

SAMPLE APPLICATION AREAS OF GIS

Whether we think of GIS as software or not, its primary purpose is the organization and analysis of spatially referenced (usually geographical) data. The utility of GIS to solve real-world geographical problems and to provide long-term return on investment has contributed to its continued growth and increasing popularity. Some general areas of endeavor for which GIS is useful include natural resources management; city, regional, and environmental planning; transportation planning; crime analysis; emergency services; and site selection to name just a few.

You have already seen some examples of the specific types of problems for which the technology is currently applied. While at first it might seem unnecessary to identify specific examples of problems, I have found that the more examples I encounter, the more possibilities I can imagine. These possibilities
Figure 1.5 A satellite image from Operation Iraqi Freedom focusing on the tactical application of 3-D representation of imagery (www.geospatial-online.com/geospatialsolutions/article/articleDetail.jsp?id=56052; last accessed August 20, 2006). The satellite image was collected on April 1, 2003. It is a 0.9 meter resolution DigitalGlobe image and shows the parade grounds in central Baghdad with the Hands of Victory monument, in the form of two crossed swords (lower center), marking the entrances. The image reveals the billowing smoke plume from a burning oil trench. The structure on the right of the smoke is the Monument of the Unknown Soldier.

often result in pushing the technology even further so that the tool improves to meet these new demands.

Take, for example, the burgeoning use of GIS and remote sensing technologies in the defense industry. During “Operation Iraqi Freedom” in 2003–4, many of us saw three-dimensional images of urban areas in Baghdad and other Iraqi cities, both as static pictures (Figure 1.5) and as dynamic “flythroughs.” Not only was the general public able to view these images in extreme detail on their television sets as the news media tried to explain tactical details of operations, but the U.S. Congress saw them as well. Within months of these images appearing on the evening news, the U.S. federal agency then known as the National Imagery and Mapping Agency (NIMA) was ordered to change its name to the National Geospatial-Intelligence Agency (NGA) to more closely reflect its increasing use of GIS and remote-sensing technologies in the defense and intelligence missions.

Prior to that, the terrorist attacks on September 11, 2001 on the World Trade Center, the Pentagon, and the thwarted attack on Washington D.C. brought about new applications of the technology. Within hours after the World Trade Center buildings collapsed, some entrepreneurial students at the City University of New York began creating a database that could, and ultimately would, be used to reroute traffic around the site. In fact, the GIS database was also used to plan for debris removal, to allocate and route service vehicles, and to perform a wide variety of planning strategies in and around the area. Figure 1.6 shows a 3-D image of the World Trade Center towers (www1.cuny.edu/events/cunymatters/2001_december/groundzero.html; last visited 7/27/2007). With the resulting development in the United States of a cabinet-level Office of Homeland Security (OHS), the utility of GIS was quickly recognized. It is now an integral part of OHS operations both at the state and the national levels. It may one day become an integrative tool to empower the various agencies to share vital security-related geospatial data and information.

The recognition of the utility of geospatial data and software has also been responsible for some radical changes in how police and federal crime agencies perform their missions. In September of 2000 a series of related sniper attacks on innocent civilians in the Virginia and Washington, D.C. area prompted the FBI to request the assistance of D. Kim Rossmo of the Vancouver Police Department to employ the newly developing geospatial toolkit now known as “geographic profiling” to identify suspects. By comparing geographic space used by these
perpetrators with that of their victims (sometimes called activity space), together with psychological profiles of similar types of criminals, the agencies hoped to narrow down the potential search area for their investigations. Although the results were not clearly responsible for the eventual apprehension of the suspects, it shows once again the high level of sophistication and increasing
application areas of GIS and related technologies. In fact, the U.S. Department of
Justice (DOJ) created the Crime Mapping Research Center (CMRC) to encourage
and enhance the utility of GIS and related technologies within the DOJ.

In recent years there has been a major concern about the potential pandemic
effects of the avian flu. This has prompted a variety of international health orga-
nizations to begin tracking the occurrences of the disease worldwide (Fig-
While these maps may be relatively crude by cartographic standards, they
represent an increasing use of GIS for such things as epidemiology and other
forms of medical research. There is even an effort by the National Geographic
Society to map the deep ancestry of people from all over the world.

THE STUDY OF GIS

GIS is an exciting, even glamorous, field with rapidly expanding opportunities
for those who are familiar with the concepts and the technology (University
Consortium for Geographic Information Science, 2007). A common fallacy is that
because GIS has become readily available and is showing up in a wide variety
of organizations, anyone can just sit down and start using the software. GIS
software, however, is not like the personal computer word processing software
we are so accustomed to. Although most of us know some basics about writing
and are perhaps very familiar with computer word processing, few of us are
comfortable with the analytical operations necessary to make decisions with
maps. Just as word processing software assumes that you can organize your
thoughts and ideas into coherent sentences and paragraphs, GIS assumes you
are familiar with the vocabulary of maps.

When asked, most of us will say that we are fairly comfortable with maps.
We use road maps routinely, and when necessary we consult a world atlas
with its political, physical, and economic boundaries, and associated colors,
graphic symbols, text, and, of course, north arrows. Most of us, however, don’t
often think about how much information a map contains. Nor do we give much
thought to the generalization processes that take place to decide which details
get included and which do not. Nobody wants to think about the problem of
representing an essentially spherical surface onto a flat piece of paper. Because
the map is such an elegantly designed document—so well thought out—we
simply accept it at face value.

On occasion, however, the limitations of the cartographic craft begin to show
through. How often have you wondered why a road that looks straight on a map
really curves all over the place? The graphic limits imposed on the cartographer
by available data quality, pen size, size of paper, and other conditions all
require him or her to make conscious decisions about how much detail can
and should be placed on a given map document. Much of this generalization is
imposed by the map scale. The smaller the map scale (the larger the mapped
area), the greater is the required generalization to produce the cartographic
model.

This concept of the map as a model of reality is perhaps the most important
concept that the future GIS professional must learn. Because the map has such
a strong visual appeal, the viewer tends to accept it as reality. Those who
work with maps, and especially those who work with the interactions of many maps, must constantly remind themselves of the limitations of the cartographic product. Here are just a few simple exercises you can do to become familiar with the cartographic model and some of its limitations.

Take a look at a number of world maps from different atlases you might find in your library. Pick out a country familiar to you. Notice how maps of it differ with respect to sizes, shapes, boundary configurations, numbers of cities, and the like. You might be surprised at the wide variation from one map to another. Consider, then, what you would have to do if you were to digitize a map of this country into a GIS. Which one would you select? Why? How does focusing on the purpose of your GIS project help you decide which map you want?

Obtain two or three adjacent topographic maps for your areas. What are the dates for each map? Are they the same? Different? Now the fun begins. With clear plastic tape (preferably removable), tape the maps together so that all the lines match. Be sure to turn on some relaxing music while you do this. What do you discover? The lines don’t match exactly. Imagine how you are going to input 20 or 30 of these documents into a GIS if the lines don’t line up.

Soil data might be nice to include in your GIS. Try the last experiment with your local soil map sheets. The match between sheets is even worse. If you are using soil maps from the U.S. Department of Agriculture Soil Conservation Service, you might be quite taken with the use of the aerial photography in the background. Admittedly, this feature is nice to have. But the addition comes at a cost. If you are going to input this map with other maps inside a geographic information system, you will have to co-register it with all the others so that the features match. This requires that the locational coordinates be specified on all maps. Try to find these on the soil survey maps. How do you solve this little dilemma?

If the foregoing examples haven’t convinced you of the importance of understanding the vocabulary of maps before you begin speaking GIS, perhaps this one will. You need to create a map of presettlement vegetation for your state or region. It turns out that three very well-known vegetation mappers have compiled such maps for portions of your area of interest. Taking a trip to the library to obtain these maps, you discover that the first shows vegetation classified by its structural components (herbaceous, grasses, trees, shrubs, etc.), and the second map, which intersects with the first map, shows vegetation classed by floristics (based on species). You also note, to your annoyance, that the two systems seem to have only limited map areas that correspond. Hoping for help from the third map, you discover that although it is classed on the basis of a combination of floristics and structure, its area does not overlap either of the other two maps; in fact, it is well separated from them.

Classification problems of the type just described are common and require the student of GIS to become more than a student of the terminology. Before you can master the technology, you should first master its concepts. We will begin this first step in the journey in the next chapter, where we will look closely at the nature of geographic data and the methods by which they can be represented on map documents. This first step will give you a better appreciation of the fundamental building blocks of GIS and will ensure a more cautious approach when you begin implementing geographic analysis and cartographic modeling.
Terms

attributes  
Canada Geographic Information System  
computer-aided drafting (CAD)  
computer-assisted cartography (CAC)  
digitizer  
global positioning system (GPS)  
mental map  
Morton Matrix  
retrieval monitor  
spatial tiling  
topology

Review Questions

1. What was the initial impetus for the development of the first GIS?
2. Provide a description of the change in geographic thought from pure exploration through to prediction and planning. Describe the place of GIS in this context.
3. What is a GIS? Why is the software-only definition of GIS incomplete? What other components make up a GIS?
4. What are the six basic types of analytical techniques generally found in a geographic information system? Can you think of some examples of each?
5. What is the difference between GIS and CAC? Between GIS and CAD?
6. What are some of the technical difficulties encountered by Roger Tomlinson’s team in the early development of GIS?
7. What is the Morton Matrix? Topology? Retrieval monitor? What role did each of these play in the early development of GIS?
8. Who would normally use a GIS? What accounts for its popularity?

References
