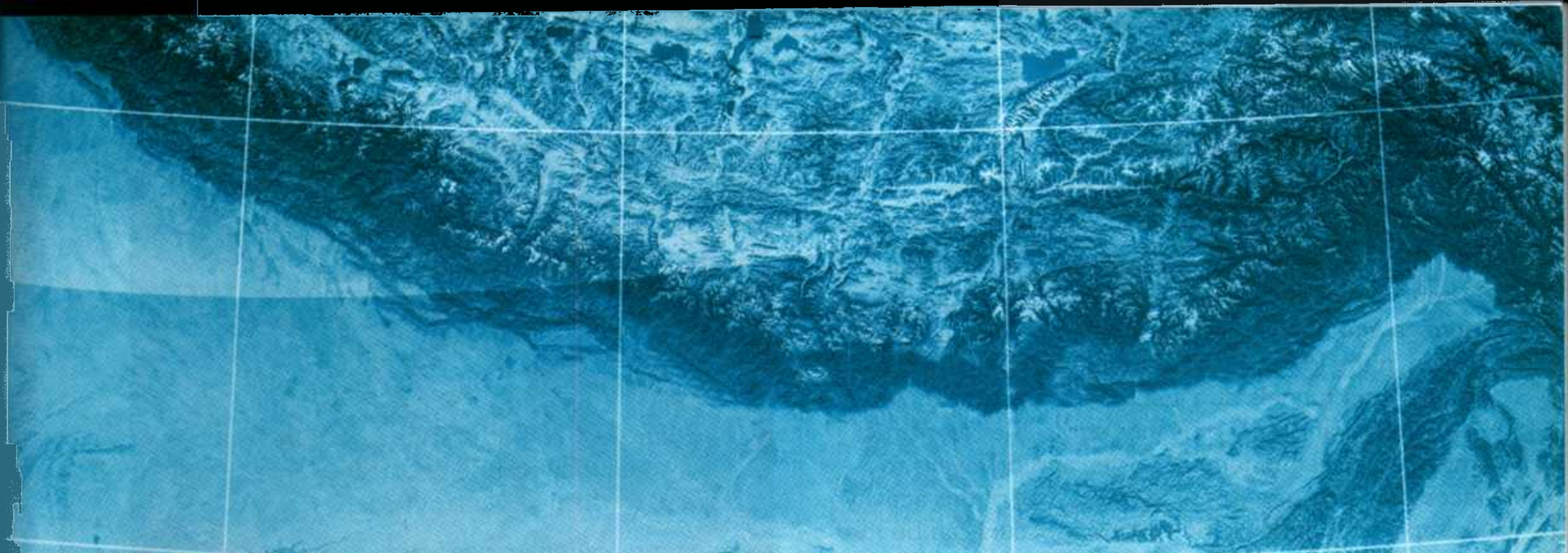


1 Systems, Science, and Study

This chapter introduces the conceptual framework for the book by addressing several major questions:

- What exactly is geographic information, and why is it important? What is special about it?
- What is information generally, and how does it relate to data, knowledge, evidence, wisdom, and understanding?
- What kinds of decisions make use of geographic information?
- What is a geographic information system (GIS), and how would I know one if I saw one?
- What is geographic information science, and how does it relate to the use of GIS for scientific purposes?
- How do scientists use GIS, and why do they find it helpful?
- How do companies make money from GIS?

LEARNING OBJECTIVES

After studying this chapter you will:

- Know definitions of the terms used throughout the book, including GIS itself.
- Be familiar with a brief history of GIS.
- Recognize the sometimes invisible roles of GIS in everyday life and the roles of GIS in business.
- Understand the significance of geographic information science and how it relates to geographic information systems.
- Understand the many impacts GIS is having on society and the need to study those impacts.

1.1 Introduction: Why Does GIS Matter?

Almost everything that happens, happens somewhere. We humans confine our activities largely to the surface and near surface of the Earth. We travel over it and in the lower levels of the atmosphere, and we go through tunnels dug just below the surface. We dig ditches and bury pipelines and cables, construct mines to get at mineral deposits, and drill wells to access oil and gas. Keeping track of all of this activity is important, and knowing where it occurs can be the most convenient basis for tracking. Knowing where something happens is of critical importance if we want to go there ourselves or send someone there, to find other information about the same place, or to inform people who live nearby. In addition, decisions have geographical consequences. For example, adopting a particular funding formula creates geographical winners and losers, most obviously when the outcome is a "zero-sum game." Therefore geographic location is an important attribute of activities, policies, strategies, and plans. Geographic information systems (GIS) are a special class of information systems that keep track not only of events, activities, and things, but also of where these events, activities, and things happen or exist.

Almost everything that happens, happens somewhere. Knowing where something happens can be critically important.

Because location is so important, it is an issue in many of the problems society must solve. Some of these problems are so routine that we almost fail to notice them—the daily question of which route to take to and from work, for example. Others are quite extraordinary occurrences and require rapid, concerted, and coordinated responses by a wide range of individuals and organizations—such as the events of August 29, 2005 in New Orleans (Box 1.1). Problems that involve an aspect of location, either in the information used to solve them or in the solutions themselves, are termed geographic problems. Here are some more examples:

- Health care managers solve geographic problems (and may create others) when they decide where to locate new clinics and hospitals.
- Delivery companies solve geographic problems when they decide the routes and schedules of their vehicles, often on a daily basis.
- Transportation authorities solve geographic problems when they select routes for new highways.
- Geodemographics consultants solve geographic problems when they assess the performance of retail outlets and recommend where to expand or rationalize store networks.
- Forestry companies solve geographic problems when they determine how best to manage forests, where to cut, where to locate roads, and where to plant new trees.
- National park authorities solve geographic problems when they schedule recreational path maintenance and improvement (Figure 1.1).
- Governments solve geographic problems when they decide how to allocate funds for building sea defenses.
- Travelers and tourists solve geographic problems when they give and receive driving directions, select hotels in unfamiliar cities, and find their way around theme parks (Figure 1.2).
- Farmers solve geographic problems when they employ new information technology to make better decisions about the amounts of fertilizer and pesticide to apply to different parts of their fields.

Figure 1.1 Maintaining and improving footpaths in national parks is a geographic problem.

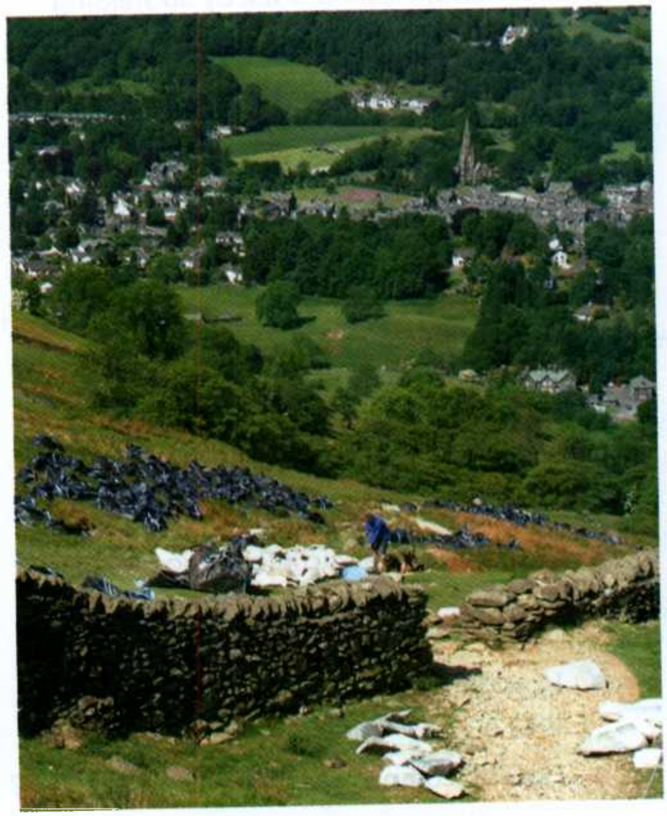


Figure 1.2 Navigating tourist destinations is a geographic problem.

If so many problems are geographic, what distinguishes them from each other? Here are three bases for classifying geographic problems. First, there is the question of **scale**, or level of geographic detail. The architectural design of a building can present geographic problems, as in the case of disaster management (Box 1.1), but only at a very detailed or local scale. The information needed to service the building is also local—the size and shape of the parcel, the vertical and subterranean extent of the buildings, the slope of the land, and its accessibility using normal and emergency infrastructure. At the other end of the scale range, the global diffusion of the 2003 severe acute respiratory syndrome (SARS) epidemic and of bird flu in 2004 were problems at a much broader and coarser scale, involving information about entire national populations and global transport patterns.

Scale or level of geographic detail is an essential property of any GIS project.

Second, geographic problems can be distinguished on the basis of intent, or **purpose**. Some problems are strictly practical in nature—they must often be solved as quickly as possible and/or at minimum cost, in order to achieve such practical objectives as saving money, avoiding fines by regulators, or coping with an emergency. Others are better characterized

Applications Box 1.1

Hurricane Katrina, August 29, 2005

Hurricane hazards come in many forms: storm surges, high winds, tornadoes, and flooding. This means it is important for households and communities to have plans of safety actions that anticipate these hazards. Hurricane Katrina (Figure 1.3) hit the City of New Orleans, Louisiana, with the full force of a Category 5 storm on August 29, 2005, having

Figure 1.3 (A) Hurricane Katrina as at August 28, 2005. (Courtesy NOAA/NESDIS: www.nnvl.noaa.gov)

Figure 1.3 (B) Its aftermath in New Orleans on August 29, 2005, showing the flooding of the I-10 Interstate Highway, directly caused by the breaching of the levees of the 17th Street Canal. (Image from Wikipedia: http://en.wikipedia.org/wiki/Image:KatrinaNewOrleansFlooded_edit2.jpg)

already cut a swath across the Deep South of the United States from Florida through Mississippi. Meteorologists were very successful in predicting its trajectory and strength, and much of the affected area had been evacuated prior to the storm's arrival. New Orleans was declared a federal emergency area on August 24. The physical damage caused by its passage and aftermath breached flood protection levees in more than 50 places, leading to flooding of 80% of the City of New Orleans (Figure 1.4). Hurricane Katrina caused an estimated $81 billion (2005 US dollars) of damage and 1836 lives were lost.

Dealing with the aftermath of this emergency posed a number of geographic problems. Many of the GIS maps that were used to deal with the situation were produced by volunteers, as well as official agencies. The initial demand for GIS maps was from first responders and emergency staff on the ground, who needed customized street maps for search and rescue. These included street maps showing the density of resident population, or the key urban features that were cited in emergency calls, or the latitude and longitude coordinates needed for helicopter rescues, or the last known locations of missing persons. Other "situational awareness" maps were required for use by incident commanders and other decision makers working at scales ranging from the county to the federal level. These identified sites that were key to power outage or restoration, the changing availability of cell phone bandwidth as towers came back online, the areas that had likely experienced (or would experience) flooding, road closures and access restrictions, availability of shelters and kitchens, locations of water and ice distribution points, and the locations of environmentally hazardous sites.

In these operational and tactical applications, GIS deployment ensured that the days and hours before and immediately after the impact of the storm were used productively. Yet, the government's relief efforts and the delayed response to the flooding of New Orleans came in for considerable subsequent criticism. In a more strategic sense, it has also been pointed out that Hurricane Katrina was an avoidable disaster, caused by funding cutbacks and failure to understand the design strength of the levees. Strategic intervention failed, but GIS was nevertheless of utmost importance in short-term disaster management and medium-term cleanup operations.

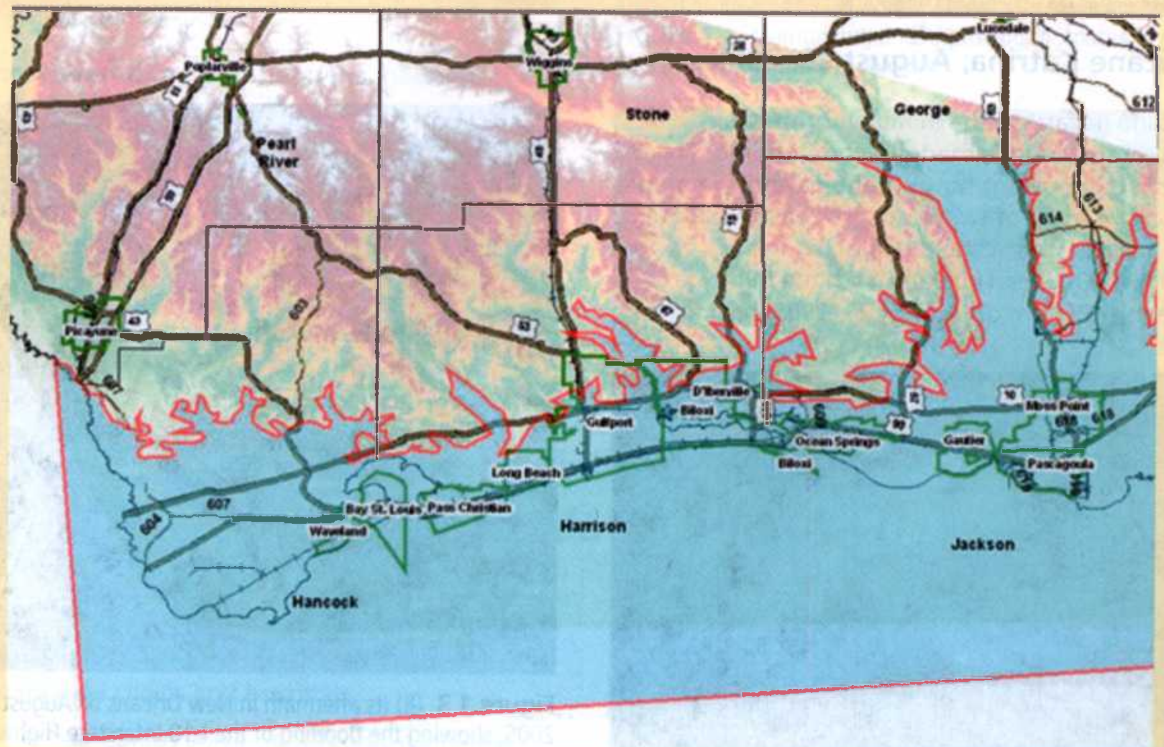


Figure 1.4 A prediction of the effects of a 32-foot storm surge with 20-foot wave action, as modeled using a GIS. The city boundary is shown in green, and the limit of the storm surge in red. (Source: ArcNews)

as driven by human curiosity. When geographic data are used to verify the theory of continental drift, or to map distributions of glacial deposits, or to analyze the historic movements of people in anthropological or archaeological research (Box 1.2 and Figure 1.5), there is no sense of an immediate problem that needs to be solved. Rather, the intent is the advancement of human understanding of the world, which we often recognize as the intent of science.

Although science and practical problem solving can be thought of as distinct human activities, it is often argued that there is no longer any effective distinction between their methods. The tools and methods used by a scientist in a government agency to ensure the protection of an endangered species are essentially the same as the tools used by an academic ecologist to advance our scientific knowledge of biological systems. Both use the most accurate measurement devices, employ terms whose meanings have been widely shared and agreed, insist that their results be replicable by others, and in general follow all of the principles of science that have evolved over the past centuries.

The use of GIS for both forms of activity reinforces the idea that science and practical problem solving are no longer distinct in their methods, as does the fact that GIS is used widely in all kinds of organizations, from academic institutions to government agencies and corporations. The use of similar

Figure 1.5 Store location principles are very important in developing markets across the world, as with Tesco's investment in Beijing, China. (© Lou-Foto/Alamy Limited)

tools and methods right across science and problem solving is part of a shift from the pursuit of curiosity within traditional academic disciplines to solution-centered, interdisciplinary team work.

In this book we distinguish between uses of GIS that focus on design, or so-called normative uses, and uses that advance science, or so-called positive uses (a rather confusing meaning of that term, unfortunately, but the one commonly used by philosophers of science—its use implies that science confirms theories by finding positive evidence in support of them, and rejects theories when negative evidence is found). Finding new locations for

Applications Box 1.2

Where Did Your Ancestors Come From?

As individuals, many of us are interested in *where* we came from—not just geographically, but possibly also in terms of social standing, or our inherited genes. Some of the best clues to our ancestry come from our (family) surnames, and Western surnames have different types of origins, many of which are explicitly or implicitly geographic in origin. (Such clues are less important in some Eastern societies where family histories are generally much better documented.) Research at University College London is using GIS and historic censuses and records to investigate the changing local and regional geographies of surnames within the UK since the late Nineteenth Century (Figure 1.6). Aggregating names into cultural, ethnic, or linguistic groups can tell us quite a lot about migration, about changes in local and regional economies, and even about measures of local economic health and vitality. Similar GIS-based analysis can be used to generalize about the intergenerational characteristics of international emigrants (for example, to North America, Australia, and New Zealand—see Figure 1.7), or the regional naming patterns of immigrants to the United States from the Indian subcontinent or China. This helps us understand our place in the world. Fundamentally, this is curiosity-driven research: it is interesting to us as individuals to understand more about our origins, and it is interesting to everyone with planning or policy concerns with any particular place to understand the social and cultural mix of people who live there. But it is not central to resolving any specific problem within a specific timescale.

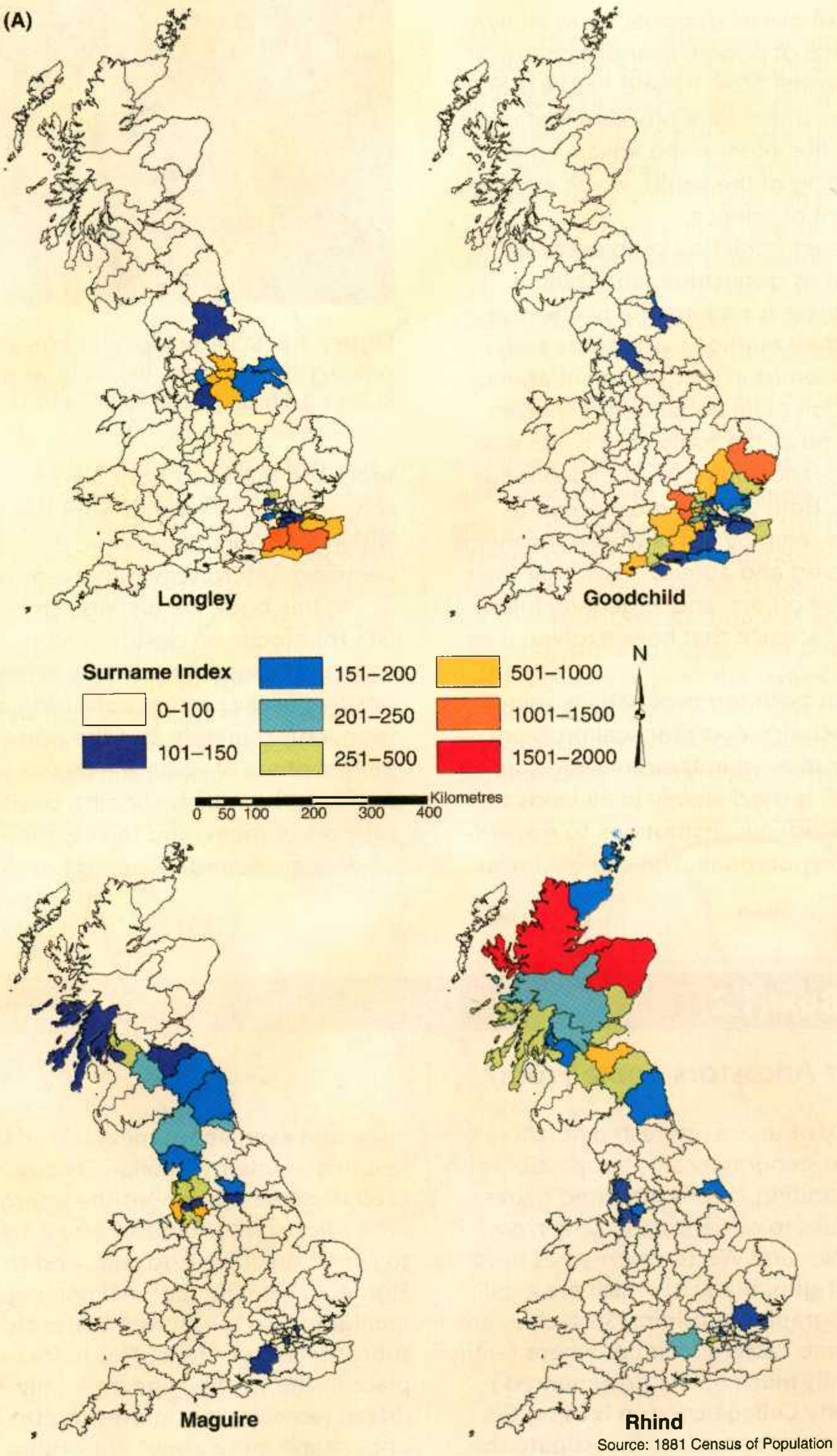


Figure 1.6 The UK geography of the Longleys, the Goodchilds, the Maguires, and the Rhinds in (A) 1881 and (B) 1998. (Reproduced with permission of Daryl Lloyd)

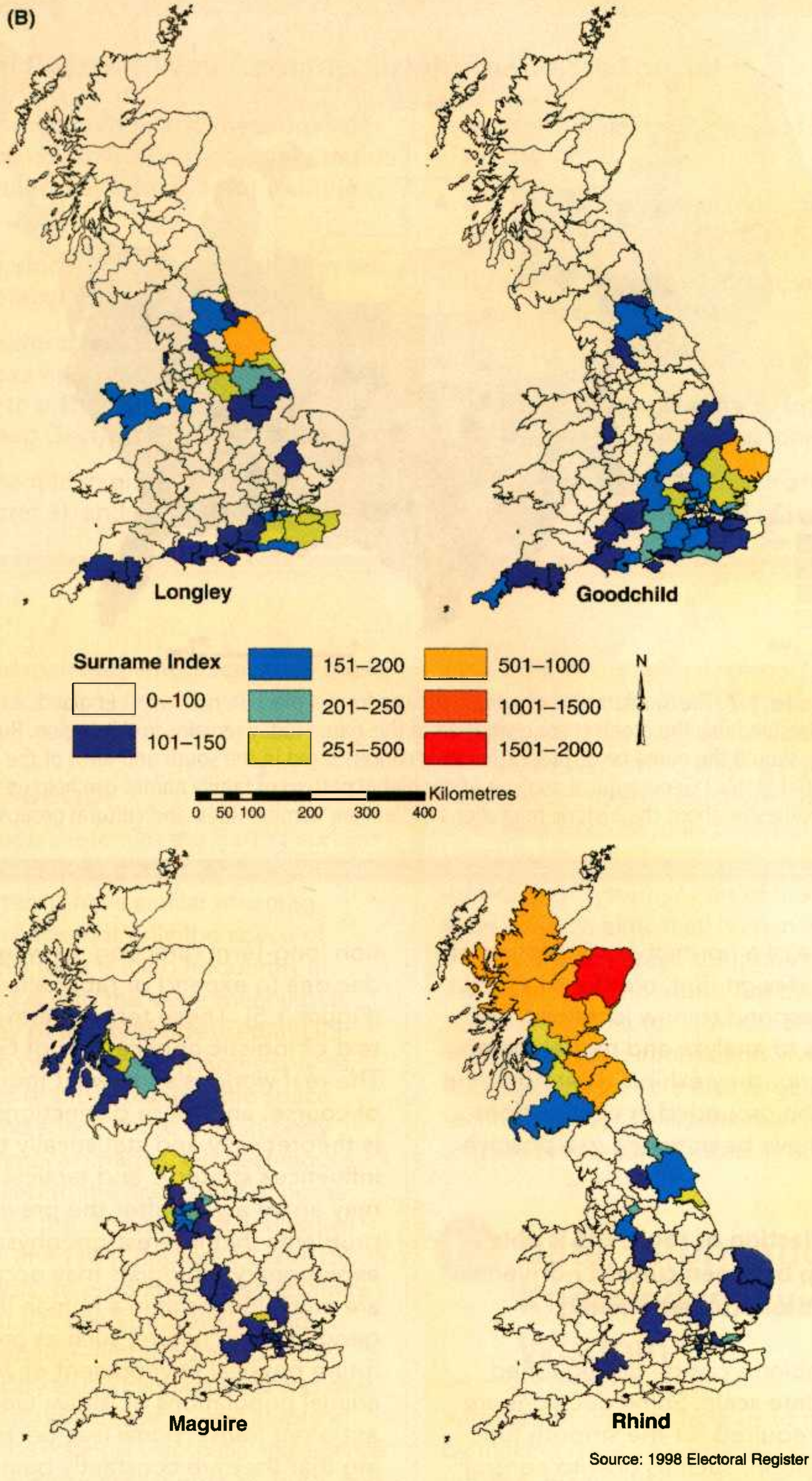


Figure 1.6 (*continued*)

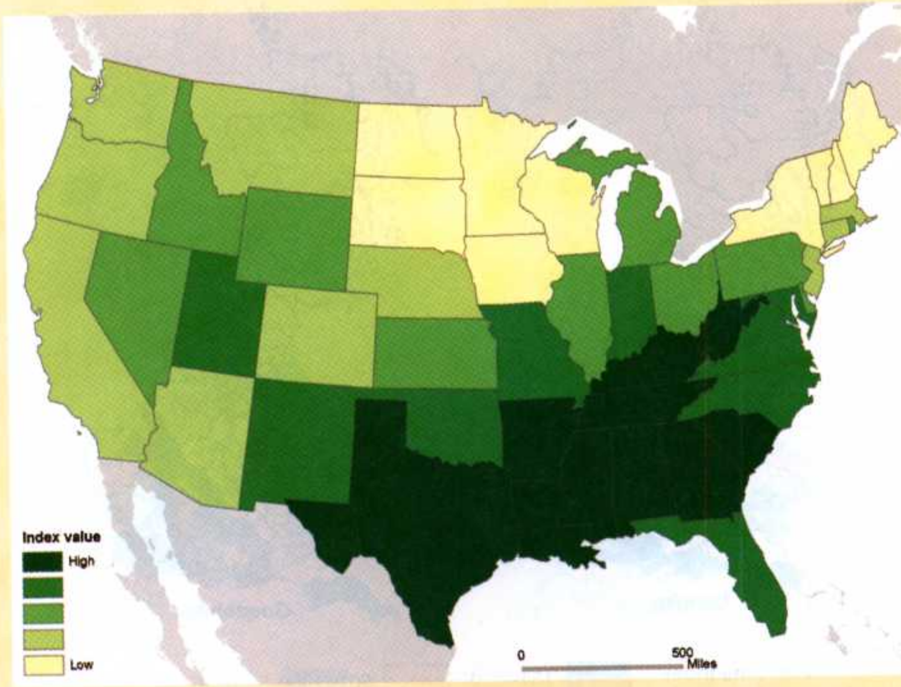


Figure 1.7 The Singleton family name derives from a place in northwest England, and understandably the greatest concentration of this name today remains in this region. But why should the name be disproportionately concentrated in the south and west of the United States? Geographical analysis of the global pattern of family names can help us to hypothesize about the historic migrations of families, communities, and cultural groups.

retailers is an example of a normative application of GIS, with its focus on design. But in order to predict how consumers will respond to new locations, it is necessary for retailers to analyze and model the actual patterns of behavior they exhibit. Therefore, the models they use will be grounded in observations of messy reality that have been tested in a positive manner.

With a single collection of tools, GIS is able to bridge the gap between curiosity-driven science and practical problem solving

Third, geographic problems can be distinguished on the basis of their **time scale**. Some decisions are operational and are required for the smooth functioning of an organization, such as how to control electricity inputs into grids that experience daily surges and troughs in usage (see Section 10.9). Others are tactical and concerned with medium-term decisions, such as where to cut trees in next year's forest harvesting plan. Still other decisions are strategic and are required to give an organization long-term direction, as when a retailer decides to expand or rationalize its store net-work (Figure 1.5). These terms are explored in the context of logistic applications of GIS in Section 2.3.4. The real world is somewhat more complex than this, of course, and these distinctions may blur—what is theoretically and statistically the 1000-year flood influences strategic and tactical considerations but may arrive a year after the previous one! Other problems that interest geophysicists, geologists, or evolutionary biologists may occur on timescales that are much longer than a human lifetime, but are still geographic in nature, such as predictions about the future physical environment of Japan or about the animal populations of Africa. Geographic databases are often *transactional* (see Section 10.9.1), meaning that they are constantly being updated as new information arrives, unlike paper maps, which stay the same once printed. Chapter 2 contains a more detailed discussion of the range and remit of GIS applications, and provides a view of how GIS pervades many aspects of our daily lives. Other applications are discussed to illustrate particular principles, techniques,

Technical Box 1.3

Some Technical Reasons Why Geographic Information Is Special

- Geographic information is multidimensional, because *two* coordinates must be specified to define a location, whether they be *x* and *y* or latitude and longitude.
- It is voluminous, since a geographic database can easily reach a terabyte in size (see Table 1.1).
- It may be represented at different levels of spatial resolution, for example, using a representation equivalent to a 1:1 million scale map and a 1:24,000 scale map (Section 3.7).
- It may be represented in different ways inside a computer (Chapter 3), and how this is done can strongly influence the ease of analysis and the end results.
- It must often be projected onto a flat surface, for reasons identified in Section 5.8.
- It requires many special methods for its analysis (see Chapters 14 and 15).
- It can be time-consuming to analyze.
- Although much geographic information is static, the process of updating is complex and expensive.
- Display of geographic information in the form of a map requires the retrieval of large amounts of data.

analytic methods, and management practices as these arise throughout the book.

1.1.1 Spatial Is Special

The adjective *geographic* refers to the Earth's surface and near surface, and defines the subject matter of this book, but other terms have similar meaning. *Spatial* refers to any space, not only the space of the Earth's surface; this term is used frequently in the book, almost always with the same meaning as *geographic*. But many of the methods used in GIS are also applicable to other nongeographic spaces, including the surfaces of other planets, the space of the cosmos, and the space of the human body that is captured by medical images. GIS techniques have even been applied to the analysis of genome sequences on DNA. So the discussion of analysis in this book is of *spatial* analysis (Chapters 14 and 15), not geographic analysis, to emphasize this versatility.

Another term that has been growing in usage in recent years is *geospatial*—implying a subset of spatial applied specifically to the Earth's surface and near surface. The former National Intelligence and Mapping Agency was renamed the National Geospatial-Intelligence Agency in late 2003 by President George W. Bush, and the Web portal for federal government data is called Geospatial One-Stop. In this book we have tended to avoid geospatial, preferring geographic, and we use spatial where we need to emphasize generality.

People who encounter GIS for the first time are sometimes driven to ask why geography is so important; why, they ask, is spatial special? After all, there is plenty of information around about geriatrics, for example, and in principle one could create a geriatric information system. So why has geographic information spawned an entire industry, if geriatric information has not done so to anything like the same extent? Why are there no courses in universities specifically in geriatric information systems? Part of the answer should be clear already: almost all human activities and decisions involve a geographic component, and the geographic component is important. Another reason will become apparent in Chapter 3, where we will see that working with geographic information involves complex and difficult choices that are also largely unique. Other, more technical reasons will become clear in later chapters and are briefly summarized in Box 1.3.

1.2 Data, Information, Knowledge, Evidence, Wisdom

Information systems help us to manage *what we know* by making it easy to organize and store, access and retrieve, manipulate and synthesize, and apply to the solution of problems. We use a variety of terms to describe what we know, including the five that head this section and that are shown in Table 1.2. There are no universally agreed-upon definitions of these terms, the first two of which are used frequently in the GIS arena. Nevertheless, it is worth trying to come to grips

Table 1.1 Potential GIS database volumes for some typical applications (volumes estimated to the nearest order of magnitude). Strictly, bytes are counted in powers of 2 – 1 kilobyte is 1024 bytes, not 1000.

1 megabyte	1 000 000	Single dataset in a small project database
1 gigabyte	1 000 000 000	Entire street network of a large city or small country
1 terabyte	1 000 000 000 000	Elevation of entire Earth surface recorded at 30 m intervals
1 petabyte	1 000 000 000 000 000	Satellite image of entire Earth surface at 1 m resolution
1 exabyte	1 000 000 000 000 000 000	A future 3-D representation of entire Earth at 10 m resolution?

with their various meanings because the differences between them can often be significant. What follows draws on many sources and thus provides the basis for using these terms throughout the book. Data clearly refer to the most mundane kinds of information, and wisdom to the most substantive. *Data* consist of numbers, text, or symbols that are in some sense neutral and almost context-free. Raw geographic facts (see Section 18.5.1.2), such as the temperature at a specific time and location, are examples of data. When data are transmitted, they are treated as a stream of bits; a crucial requirement is to preserve the integrity of the dataset. The internal meaning of the data is irrelevant in such considerations. Data (the plural of datum) are assembled together in a database (see Chapter 10), and the volumes of data that are required for some typical applications are shown in Table 1.1.

The term *information* can be used either narrowly or broadly. In a narrow sense, information can be treated as devoid of meaning, and therefore as essentially synonymous with data, as defined in the previous paragraph. Others define information as *anything* that can be digitized, that is, represented in digital form (see Chapter 3), but also argue that information is differentiated from data by implying some degree of selection, organization, and preparation for particular purposes—information is data serving some *purpose*, or data that have been given some degree of interpretation. Information is often costly to produce, but once digitized it is cheap to reproduce and distribute. Geographic datasets, for example, may be very expensive to collect and assemble, but very cheap to copy and disseminate. One other characteristic of information is that it is easy to add value to it through processing and through merger with other information. GIS provides an excellent example of the latter because of the tools it provides for combining information from different sources (see Section 18.5).

GIS does a better job of sharing data and information than knowledge, which is more difficult to detach from the knower.

Knowledge does not arise simply from having access to large amounts of information. It can be considered as information to which value has been added by interpretation based on a particular context, experience, and purpose. Put simply, the information available in a book or on the Internet or on a map becomes knowledge only when it has been read and understood. How the information is interpreted and used will be different for different readers depending on their previous experience, expertise, and needs. It is important to distinguish two types of knowledge: *codified*

Table 1.2 A ranking of the support infrastructure for decision making.

Decision-making support infrastructure	Ease of sharing with everyone	GIS example
Wisdom ↑	*Impossible*	Policies developed and accepted by stakeholders
Knowledge ↑	*Difficult, especially tacit knowledge*	Personal knowledge about places and issues
Evidence ↑	*Often not easy*	Results of GIS analysis of many datasets or scenarios
Information ↑	*Easy*	Contents of a database assembled from raw facts
Data	*Easy*	Raw geographic facts

and *tacit*. Knowledge is codifiable if it can be written down and transferred with relative ease to others. Tacit knowledge is often slow to acquire and much more difficult to transfer. Examples include the knowledge built up during an apprenticeship, understanding of how a particular market works, or familiarity with using a particular technology or language. This difference in transferability means that codified and tacit knowledge need to be managed and rewarded quite differently. Because of its nature, tacit knowledge is often a source of competitive advantage.

Some have argued that knowledge and information are fundamentally different in at least three important respects:

1. Knowledge entails a knower. Information exists independently, but knowledge is intimately related to people.
2. Knowledge is harder to detach from the knower than information; shipping, receiving, transferring it between people, or quantifying it are all much more difficult than for information.
3. Knowledge requires much more assimilation—we digest it rather than hold it. While we may hold conflicting information, we rarely hold conflicting knowledge.

Evidence is considered a halfway house between information and knowledge. It seems best to regard it as a multiplicity of information from different sources, related to specific problems, and with a consistency that has been validated. Major attempts have been made in medicine to extract evidence from a welter of sometimes contradictory sets of information, drawn from worldwide sources, in what is known as meta-analysis, or the comparative analysis of the results of many previous studies.

The definition of *wisdom* is even more elusive than that of the other terms. Normally, it is used in the context of decisions made or advice given which is disinterested, based on all the evidence and knowledge available, but given with some understanding of the likely consequences. Almost invariably, it is highly individualized rather than being easy to create and share within a group. Wisdom is in a sense the top level of a hierarchy of decision-making infrastructure.

1.3 Systems and Science

Geographic information systems are computer-based systems for storing and processing geographic information. They are tools that improve the efficiency and effectiveness of handling information about geographic objects and events. They can be used to carry out many useful tasks, including storing vast amounts of geographic information in databases, conducting analytical operations in a fraction of the time it would take to do it by hand, and automating the process of making useful maps. Geographic information systems also process information, but there are limits to the kinds of procedures and practices that can be automated when turning data into information. Moreover, it is more the realm of evidence, knowledge, and wisdom to assess whether this selectivity and preparation for purpose actually adds any value, or whether the results add insight to interpretation in geographic applications. Such issues are the realm of geographic information science. This rapidly developing field is concerned with the scientific context and underpinnings of geographic information systems. It provides a framework within which new evidence, knowledge, and ultimately wisdom about the Earth can be created, in ways that are efficient, effective, and safe to use.

1.3.1 The Science of Problem Solving

Like all sciences, an essential requirement of geographic information science is a method for discovering new knowledge. The GI scientific method must support:

- Transparency of assumptions and methods so that other GI scientists can determine how previous knowledge has been discovered and how they might add to the existing body of knowledge.
- Objectivity through a detached and independent perspective that avoids or accommodates bias (unintended or otherwise).
- The ability of any other qualified scientist to reproduce the results of an analysis.
- Methods of validation using the results of the analysis (internal validation) or other information sources (external validation).

How then are problems solved using a scientific method, and are geographic problems solved in ways different from other kinds of problems? We humans have accumulated a vast storehouse about the world, including information both on how it *looks*, or its *forms*, and how it *works*, or its dynamic *processes*. Some of those processes are natural and built into the design of the planet, such as the processes of tectonic movement that lead to earthquakes and the processes of atmospheric circulation that lead to hurricanes. Others are human in origin, reflecting the increasing

Figure 1.8 Social processes, such as carbon dioxide emissions, modify the Earth's environment. (Digital Vision)

influence that we have on our natural environment, through the burning of fossil fuels, the felling of forests, and the cultivation of crops (Figure 1.8). Others are imposed by us, in the form of laws, regulations, and practices. For example, zoning regulations affect the ways in which specific parcels of land can be used.

Knowledge about how the world works is more valuable than knowledge about how it looks because it can be used to predict.

These two types of information differ markedly in their degree of generality. Form varies geographically, and the Earth's surface looks dramatically different in different places; compare the settled landscape of northern England with the deserts of the U.S. Southwest (Figure 1.9). But processes can be very general. The ways in which the burning of fossil fuels affects the atmosphere are essentially the same in China as in Europe, although the two landscapes look very different. Science has always valued such general knowledge over knowledge of the specific, and hence has valued process knowledge over knowledge of form. Geographers in particular have witnessed a long-standing debate, lasting centuries, between the competing needs of *idiographic* geography, which focuses on the description of form and emphasizes the unique characteristics of places, and *nomothetic* geography, which seeks to discover general processes. Both are essential, of course, since knowledge of general process is useful in solving specific problems only if it can be combined effectively with knowledge of form. For example, we can only assess the risk of roadside landslip in New South Wales if we know both how slope stability is generally impacted by such factors as shallow subsurface characteristics and porosity, and where slopes at risk are located (Figure 1.10).

One of the most important merits of GIS as a problem-solving tool lies in its ability to combine the general with the specific, as in this example from New South Wales. A GIS designed to solve this problem would contain knowledge of New South Wales' slopes, in the form of computerized maps, and the programs executed by the GIS would reflect general knowledge of how slopes affect the probability of mass movement under extreme weather conditions. The *software* of a GIS captures and implements general knowledge, while the *database* of a GIS represents specific information. In that sense, a GIS resolves the old debate between nomothetic and idiographic camps by accommodating both.

GIS solves the ancient problem of combining general scientific knowledge with specific information and gives practical value to both.

General knowledge comes in many forms. Classification is perhaps the simplest and most rudimentary,

Figure 1.9 The form of the Earth's surface shows enormous variability, for example, between the deserts of the southwest United States and the settled landscape of northern England. (A: Courtesy ImageState)

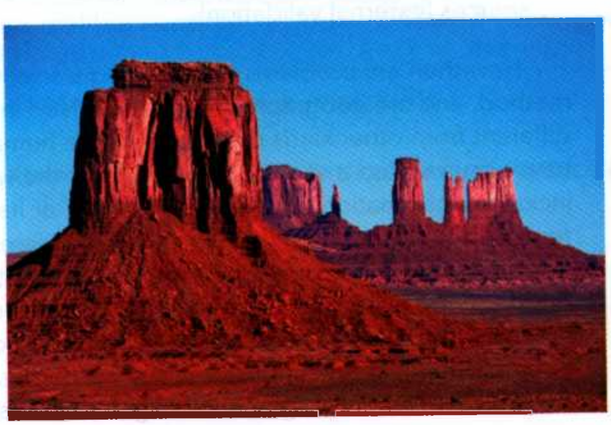


Figure 1.10 Predicting landslides requires general knowledge of processes and specific knowledge of the area—both are available in a GIS. (© Chris Selby/AlamyLimited)

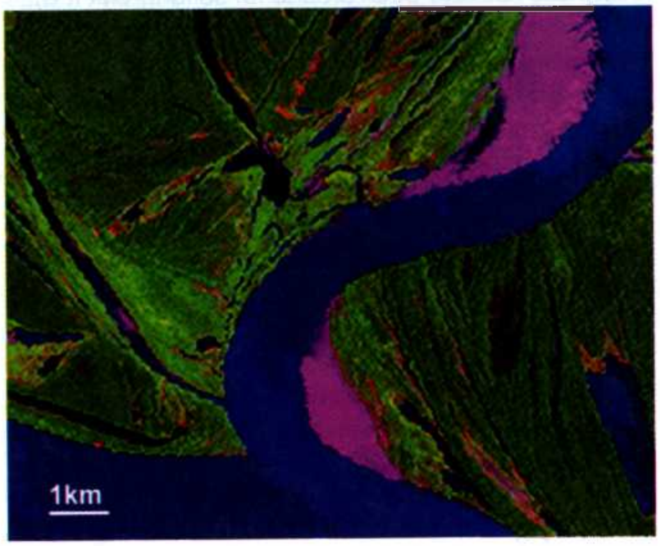
and is widely used in geographic problem solving. In many parts of the United States and other countries, efforts have been made to limit the development of wetlands in the interest of preserving them as natural habitats and avoiding excessive impact on water resources. To support these efforts, resources have been invested in mapping wetlands, largely from aerial photography and satellite imagery. These maps simply classify land, using established rules that define what is and what is not a wetland (Figure 1.11).

More sophisticated forms of knowledge include *rule sets*—for example, rules that determine what use can be made of wetlands, or what areas in a forest can be legally logged. The U.S. Forest Service has rules to define wilderness and to impose associated regulations regarding the use of wilderness, including prohibition on logging and road construction.

Much of the knowledge gathered by the activities of scientists suggests the term *law*. The work of Sir Isaac Newton established the Laws of Motion, according to which all matter behaves in ways that can be perfectly predicted. From Newton's laws we are able to predict the motions of the planets almost perfectly, although Einstein later showed that certain observed deviations from the predictions of the laws could be explained with his Theory of Relativity. Laws of this level of predictive quality are few and far between in the geographic world of the Earth's surface. The real world is the only geographic-scale laboratory that is available for most GIS applications, and considerable uncertainty is generated when we are unable to control for all conditions. These problems are compounded in the socioeconomic realm, where the role of human agency makes it almost inevitable that any attempt to develop rigid laws will be frustrated by isolated exceptions. Thus, while market researchers use spatial interaction models, in conjunction with GIS, to predict how many people will shop at each shopping center in a city, substantial errors will occur in the predictions. Nevertheless, the results are of great value in developing location strategies for retailing. The Universal Soil Loss Equation, used by soil scientists in conjunction with GIS to predict soil erosion, is similar in its rather low predictive power, but again the results are sufficiently accurate to be very useful in the right circumstances.

Solving problems involves several distinct components and stages. First, there must be an *objective*, or a goal that the problem solver wishes to achieve. Often this is a desire to maximize or minimize—find the solution of least cost, or shortest distance, or least time, or greatest profit; or make the most accurate prediction possible. These objectives are all expressed

Figure 1.11 A wetland map of part of the Amazon region of Brazil. The map has been made by classifying Landsat imagery at 30 meter resolution. (Courtesy National Institute for Space Research (INPE), Brazil)



intangible form; that is, they can be measured on some well-defined scale. Others are said to be *intangible* and involve objectives that are much harder, if not impossible, to measure. They include maximizing *quality of life* and *satisfaction* and minimizing *environmental impact*. Sometimes the only way to work with such intangible objectives is to involve human subjects, through surveys or focus groups, by asking them to express a preference among alternatives. A large body of knowledge has been acquired about such human-subjects research, and much of it has been employed in connection with GIS. For discussion of the use of such mixed objectives see Section 16.4. This topic is taken up again in Chapter 17 in the context of estimating the return on investment of GIS.

Often a problem will have *multiple objectives*. For example, a company providing a mobile snack service to construction sites will want to maximize the number of sites that can be visited during a daily operating schedule, and will also want to maximize the expected returns by visiting the most lucrative sites. An agency charged with locating a corridor for a new power transmission line may decide to minimize cost, while at the same time seeking to minimize environmental impact. Such problems employ methods known as *multicriteria decision making* (MCDM).

Many geographic problems involve multiple goals and objectives, which often cannot be expressed in commensurate terms.

1.3.2 The Technology of Problem Solving

The previous sections have presented GIS as a technology to support both science and problem solving, using both specific and general knowledge about geographic reality. GIS has now been around for so long that it is, in many senses, a background technology, like word processing. Yet in other important respects, GIS is more than a technology, and continues to attract attention as a focus for scientific journals and conferences.

Many definitions of GIS have been suggested over the years, and none of them is entirely satisfactory. Today, the label GIS is attached to many things, including a collection of software tools (sometimes bought from a vendor) to carry out certain well-defined functions (*GIS software*); digital representations of various aspects of the geographic world, in the form of datasets (*GIS data*); a community of people who use and perhaps advocate the use of these tools for various purposes (the *GIS community*); and the activity of using a GIS to solve problems or advance science (*doing GIS*). The basic label works in all of these ways, and its meaning surely depends on the context in which it is used.

Table 1.3 Definitions of a GIS, and the groups who find them useful.

A container of maps in digital form	The general public
A computerized tool for solving geographic problems	Decision makers, community groups, planners
A spatial decision support system	Management scientists, operations researchers
A mechanized inventory of geographically distributed features and facilities	Utility managers, transportation officials, resource managers
A tool for revealing what is otherwise invisible in geographic information	Scientists, investigators
A tool for performing operations on geographic data that are too tedious or expensive or inaccurate if performed by hand	Resource managers, planners

Certain definitions of GIS (and the audiences for which they may be helpful) are summarized in Table 1.3. As we describe in Chapter 3, GIS is much more than *a container of maps in digital form*. This description can be misleading, but it may nonetheless be helpful to give to someone looking for a simple explanation—a guest at a cocktail party, a relative, or a seat neighbor on an airline flight. We all know and appreciate the value of maps, and the notion that maps could be processed by a computer is directly analogous to the use of word processing or spreadsheets to handle other types of information. A GIS is also *a computerized tool for solving geographic problems*. This definition speaks to the purposes of GIS rather than to its functions or physical form—an idea that is expressed in another definition, *a spatial decision support system*. A GIS is *a mechanized inventory of geographically distributed features and facilities*. This definition explains the value of GIS to the utility industry, where it is used to keep track of such entities as underground pipes, transformers, transmission lines, poles, and customer accounts. A GIS is *a tool for revealing what is otherwise invisible in geographic information*. This interesting definition emphasizes the power of a GIS, as an analysis engine, to examine data and reveal its patterns, relationships, and anomalies—things that might not be apparent to someone looking at a map. A GIS is *a tool for performing operations on geographic data that are too tedious or expensive or inaccurate if performed by hand*. This definition speaks to the problems associated with manual analysis of maps, particularly the extraction of simple measures, of area for example.

Everyone has a favorite definition of a GIS, and there are many to choose from.

1.4 A Brief History of GIS

As might be expected, some controversy surrounds the history of GIS since parallel developments occurred in North America, Europe, and Australia (at least). Much of the published history focuses on the U.S. contributions. We therefore do not yet have a well-rounded history of our subject. What is clear, however, is that the extraction of simple geographic measures largely drove the development of the first real GIS, the Canada Geographic Information System, or CGIS, in the mid-1960s (see Section 17.3). The Canada Land Inventory was a massive effort by the federal and provincial governments to identify the nation's land resources and their existing and potential uses. The most useful results of such an inventory are measures of area, yet area is notoriously difficult to measure accurately from a map (see Section 15.1.1). CGIS was planned and developed as a measuring tool, a producer of tabular information, rather than as a mapping tool.

The first GIS was the Canada Geographic Information System, designed in the mid-1960s as a computerized map-measuring system.

A second burst of innovation occurred in the late 1960s in the U.S. Bureau of the Census, in planning the tools needed to conduct the 1970 Census of Population. The DIME program (Dual Independent Map Encoding) created digital records of all U.S. streets in order to support automatic referencing and aggregation of census records. The similarity of this technology to that of CGIS was recognized immediately and led to a major program at Harvard University's Laboratory for Computer Graphics and Spatial Analysis to develop a general-purpose GIS that could handle the needs of both applications. This project eventually led to the ODYSSEY GIS software of the late 1970s.

Early GIS developers recognized that the same basic needs were present in many different application areas, from resource management to the census.

In a largely separate development during the latter half of the 1960s, cartographers and mapping agencies had begun to ask whether computers might be adapted to their needs, possibly reducing costs and shortening the time of map creation. The UK Experimental Cartography Unit (ECU) pioneered high-quality computer mapping in 1968; it published the world's first computer-made map in a regular series in 1973 with the British Geological Survey (Figure 1.12). The ECU also pioneered GIS work in education, post- and ZIP codes as geographic references, visual perception of maps, and much else. National mapping agencies, such as Britain's Ordnance Survey, France's Institut Géographique National, and the U.S. Geological Survey and the Defense Mapping Agency (now the National Geospatial-Intelligence Agency) began to investigate the use of computers to support the editing of maps that would avoid the expensive and slow process of hand correction and redrafting. The first automated cartography developments occurred in the 1960s, and by the late 1970s most major cartographic agencies were already computerized to some degree. But the magnitude of the task ensured that it would not be until 1995 that the first country (Britain) achieved complete digital map coverage in a database.

Remote sensing also played a part in the development of GIS, as a source of technology as well as a source of data. The first military satellites of the 1950s were developed and deployed in great secrecy to gather intelligence, but the declassification of much of this material in recent years has provided interesting insights into the role played by the military and intelligence communities in the development of GIS. Although the early spy satellites used conventional film cameras to record images, digital remote sensing began to replace them in the 1960s, and by the early 1970s civilian remote-sensing systems such as Landsat were beginning to provide vast new data resources on the appearance of the planet's surface from space, as well as to exploit the technologies of image classification and pattern recognition that had been developed earlier for military applications. The military was also responsible for the development in the 1950s of the world's first uniform system of measuring location, driven by the need for accurate targeting of intercontinental ballistic missiles. This development led directly to the methods of positional control in use today. Military needs were also responsible for the initial development of the Global Positioning System (GPS; see Section 5.9).

Many technical developments in GIS originated during the Cold War.

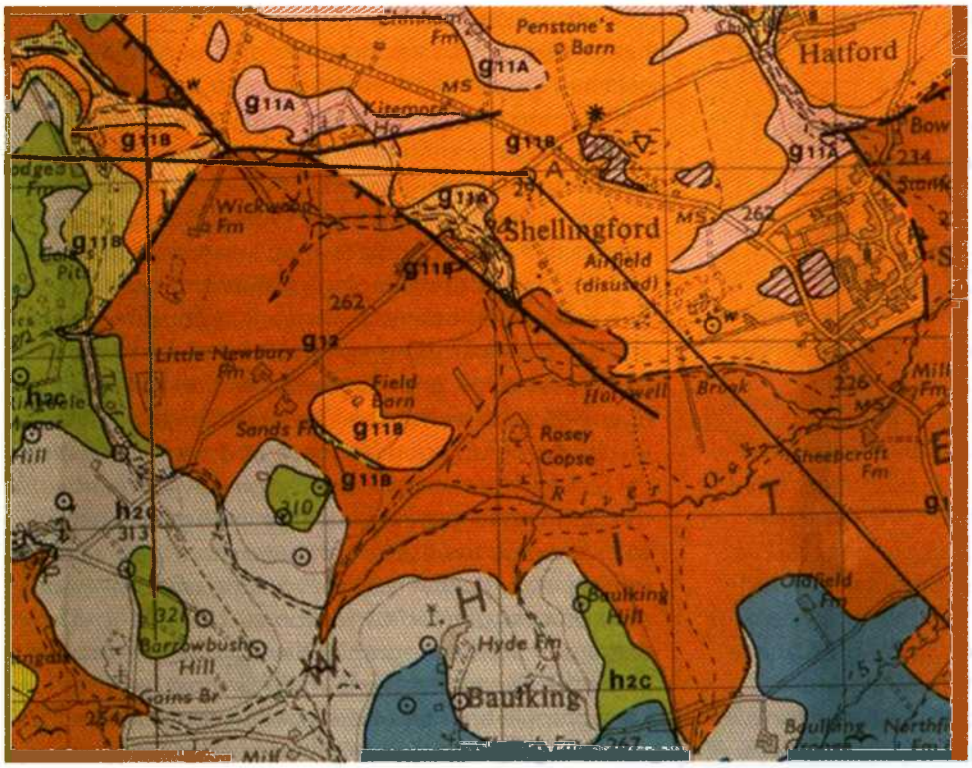


Figure 1.12 Section of the 1:63,360 scale geological map of Abingdon—the first known example of a map produced by automated means and published in a standard map series to established cartographic standards. (Reproduced by permission of the British Geological Survey and Ordnance Survey © NERC. All rights reserved. IPR/59-13C)

GIS really began to take off in the early 1980s, when the price of computing hardware had fallen to a level that could sustain a significant software industry and cost-effective applications. Among the first customers were forestry companies and natural resource agencies, driven by the need to keep track of vast timber resources and to regulate their use effectively. At the time a modest computing system—far less powerful than today's personal computer—could be obtained for about $250,000, and the associated software for about $100,000. Even at these prices the benefits of consistent management using GIS, and the decisions that could be made with these new tools, substantially exceeded the costs. The market for GIS software continued to grow, computers continued to fall in price and increase in power, and the GIS software industry has been growing ever since.

The modern history of GIS dates from the early 1980s, when the price of sufficiently powerful computers fell below a critical threshold.

As indicated earlier, the history of GIS is a complex story, much more complex than can be described in this brief history, but Table 1.4 summarizes some of the major events.

1.5 Views of GIS

As the previous discussion shows, GIS is a complex beast, with many distinct appearances. To some it is a way to automate the production of maps, whereas to others this application seems far too mundane compared to the complexities associated with solving geographic problems and supporting spatial decisions, and with the power of a GIS as an engine for analyzing data and revealing new insights. Others see a GIS as a tool for maintaining complex inventories, one that adds geographic perspectives to existing information systems and allows the geographically distributed resources of a forestry or utility company to be tracked and managed. The sum of all of these perspectives is clearly too much for any one software package to handle. As a result, GIS has grown from its initial commercial beginnings as a simple off-the-shelf package to a complex of software, hardware, people, institutions, networks, and activities, all of which can be very confusing to the novice. Thus, for example, the major software vendor ESRI, Inc. (Redlands, California) today sells a family of products under the ArcGIS brand name in order to service the disparate needs of its diverse user-base: ArcInfo is the high-end full-feature desktop system; ArcView is a

Table 1.4 Major events that shaped GIS.

Date	Type	Event	Notes
		The Era of Innovation	
1957	Application	First known automated mapping produced	Swedish meteorologists and British biologists
1963	Technology	CGIS development initiated	Canada Geographic Information System is developed by Roger Tomlinson and colleagues for Canadian Land Inventory. This project pioneers much technology and introduces the term GIS.
1963	General	URISA established	The Urban and Regional Information Systems Association founded in the US. Soon becomes point of interchange for GIS innovators.
1964	Academic	Harvard Lab established	The Harvard Laboratory for Computer Graphics and Spatial Analysis is established under the direction of Howard Fisher at Harvard University. In 1966 SYMAP, the first raster GIS, is created by Harvard researchers.
1967	Technology	DIME developed	The US Bureau of Census develops DIME-GBF (Dual Independent Map Encoding—Geographic Database Files), a data structure and street-address database for 1970 census.
1967	Academic and general	UK Experimental Cartography Unit (ECU) formed	Pioneer organization in a range of computer cartography and GIS areas.
1969	Commerical	ESRI Inc. formed	Jack Dangermond, a student from the Harvard Lab, and his wife Laura form ESRI to undertake projects in GIS.
1969	Commercial	Intergraph Corp. formed	Jim Meadlock and four others that worked on guidance systems for Saturn rockets form M&S Computing, later renamed Intergraph.
1969	Academic	'Design With Nature' published	Ian McHarg's book is the first to describe many of the concepts in modern GIS analysis, including the map overlay process (see Section 14.2.4).
1969	Academic	First technical GIS textbook	Nordbeck and Rystedt's book details algorithms and software developed for spatial analysis.
1972	Technology	Landsat 1 launched	Originally named ERTS (Earth Resources Technology Satellite), this is the first of many major Earth remote sensing satellites.
1973	General	First digitizing production line	Set up by Ordnance Survey, Britain's national mapping agency.
1974	Academic	AutoCarto 1 Conference	Held in Reston, Virginia, this is the first in an important series of conferences that set the GIS research agenda.
1976	Academic	GIMMS now in worldwide use	Written by Tom Waugh (a Scottish academic), this vector-based mapping and analysis system is run at 300 sites worldwide.
1977	Academic	Topological Data Structures	Harvard Lab organizes a major conference and develops the ODYSSEY GIS.
		The Era of Commercialization	
1981	Commercial	ArcInfo launched	ArcInfo is the first major commerical GIS software system. Designed for minicomputers and based on the vector and relational database data model, it sets a new standard for the industry.

(continued overleaf)

Table 1.4 *(continued)*

Date	Type	Event	Notes
1984	Academic	'Basic Readings in Geographic Information Systems' published	This collection of papers published in book form by Duane Marble, Hugh Calkins, and Donna Peuquet is the first accessible source of information about GIS.
1985	Technology	GPS operational	The Global Postitioning System gradually becomes a major source of data for navigation, surveying, and mapping.
1986	Academic	'Principles of Geographical Infomation Systems for Land Resources Assessment' published	Peter Burrough's book is the first specifically on GIS principles. It quickly becomes a worldwide reference text for GIS students.
1986	Commercial	MapInfo Corp. formed	MapInfo software develops into first major desktop GIS product. It defines a new standard for GIS products, complementing earlier software systems.
1987	Academic	*International Journal of Geographical Information Systems,* now *IJGI Science,* launched	Terry Coppock and others publish the first journal on GIS. The first issue contains papers from the USA, Canada, Germany, and UK.
1987	General	Chorley Report	'Handling Geographical Information' is an influential report from the UK government that highlights the value of GIS.
1988	General	*GISWorld* begins	*GISWorld,* now *GeoWorld,* the first worldwide magazine devoted to GIS, is published in the USA.
1988	Technology	TIGER announced	TIGER (Topologically Integrated Geographic Encoding and Referencing), a follow-on from DIME, is described by the US Census Bureau. Low-cost TIGER data stimulate rapid growth in US business GIS.
1988	Academic	US and UK Research Centers announced	Two separate initiatives, the US NCGIA (National Center for Geographic Information and Analysis) and the UK RRL (Regional Research Laboratory) Initiative show the rapidly growing interest in GIS in academia.
1991	Academic	*Big Book 1* published	Substantial two-volume compendium *Geographical Information Systems: principles and applications,* edited by David Maguire, Mike Goodchild, and David Rhind documents progress to date.
1992	Technical	DCW released	The 1.7 GB Digital Chart of the World, sponsored by the US Defense Mapping Agency, (now NGA), is the first integrated 1:1 million scale database offering global coverage.
1994	General	Executive Order signed by President Clinton	Executive Order 12906 leads to creation of US National Spatial Data Infrastructure (NSDI), clearinghouses, and the Federal Geographic Data Committee (FGDC).
1994	General	OpenGIS Consortium® born (now Open Geospatial Consortium®)	The OpenGIS® Consortium of GIS vendors, government agencies, and users is formed to improve interoperability.
1995	General	First complete national mapping coverage	Great Britain's Ordnance Survey completes creation of its initial database—all 230,000 maps covering country at largest scale (1:1,250, 1:2,500 and 1:10,000) encoded.

Table 1.4 *(continued)*

Date	Type	Event	Notes
1996	Technology	Internet GIS products introduced	Several companies, notably Autodesk, ESRI, Intergraph, and MapInfo, release new generation of Internet-based products at about the same time.
1996	Commercial	MapQuest	Internet mapping service launched, producing over 130 million maps in 1999. Is subsequently purchased by AOL for $1.1 billion.
1999	General	GIS Day	First GIS Day attracts over 1.2 million global participants who share an interest in GIS.
		The Era of Exploitation	
1999	Commercial	IKONOS	A new generation of very high resolution satellite sensors: IKONOS claims 90 cm ground resolution; Quickbird (launched 2001) claims 62 cm resolution.
2000	Commercial	GIS passes $7 bn	Industry analyst Daratech reports GIS hardware, software, and services industry at $6.9 bn, growing at more than 10% per annum.
2000	General	GIS has 1 million users	GIS has more than 1 million core users, and there are perhaps 5 million casual users of GI.
2002	General	Launch of online National Atlas of the United States	Online summary of US national-scale geographic information with facilities for map making (www.nationalatlas.gov)
2003	General	Launch of online national statistics for the UK	Exemplar of new government Web sites describing economy, population, and society at local and regional scales (www.statistics.gov.uk)
2003	General	Launch of Geospatial One-Stop	A US Federal E-government initiative providing access to geospatial data and information (www.geodata.gov/gos)
2004	General	National Geospatial-Intelligence Agency (NGA) formed	Biggest GIS user in the world, National Imagery and Mapping Agency (NIMA), renamed NGA to signify emphasis on geo-intelligence
2006	Technology	Launch of Google Earth	First major virtual globe—a Web-based 3D GIS application. 150 million downloads in first 12 months.
2007	Commercial	Pitney Bowes, Inc. purchases MapInfo	Maker of mail-handling machines buys MapInfo Corp. for $408 million.
2007	Commercial	Navtech purchased by Nokia	Mobile phone company purchases street data provider for $8.1 billion.
2008	Commercial	TeleAtlas purchased by TomTom	Relatively new consumer GIS company purchases street data provider for $2.9 billion.

simpler system designed for viewing, analyzing, and mapping data; ArcGIS Engine is a set of software components that developers can embed in their applications; ArcGIS Mobile is a lightweight software system that can be deployed on hand-held, mobile devices; ArcGIS Server can support sophisticated data management and GIS-oriented Web sites; ArcExplorer is a free-access Web browser; and ArcGIS Online is an ESRI-hosted data and applications resource that can be accessed over the Web. Other vendors specialize in certain niche markets, such as the utility industry, or military and intelligence applications. GIS is a dynamic and evolving field, and its future is certain to be exciting, but speculations on where it might be headed are reserved for the final chapter.

Today a single GIS vendor offers many different products for distinct applications.

1.5.1 Anatomy of a GIS

1.5.1.1 The *Network*

Despite the complexity noted in the previous section, a GIS does have its well-defined component parts. Today, the most fundamental of these is probably the *network*, without which no rapid communication or sharing of digital information could occur, except between a small group of people crowded around a computer monitor. GIS today relies heavily on the Internet, and on its limited-access cousins, the *intranets* of corporations, agencies, and the military. The Internet was originally designed as a network for connecting computers, but it has grown to become society's mechanism of information exchange, handling everything from personal messages to massive shipments of data, and increasing numbers of business transactions.

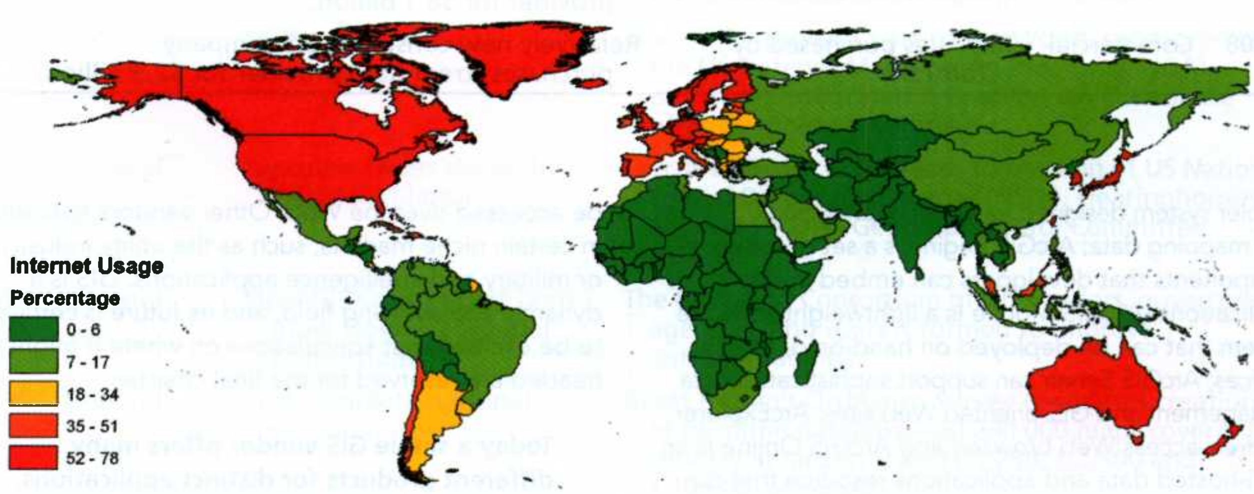
It is no secret that the Internet in its many forms has had a profound effect on technology, science, and society in the last 20 or so years. Who could have foreseen in 1990 the impact that the Web, e-commerce, digital government, mobile systems, and information and communication technologies would have on our everyday lives (see Chapter 18)? These technologies have radically changed forever the way we conduct business, how we communicate with our colleagues and friends, the nature of education, and the value and transitory nature of information.

The Internet began life as a U.S. Department of Defense communications project called ARPANET (Advanced Research Projects Agency Network) in 1972. In 1980 Tim Berners-Lee, a researcher at CERN, the European organization for nuclear research, developed the hypertext capability that underlies today's World Wide Web—a key application that has brought the Internet into the realm of everyday use. Uptake and use of Web technology have been remarkably quick, diffusion being considerably faster than almost all comparable innovations (for example, the radio, the telephone, and the television). By 2008, 1.4 billion people worldwide used the Internet, and the fastest growth rates were to be found in the Middle East, Africa, and Latin America (www.internetworldstats.com). However, the global penetration of the medium remained very uneven; for example, as of 2009 74% of North Americans used the medium, but only 5% of Africans (Figure 1.13).

The use of the WWW to give access to maps dates from 1993.

In the early years of the Internet, GIS turned out to be a compelling application that prompted many people to take advantage of the Web. At the same time, GIS benefited greatly from adopting the Internet paradigm and the momentum that the Web has generated. Many of the early Internet applications of GIS on the Internet remain in use, in updated form, today. They range from using GIS on the Internet to disseminate information, a type of electronic yellow pages (e.g., www.yell.com), to selling goods and services (e.g., www.nestoria.com; Figure 1.14), to direct revenue generation through subscription services (e.g., www.mapquest.com/solutions/), to helping members of the public to participate in important local, regional, and national debates. The Internet became very popular as a vehicle for delivering GIS applications for several reasons. It provides an established, widely used platform and accepted standard for interacting with information of many types. It also offers a cost-effective

Figure 1.13 The world geography of Internet usage as of April 2008. (Image courtesy Kwintessential Ltd.)



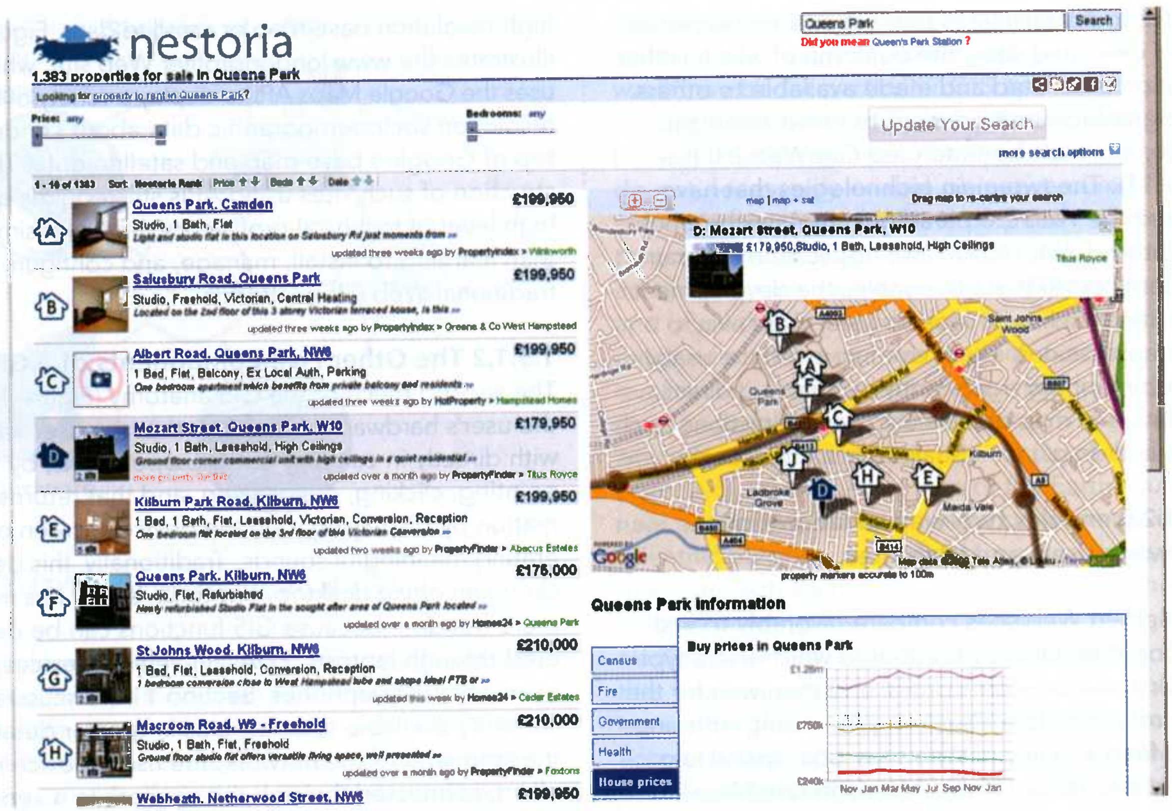


Figure 1.14 Marketing of residential real estate in the UK. (Source: www.nestoria.co.uk)

way of linking together distributed users (for example, telecommuters and office workers, customers and suppliers, students and teachers). From the early days onward, the interactive and exploratory nature of navigating linked information became a great hit with users.

In the early 2000s, Internet technology became increasingly portable (see Section 11.3.3). This meant not only that port-able GIS-enabled devices could be used in conjunction with the wireless networks available in public places such as airports and railway stations, but also that such devices could be connected through broadband in order to deliver GIS-based representations on the move. This technology was exploited in the burgeoning GIService (yet another use of the three-letter acronym GIS) sector, which offered distributed users access to centralized GIS capabilities. Today, many GIServices are made available for personal use through mobile and handheld applications as *location-based services* (see Chapter 11). Personal devices, from pagers to mobile phones to personal digital assistants (PDAs), fill the briefcases and adorn the clothing of people in many walks of life. These devices are able to provide real-time geographic services such as mapping, routing, and geographic yellow pages. These services are often funded through advertisers, or can be purchased on a pay-as-you go or subscription basis; they have changed the business GIS model for many types of applications.

The past 10 years have also seen the development of themed geographic networks, such as the U.S. Geospatial One-Stop (www.geo-one-stop.gov; see Section 11.2.2), which is one of 24 U.S. federal e-government initiatives to improve the coordination of government at local, state, and federal levels. Its geoportal (www.geodata.gov/gos) identifies an integrated collection of geographic information providers and users that interact via the medium of the Internet. Online content can be located using the interactive search capability of the portal, and then content can be directly used over the Internet. This form of Internet application is explored further in Chapter 11.

The Internet is core to most aspects of GIS use, and the days of standalone GISystems are mostly over.

In all of these applications, the Internet provides a unidirectional flow of data and information to a large number of users from the growing number of sites that make up the World Wide Web. Over time, this system has evolved into what has been termed Web

2.0, which today facilitates bidirectional collaboration between users and sites, the outcome of which is that information is collated and made available to others. The geographical embodiment of these ideas, the GeoWeb, has even been termed GeoWeb 2.0 (see Chapter 11). The two main technologies that have stimulated the Web 2.0 paradigm are Asynchronous Javascript And XML (AJAX) and Application Programming Interfaces (API). AJAX enables the development of Web sites that have a look and feel more akin to desktop applications. They have improved the usability of Web mapping significantly by enabling direct manipulation of map data where user interactions (such as "click and drag") are visualized instantaneously.

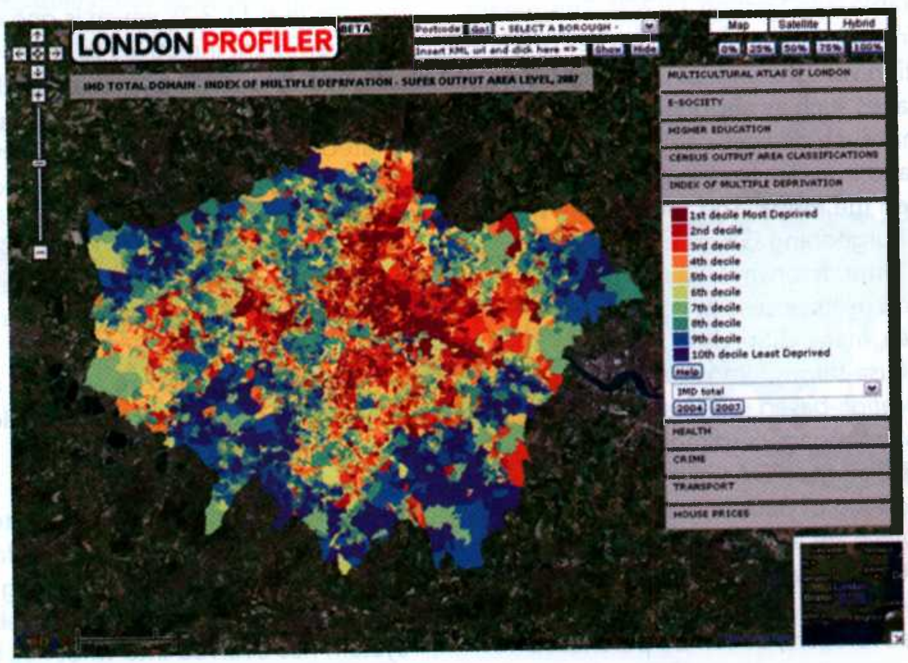
Web2.0 enables two-way collaborations between users and Web sites.

AJAX-enabled Web sites compare favorably to first-generation Web GIS applications in which users typically click a pan or zoom control and then wait for the page to reload before visualizing the result. APIs are available from a variety of Web sites, both spatial (e.g., Google Maps, Yahoo! Maps, Microsoft Live Maps) and nonspatial (e.g., Flickr, Facebook) and provide a series of functions to third-party applications. For example, the API of Google Maps provides basic GIS operations, such as the ability to draw shapes, place points, geocode locations, and display these on top of high-resolution base-map or satellite data. Figure 1.15 illustrates the www.londonprofiler Web site, which uses the Google Maps API to display a variety of high-resolution sociodemographic data about London on top of Google's base-map and satellite data. The construction of such sites using APIs still requires quite a high level of technical proficiency, but is far simpler than learning to install, manage, and configure more traditional Web GIS platforms.

1.5.1.2 The Other Five Components of a GIS

The second piece of the GIS anatomy (Figure 1.16) is the user's hardware, the device that the user interacts with directly in carrying out GIS operations, by typing, pointing, clicking, or speaking, and that returns information by displaying it on the device's screen or generating meaningful sounds. Traditionally, this device sat on an office desktop, but today's user has much more freedom because GIS functions can be delivered through laptops, PDAs, in-vehicle devices, and even cellular telephones. Section 11.3 discusses the currently available technologies in greater detail. In the language of the network, the user's device is the *client*, connected through the network to a *server* that is probably handling many other user clients simultaneously. The client may be *thick*, if it performs a large part of the work locally, or *thin* if it does little more than link the user to the server. A high-specification PC or Macintosh is an instance of a thick client, with

Figure 1.15 A Web2.0 GIS implementation: the Londonprofiler site, showing a mashup of social deprivation data against a background of satellite data. (Image courtesy of Maurizio Gibin)



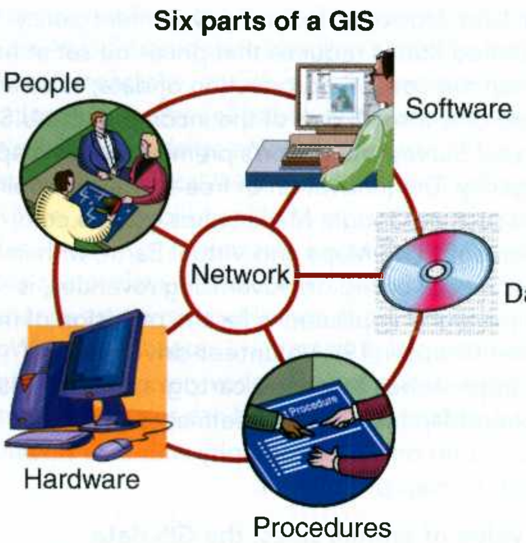


Figure 1.16 The six component parts of a GIS.

powerful local capabilities, while devices attached to TVs that offer little more than Web-browser capabilities are instances of thin clients.

The third piece of the GIS anatomy is the software that runs locally in the user's machine. This can be as simple as a standard Web browser (e.g., Microsoft Explorer or Safari) if all work is done remotely using assorted digital services offered on large servers. More likely, it is a package bought from one of the GIS vendors, such as Autodesk Inc. (San Rafael, California; www.autodesk.com), Environmental Systems Research Institute, Inc. (ESRI; Redlands, California; www.esri.com), Intergraph Corp. (Huntsville, Alabama; www.ingr.com), or MapInfo Corp. (Troy, New York; www.mapinfo.com). Each vendor offers a range of products, designed for different levels of sophistication, different volumes of data, and different application niches. Idrisi (Clark University, Worcester, Massachusetts, www.clarklabs.org) is an example of a GIS produced and marketed by an academic institution rather than by a commercial vendor. GIS software packages have become quite sophisticated in recent years and can handle all the requirements of standard GIS projects. Equally, however, Internet searches provide a means of identifying reusable software routines or non-GIS sources that facilitate spatial operations, although the provenance and applicability of less known utilities may not be immediately obvious.

Commercial software is very rarely "open source"—meaning that users can modify the code that was used to create it—for a range of reasons, including protecting copyright and maintaining user support. Even public domain software (such as the GRASS GIS suite, or more specialized software such as SWARM or Repast) is often not open source, for similar reasons. This sometimes makes it difficult for users to ascertain how fit GIS software may be for particular GIS applications. Thus, although the Internet makes it possible to assemble information about software, Internet searches do not necessarily enable objective comparison of software functions. Michael de Smith, along with two of the authors of this book, have produced an online guide (www.spatialanalysisonline.com) and book that is intended to raise awareness of the range of software options that are available and the quality of the results that may be produced.

The fourth piece of the anatomy is the database, which consists of a digital representation of selected aspects of some specific area of the Earth's surface or near surface, built to serve some problem-solving or scientific purpose. A database might be built for one major project, such as the location of a new high-voltage power transmission corridor, or it might be continuously maintained, fed by the daily transactions that occur in a major utility company (installation of new underground pipes, creation of new customer accounts, daily service crew activities). It might be as small as a few megabytes (a few million bytes, easily stored on a DVD) or as large as several terabytes (a terabyte is roughly a trillion bytes, stored on a large hard disk or many DVDs). Table 1.1 gives some sense of potential GIS database volumes.

GIS databases can range in size from a megabyte to a petabyte or more.

In addition to these four components—network, hardware, software, and database—a GIS also requires management. An organization must establish procedures, lines of reporting, control points, and other mechanisms for ensuring that its GIS activities meet its needs, stay within budgets, maintain high quality, and generally meet the needs of the organization. These issues are explored in Chapters 17, 18, and 19.

Finally, a GIS is useless without the people who design, program, and maintain it, supply it with data, and interpret its results. The people of GIS will have various skills, depending on the roles they perform. Almost all will have the basic knowledge needed to work with geographic data—knowledge of such topics as data sources, scale and accuracy, and software products—and will also have a network of acquaintances in the GIS community. Most important of all, they will have a capacity for critical spatial thinking, allowing them to filter the message of spatial data through the medium of GIS. The next section outlines some of the roles played by the people of GIS and the industries in which they work.

1.6 The Business of GIS

Very many people play many roles in GIS, from software development to software sales and from teaching about GIS to using its power in everyday activities. Many of these people are able to provide "open-source" software or data that can be used or adapted free of charge because the costs of production are met through volunteer activity or are underwritten by research institutions such as universities. Such activity has mushroomed with the ever wider use of the Internet to disseminate software and data, as well as the innovation and use of search engines, blogs, and social networking sites to spread news about what is available. This makes a huge, yet largely unquantifiable, contribution to economic activity. Yet even in narrower and more clearly bounded terms, the activity of GIS remains very big business. This section looks at the diverse roles that people play in the business of GIS, and is organized by the major areas of human activity associated with it.

1.6.1 The Software Industry

Perhaps the most conspicuous GIS business sector, though by no means the largest in either economic or human terms, is the GIS software industry. There is a diverse collection of software developers with a wide range of backgrounds: Autodesk and Intergraph from CAD, ESRI from GIS, GE Smallworld from electricity, and Pitney Bowes MapInfo from business. This has led to a range of interesting software products. Measured in economic terms, the GIS software industry currently accounts for well over $1 billion in annual sales, although estimates vary, in part because of the difficulty of defining GIS precisely. The software industry employs several thousand programmers, software designers, systems analysts, application specialists, and sales staff, with backgrounds that include computer science, geography, and many other disciplines.

The GIS software industry accounts for over $1 billion in annual sales.

1.6.2 The Data Industry

The acquisition, creation, maintenance, dissemination, and sale of GIS data also account for a huge volume of economic activity. Traditionally, a large proportion of GIS data have been produced centrally by national mapping agencies, such as Great Britain's Ordnance Survey. In most countries the funds needed to support national mapping come from sales of products to customers. Until changes introduced in 2010 (see Section 18.5), sales accounted for almost all of the Ordnance Survey's annual turnover of approximately $200 million. However, federal government policy in the United States requires that prices be set at no more than the cost of reproduction of data; sales are therefore only a small part of the income of the U.S. Geological Survey, the nation's premier civilian mapping agency. The innovation of free-to-view mapping services such as Google Maps (maps.google.com) and Microsoft Bing Maps and Virtual Earth, with its business model based on advertising revenues, is having profound implications for the provision of map data (see Chapter 19). Volunteer-driven, open-source approaches to online cartography such as OpenStreetMap (www.openstreetmap.org) are also revolutionizing online cartography with their novel approach to map production.

In value of annual sales, the GIS data industry is much more significant than the software industry.

In recent years improvements in GIS and related technologies, and reductions in prices, along with various kinds of government stimuli, have led to the rapid growth of a private GIS data industry, serving businesses and service providers (see Section 2.3.3). Data may also be integrated with software in order to offer packaged solutions, as with ESRI's Business Analyst products and services. Private companies are now also licensed to collect high-resolution data using satellites and to sell them to customers—as, for example, with GeoEye (www.geoeye.com) and IKONOS satellite data (see Table 1.4). Other companies collect similar data from aircraft. Still other companies specialize in the production of high-quality data on street networks, a basic requirement of many delivery companies. TeleAtlas (www.teleatlas.com) is an example of this industry, employing over 1800 staff in producing, maintaining, and marketing high-quality street network data worldwide.

As developments in the information economy gather still further momentum, many organizations are becoming focused on delivering integrated business solutions rather than raw or value-added data. The Internet makes it possible for GIS users to access routinely collected data from sites that may be remote from locations where more specialized analysis and interpretation functions are performed. In these circumstances, it is no longer incumbent on an organization to manage either its own data or those that it buys from value-added resellers. For example, ESRI offers a data management service, in which client data are managed and maintained for a range of clients that are at liberty to analyze them in quite separate locations. This may in time lead to greater vertical integration of the software and data industry—for example, ESRI Inc. has developed an e-bis division and acquired its own geodemographic system (called Tapestry) to service a range of business needs. As GIS-based data handling becomes increasingly commonplace, so GIS is finding increasing application in new areas of public-sector service provision, particularly where large amounts of public money are disbursed at the local level—as in policing, education provision, and public health. Many data warehouses and start-up organizations are beginning to develop public-sector data infrastructures, particularly where greater investment in public services is taking place. The GeoWeb (see Chapter 11) is creating fertile environments in which a very wide range of public- and private-sector data sources can be combined, analyzed, and displayed.

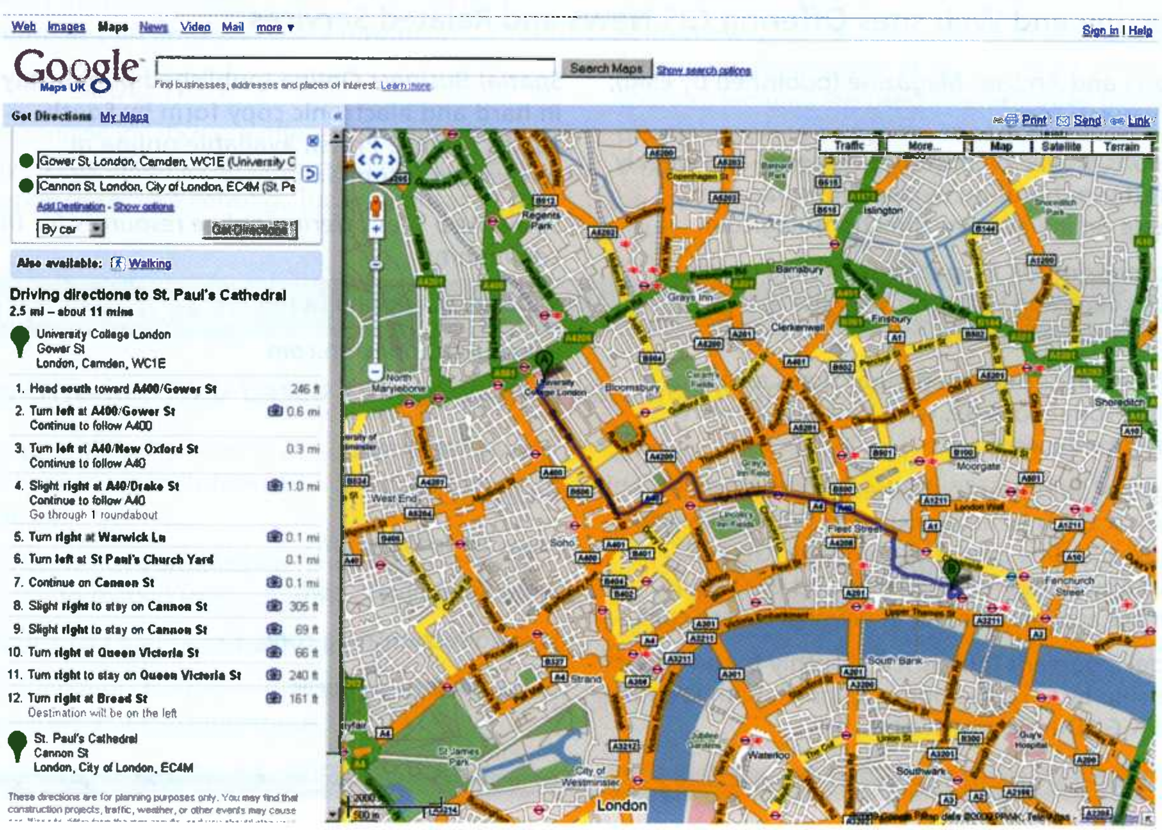
1.6.3 The GIServices Industry

Some GISystems are described as having an enterprise-wide scope; that is, they serve many users, with many applications, in multiple geographic locations. Planning, procuring, implementing, administering, and learning how to use such systems require specialist knowledge, and many specialist services providers have come to offer such knowledge and expertise. The types of services offered include consulting (of both a strategic and an operational nature: see Section 2.3.3), data collection, system customization, specialist hardware and software sales and support (e.g., supply of scanners, plotters, and GPS receivers), training, and value-added applications. GIService providers range from small businesses to the giants such as Accenture, IBM, and Oracle. It is difficult to be precise about the exact size of the GIServices market, but when stripped of multifunction organizations, it is likely to be even larger than the GIS software market.

1.6.4 The GeoWeb Services Industry

The Internet also allows GIS users to access specific functions that are provided by remote sites. For example, MapQuest in the United States (www.mapquest.com), Yellow Pages in the UK (www.yell.com), and the international Google Maps site (maps.google.com) all provide mapping, geocoding, and routing services that are used every day by millions of people to find the best route between two points. By typing a pair of street addresses, the user instructs a routing analysis (see Section 15.4.2) and receives the results in the form of a map and a set of written driving or walking directions (see Figure 1.17).

Figure 1.17 Routing instructions. (Source: Google Maps service)



This has several advantages over performing the same analysis on one's own PC: there is no need to buy software to perform the analysis or to buy the necessary data, the data are routinely updated by the GIService provider, and the calculations may even be adjusted in the light of day-to-day variability in traffic conditions. There are clear synergies of interest between GIService providers and organizations providing location-based services (see Chapter 11), and many sites that provide access to raw GIS data also provide GIServices.

GIServices are a rapidly growing form of electronic commerce.

GIServices continue to develop rapidly. In today's world one of the most important commodities is attention: the fraction of a second of attention given to a billboard or sponsored Web page link, or the audience attention that a TV station sells to its advertisers. The value of attention also depends on the degree of fit between the message and the recipient—an advertiser will pay more for the attention of a small number of people if it knows that they include a large proportion of its typical customers. Advertising directed at the individual, based on an individual profile, is even more attractive to the advertiser. Direct mail companies have exploited the power of geographic location to target specific audiences for many years, basing their strategies on neighborhood profiles constructed from census records (see Section 2.3.3). But new technologies offer to take this much further. The technology already exists to identify the buying habits of a customer who stops at a gas pump and uses a credit card, and to direct targeted advertising through a TV screen at the pump. As online advertising comes to take an increasing share of most organizations' advertising budgets, so the extent to which niche geographical markets map onto the virtual communities of social networking sites (such as Facebook and Bebo) is set to become an increasingly important focus of marketing initiatives.

1.6.5 The Publishing Industry

Much smaller, but nevertheless highly influential in the world of GIS, is the publishing industry, with its magazines, books, and journals. Several online portals and print magazines are directed at the GIS community (see Box 1.4). Several scholarly journals serve the GIS community, by publishing new advances in

Technical Box 1.4

Magazine and Web sites Offering GIS News and Related Services

ArcNews and ArcUser Magazine (published by ESRI); see www.esri.com

Directions Magazine (Internet-centered and weekly newsletter publication by directionsmag.com), available online at www.directionsmag.com

GEO:connexion UK Magazine published quarterly by GEO:connexion Ltd., with Web site at www.geoconnexion.com

GEOInformatics published eight times a year by Cmedia Productions BV, with Web site at www.geoinformatics.com

GeoSpatial Solutions (published monthly by Advanstar Communications), with Web site www.geospatial-online.com. The company (GEOTEC media) also publishes *GPSWorld* and *GEOWorld*, which are available online at www.geoplace.com

GIS@development (published monthly for an Asian readership by GIS Development, India), with Web site at www.GISDevelopment.net

Spatial Business Online (published bi-monthly in hard and electronic copy form by South Pacific Science Press), available online at www.gisuser.com.au

Some Web sites offering online resources for the GIS community:

www.gisdevelopment.net

www.geoconnexion.com

www.gis.com

www.giscafe.com

gis.about.com

www.geocomm.com

www.spatialnews.com

www.directionsmag.com

www.opengis.org/press

Technical Box (1.5)

Some Scholarly Journals Emphasizing GIS Research

Annals of the Association of American Geographers

Applied Spatial Analysis and Planning

Cartography and Geographic Information Science

Cartography—The Journal

Computers and Geosciences

Computers, Environment and Urban Systems

Geographical Analysis

GeoInformatica

International Journal of Geographical Information Science (formerly International Journal of Geographical Information Systems)

ISPRS Journal of Photogrammetry and Remote Sensing

Journal of Geographical Systems

Photogrammetric Engineering and Remote Sensing (PE&RS)

The Photogrammetric Record

Terra Forum

Transactions in GIS

URISA Journal

GIS research. The oldest journal specifically targeted at the community is the *International Journal of Geographical Information Science*, established in 1987. Other still older journals in areas such as cartography and geographic analysis regularly accept GIS articles, and several have changed their names and shifted focus significantly. Box 1.5 presents a list of the journals that emphasize GIS research.

1.6.6 GIS Education

The first courses in GIS were offered in universities in the early 1970s, often as an outgrowth of courses in cartography or remote sensing. Today, thousands of such courses can be found in universities and colleges all over the world. Training courses are offered by the vendors of GIS software, and increasing use is made of the Web in various forms of remote GIS education and training (see Box 1.6).

Often, a distinction is made between education and training in GIS: training in the use of a particular software product is contrasted with education in the fundamental principles of GIS. In many university courses, lectures are used to emphasize fundamental principles, while computer-based laboratory exercises emphasize training. In our view, an education should be for life, and the material learned during an

Technical Box (1.6)

Sites Offering Web-based Education and Training Programs in GIS

Birkbeck College (University of London) GIScOnline M.Sc. in Geographic Information Science at www.bbk.ac.uk

Curtin University's distance learning programs in geographic information science at www.cage.curtin.edu.au

ESRI's Virtual Campus at training.esri.com

Kingston Centre for GIS, Distance Learning Programme at www.kingston.ac.uk

Pennsylvania State University Certificate Program in Geographic Information Systems at www.worldcampus.psu.edu

UNIGIS International, Postgraduate Courses in GIS at www.unigis.org University of Southern California GIS distance learning certificate program at www.usc.edu education should be applicable as far into the future as possible. Fundamental principles tend to persist long after software has been replaced with new versions, and the skills learned in running one software package may be of very little value when a new technology arrives. On the other hand, much of the fun and excitement of GIS comes from actually working with it, and fundamental principles can be very dry and dull without hands-on experience.

1.7 GISystems, GIScience, and GIStudies

Geographic information systems are useful tools, helping everyone from scientists to citizens to solve geographic problems. But like many other kinds of tools, such as computers themselves, their use raises questions that are sometimes frustrating and sometimes profound. For example, how does a GIS user know that the results obtained are accurate? What principles might help a GIS user to design better maps? How can location-based services be used to help users to navigate and understand human and natural environments? Some of these questions concern GIS design, and others are about GIS data and methods. Taken together, we can think of them as questions that arise from the use of GIS—that are stimulated by exposure to GIS or to its products. Many of them are addressed in detail at many points in this book, and the book's title emphasizes the importance of both systems and science.

The term *geographic information science* was coined in a paper by Michael Goodchild published in 1992. In it, the author argued that these questions and others like them were important and that their systematic study constituted a science in its own right. Information science studies the fundamental issues arising from the creation, handling, storage, and use of information. Similarly, GIScience should study the fundamental issues arising from geographic information, as a well-defined class of information in general. Other terms have much the same meaning: *geomatics* and *geoinformatics, spatial information science, geoinformation engineering*. All suggest a scientific approach to the fundamental issues raised by the use of GIS and related technologies, though they all have different roots and emphasize different ways of thinking about problems (specifically geographic or more generally spatial, emphasizing engineering or science, etc.).

GIScience has evolved significantly in recent years. It is now the principle focus of several renamed research journals (see Box 1.5), as well as the focus of the

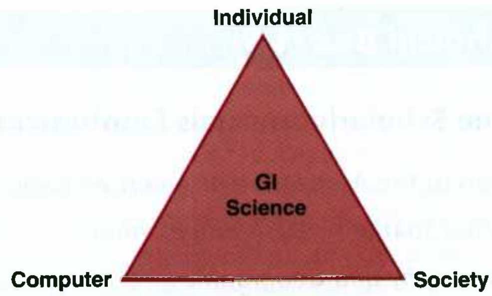


Figure 1.18 The remit of GIScience, according to Project Varenius (www.ncgia.org).

U.S. University Consortium for Geographic Information Science (www.ucgis.org), an organization of roughly 70 research universities that engages in research agenda setting, lobbying for research funding, and related activities. An international conference series on GIScience has been held biannually since 2000 (see www.giscience.org). The Varenius project (www.ncgia.org) provides one disarmingly simple way to view developments in GIScience (Figure 1.18). Here, GIScience is viewed as anchored by three concepts: the individual, the computer, and society. These form the vertices of a triangle, and GISc lies at its core. The various terms that are used to describe GISc activity can be used to populate this triangle. Thus research about the individual is dominated by cognitive science, with its concern for understanding of spatial concepts, learning and reasoning about geographic data, and interaction with the computer. Central to such research is the desire to engineer more readily intelligible user interfaces, in the interest of improved human—computer interaction. Allied to this is the desire to improve geovizualization and render intelligible the results of spatiotemporal analysis. Research about the computer is dominated by issues of representation, the adaptation of new technologies, computation, and visualization. And finally, research about society addresses issues of impact and societal context. Others have developed visions of how higher education should prepare students for success in the variety of professions that rely on geospatial technologies, such as the U.S. University Consortium for Geographic Information Science (Box 1.7). It is possible to imagine how the themes presented in Box 1.7 could be used to populate Figure 1.18 in relation to the three vertices of this triangle.

In some important respects, GIScience is about using the software environment of GIS as an environment in which old problems can be redefined, reshaped, and resolved. Many of the research topics in GIScience are actually much older than GIS. The

Technical Box (1.7)

The 2006 Geographic Information Science and Technology Higher Education Agenda of the U.S. University Consortium for Geographic Information Science (www.ucgis.org), and Related Chapters in this Book

I. Analytical Methods

1 Academic and analytical origins (Chapter 1)

2 Query operations and query languages (Chapters 14, 8, 7)

3 Geometric measures (Chapter 14)

4 Basic analytical operations (Chapter 14)

5 Basic analytical methods (Chapter 15)

6 Analysis of surfaces (Chapter 15)

7 Spatial statistics (Chapter 15)

8 Geostatistics (Chapter 16)

9 Spatial regression and econometrics (Chapters 15, 16)

10 Data mining (Chapters 15, 16)

11 Network analysis (Chapters 14, 15)

12 Optimization and location-allocation modeling (Chapters 14, 15)

II. Conceptual Foundations

1 Philosophical foundations (Chapters 1, 3, 4)

2 Cognitive and social foundations (Chapter 1)

3 Domains of geographic information (Chapter 3)

4 Elements of geographic information (Chapter 3)

5 Relationships (Chapters 4, 6)

6 Imperfections in geographic information (Chapter 6)

III. Cartography and Visualization

1 History and trends (Chapter 12)

2 Data considerations (Chapters 5, 9, 12)

3 Principles of map design (Chapter 12)

4 Graphic representation techniques (Chapters 11, 12, 13, 14)

5 Map production (Chapter 12)

6 Map use and evaluation (Chapters 12, 6, 3)

IV. Design Aspects

1 The scope of GIS&T system design (Chapters 7, 17, 1)

2 Project definition (Chapters 2, 17, 18)

3 Resource planning (Chapters 18, 19)

4 Database design (Chapters 8, 9, 7)

5 Analysis design (Chapter 8)

6 Application design (Chapters 2, 17, 18)

7 System implementation (Chapters 17, 18, 19)

V. Data Modeling

1 Basic storage and retrieval structures (Chapter 8)

2 Database management systems (Chapter 8)

3 Tessellation data models (Chapters 8, 3)

4 Vector and object data models (Chapters 3, 8)

5 Modeling 3D, uncertain, and temporal phenomena (Chapters 13, 6, 16)

VI. Data Manipulation

1 Representation transformation (Chapters 3, 4, 8)

2 Generalization and aggregation (Chapters 4, 3)

3 Transaction management (Chapters 8, 7)

VII. Geocomputation

1 Emergence of geocomputation (Chapter 16)

2 Computational aspects and neurocomputing (Chapters 15, 16)

3 Cellular Automata (CA) (Chapter 16)

4 Heuristics (Chapters 15, 16)

5 Genetic algorithms (GA) (Chapter 16)

6 Agent-based models (Chapter 16)

7 Simulation modeling (Chapter 16)

8 Uncertainty (Chapter 6)

9 Fuzzy sets (Chapter 16)

VIII. Geospatial Data
1 Earth geometry (Chapter 5)
2 Land partitioning systems (Chapter 5)
3 Georeferencing systems (Chapter 5)
4 Datums (Chapter 5)
5 Map projections (Chapter 5)
6 Data quality (Chapters 6, 9)
7 Land surveying and GPS (Chapter 9)
8 Digitizing (Chapter 9)
9 Field data collection (Chapter 9)
10 Aerial imaging and photogrammetry (Chapter 9)
11 Satellite and shipboard remote sensing (Chapter 9)
12 Metadata, standards, and infrastructures (Chapters 11, 19)

IX. GIS&T and Society
1 Legal aspects (Chapters 19, 18)
2 Economic aspects (Chapters 17, 18)
3 Use of geospatial information (Chapters 2, 18, 19, 11)
4 Geospatial information as property (Chapters 17, 19)
5 Dissemination of geospatial information (Chapter 19)
6 Ethical aspects (Chapters 18, 19, 1)
7 Critical GIS (Chapters 1, 20)

X. Organizational and Institutional Aspects
1 Origins of GIS&T (Chapters 1, 2)
2 Managing the GI system: operations and infrastructure (Chapter 17)
3 Organizational structures and procedures (Chapters 1, 17, 2)
4 GIS&T workforce themes (Chapters 1, 18, 17)
5 Institutional and interinstitutional aspects (Chapter 19)
6 Coordinating organizations (Chapters 17, 19, 1)

More detail on all of these topics, and additional topics presented at more recent UCGIS assemblies, can be found at www.ucgis.org/priorities/research/2002researchagenda.htm. Note that we give some of the advanced topics listed above are discussed in more detail at www.spatialanalysisonline.com.

need for methods of spatial analysis, for example, dates from the first maps, and many methods were developed long before the first GIS appeared on the scene in the mid-1960s. Another way to look at GIScience is to see it as the body of knowledge that GISystems implement and exploit. Map projections (Chapter 5), for example, are part of GIScience and are used and transformed in GISystems. A further area of great importance to GIS is cognitive science, particularly the scientific understanding of how people think about their geographic surroundings. If GISystems are to be easy to use, they must fit with human ideas about such topics as driving directions or how to construct useful and understandable maps. Box 1.8 introduces Peter Gould, a quantitative and behavioral geographer whose various research activities did much to prepare geography for the GIS revolution and the inception of GIScience.

Many roots to GIS can be traced to the spatial analysis tradition in the discipline of geography.

In the 1970s it was easy to define or delimit a geographic information system: it was a single piece of software residing on a single computer. With time, and particularly with the development of the Internet, Web 2.0 and new approaches to software engineering, the old monolithic nature of GIS has been replaced by something much more fluid. GIS is no longer an activity confined to the desktop (Chapter 11). The emphasis throughout this book is on this new vision of GIS, as the set of coordinated parts discussed earlier in Section 1.5. Perhaps the *system* part of GIS is no longer necessary. Certainly the phrase *GIS data* suggests some redundancy, and various people have suggested that we could drop the "S" altogether in favor of GI, for geographic information. GI*Systems* are only one part of the GI whole, which also includes the fundamental issues of GI*Science*. Much of this book is also about GI*Studies*, which can be defined as the systematic study of society's use of geographic information, including its institutions, standards, and procedures. Many of these topics are addressed in the later chapters. Several of the

Biographical Box (1.8)

Peter Gould, Geographer

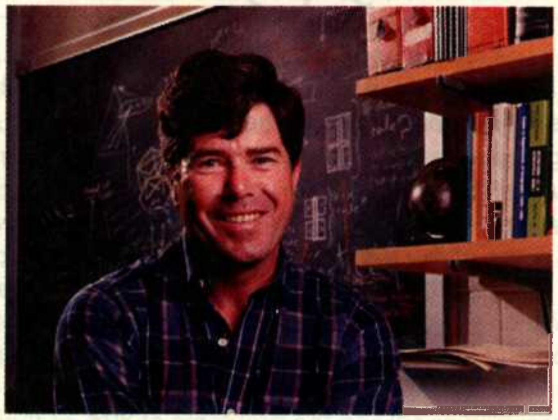


Figure 1.19 (A) Peter Gould, Geographer. (James Collins, Photographer, Penn State University)

Peter R. Gould (1932–2000) (Figure 1.19A) taught in the Department of Geography at Pennsylvania State University for 35 years following the award of a Ph.D. from Northwestern University, until his retirement in 1998. He was the author of many influential books, including two that focused on his passion for the subject: *The Geographer at Work* (Routledge, 1985) and *Becoming a Geographer* (Syracuse University Press, 1999). Among many other topics, he undertook pathbreaking work on the use of statistical methods with spatial data; on the nature of the cognitive maps people construct in their minds; on the impacts of the Chernobyl disaster; and on the mechanisms that spread the AIDS epidemic (he published an early column on this subject in *Playboy* magazine).

In the late 1980s Gould and Professor Waldo Tobler of the University of California, Santa Barbara, conducted a small experiment designed to demonstrate the power of alternative modes of georeferencing (see Chapter 5). Using nothing more than the latitude and longitude of Tobler's house, Gould and several co-conspirators mailed a series of letters and postcards from various parts of the world. A postcard mailed at Cape Hatteras in North Carolina, one of several that eventually found their way to Tobler through the mail system, is reproduced in Figure 1.19B. In an era in which many social scientists have concerns about the "surveillance society" and the use of geographic information technologies to enforce it, it is perhaps salutary to reflect that the different georeferencing systems that can so readily be adapted to surveillance have their roots in previous eras

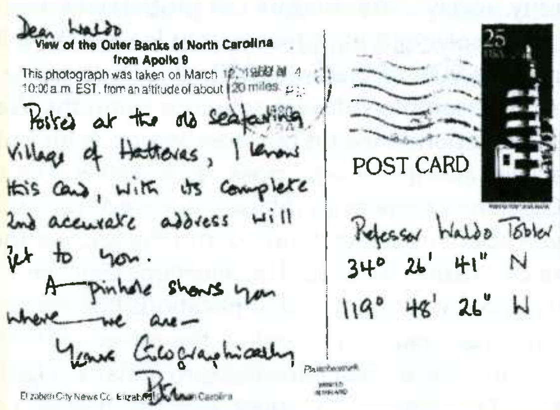


Figure 1.19 (B) A postcard from Peter to geographer Waldo Tobler, identifying Tobler's address using precise latitude and longitude coordinates.

UCGIS research topics (Box 1.7) suggest this kind of focus, including *GIS&T and Society* and *Organizational and Institutional Aspects*. In recent years the role of GIS in society—its impacts and its deeper significance—has become the focus of extensive writing in the academic literature, particularly in the discipline of geography, and much of it has been critical of GIS. We explore these critiques in some detail in the next section.

The importance of social context is nicely expressed by Nick Chrisman's definition of GIS, which might also serve as an appropriate final comment on the earlier discussion of definitions:

> **"The organized activity by which people:**
>
> **1) measure aspects of geographic phenomena and processes; 2) represent these measurements, usually in the form of a computer database, to emphasize spatial themes, entities, and relationships; 3) operate upon these representations to produce more measurements and to discover new relationships by integrating disparate sources; and 4) transform these representations to conform to other frameworks of entities and relationships. These activities reflect the larger context (institutions and cultures) in which these people carry out their work. In turn, the GIS may influence these structures." (Chrisman 2003, p. 13)**

Chrisman's social structures are clearly part of the GIS whole, and as students of GIS we should be aware of the ethical issues raised by the technology we study. Social structures are core to *GIStudies*.

1.8 GIS and the Study of Geography

GIS has always had a special relationship to the academic discipline of geography, as it has to other disciplines that deal with the Earth's surface, including geodesy, landscape architecture, planning, and surveying. This section explores that special relationship and its sometimes tense characteristics, as well as some of the responses of the GIS field to criticism.

In the 1980s GIS technology began to offer a solution to the problems of inadequate computation and limited data handling. However, the quite sensible priorities of vendors at the time might be described as solving the problems of 80% of their customers 80% of the time, and the integration of techniques based on higher-order concepts was a low priority. Today's GIS vendors can probably be credited with solving the problems of at least 90% of their customers 90% of the time, while the opportunity for users to assemble software solutions using the Web relieves dependence on business solutions for both specialist and general-purpose applications. The remit of GIScience remains to diffuse improved, curiosity-driven scientific understanding into the knowledge base of existing successful applications. But the development of improved applications has also been driven to a significant extent by the advent of GPS and other digital data infrastructure initiatives by the late 1990s. New data-handling technologies and new rich sources of digital data open up prospects for refocusing and reinvigorating academic interest in applied scientific problem solving. Although repeat purchases of GIS technology leave the field with a buoyant future in the IT mainstream, there is enduring unease in some academic quarters about GIS applications and their social implications. Much of this unease has been expressed in the form of critiques, notably from geographers, and John Pickles's 1993 edited volume *Ground Truth: The Social Implications of Geographic Information Systems* remains an enduring consolidation of these concerns. Several types of arguments have surfaced:

- The ways in which GIS represents the Earth's surface, and particularly human society, favor certain people, phenomena and perspectives, at the expense of others. For example, GIS databases tend to emphasize homogeneity, partly because of the limited space available on the computer screen and partly because of the costs of more accurate data collection (see Chapters 3, 4, and 8). Minority views, and the views of individuals, can be submerged in this process, as can information that differs from the official or consensus view. For example, a soil map represents the geographic variation in soils by depicting areas of constant class, separated by sharp boundaries. This is clearly an approximation, and in Chapter 6 we explore the role of uncertainty in GIS. GIS often forces knowledge into forms that are more likely to reflect the view of the majority, or the official view of government, and as a result *marginalizes* the opinions of minorities or the less powerful. Seen from this perspective, even the widely available mapping and analysis functions of Google Maps (maps.google.com) or virtual Earths (www.microsoft.com/virtualearth; earth.google.com) offer a privileged view of the world.
- Although in principle it is possible to use GIS for any purpose, in practice it is often used for purposes that may be ethically questionable or may invade individual privacy, such as surveillance and the gathering of military and industrial intelligence. The technology may appear neutral, but it is always used in a social context. As with the debates over the atomic bomb in the 1940s and 1950s, the scientists who develop and promote the use of GIS surely bear some responsibility for how it is eventually used. The idea that a tool can be inherently neutral, and its developers therefore immune from any ethical debates, is strongly questioned in this literature.
- The very success of GIS is a cause of concern. There are qualms about a field that appears to be led by technology and the marketplace, rather than by human need. There are fears that GIS has become *too* successful in modeling socioeconomic distributions and that as a consequence GIS has become a tool of the "surveillance society." Countering this outlook is the view that greater access to information, especially over the Web, has enlivened debate and has gone some considerable way toward leveling the playing field in terms of data access.
- There are concerns that GIS remains a tool in the hands of the already powerful—notwithstanding the diffusion of technology that has accompanied the plummeting cost of computing and wide adoption of the Internet. As such, it is seen as maintaining the status quo in terms of power structures. By implication, any vision of GIS for all of society is viewed as unattainable. The falling

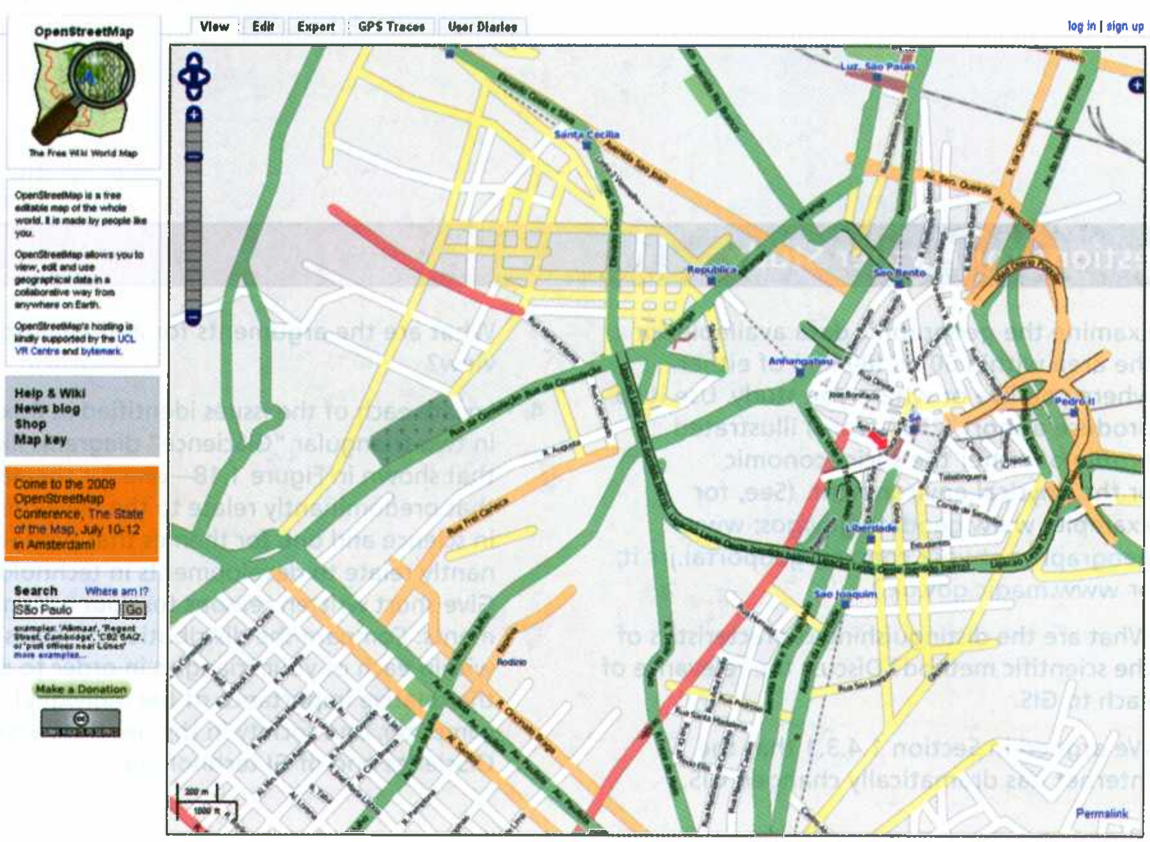
cost of GIS and the greater level of awareness are allowing a much greater proportion of the population to access GIS directly or indirectly via other media channels. Today, the GeoWeb is empowering more and more individuals and groups to present their perspectives to a wide audience.

- There appears to be an underrepresentation of applications of GIS in *critical* research. This academic perspective is centrally concerned with the connections between human agency and particular social structures and contexts. Some of its protagonists maintain that such connections are not amenable to digital representation in whole or in part. A few studies of this type are beginning to be reported that investigate, for example, the compatibility between GIS and feminist epistemologies and politics.
- Some view the association of GIS with the scientific and technical project as fundamentally flawed. More narrowly, there is a view that GIS applications (like spatial analysis before it) are inextricably bound to the philosophy and assumptions of the approach to science known as *logical positivism* (see also the reference to "positive" in Section 1.1). As such, the argument goes, GIS can never be more than a positivist tool and a normative instrument, and cannot enrich other more critical perspectives in geography. This is a criticism not just of GIS, but also of the application of the scientific method to the analysis of social systems.

Many geographers remain suspicious of the use of GIS in geography.

Recent years have seen the popularization of the term *neogeography* to describe developments in Web mapping technology and spatial data infrastructures that have greatly enhanced our abilities to assemble, share, and interact with geographic information online. Allied to this is the increased crowd sourcing

Figure 1.20 A crowd-sourced street map of part of São Paulo, Brazil. (Source: OpenStreetMap.org)



by online communities of *volunteered geographic information* (VGI). Neogeography is founded on the two-way, many-to-many interactions between users and Web sites that have emerged under Web 2.0, as embodied in projects such as Wikimapia (www.wikimapia.org) and OpenStreetMap (www.openstreetmap.org). Today, Wikimapia contains user-generated entries for more places than are available in any official list of place-names, while OpenStreetMap is well on the way to creating a free-to-use global map database through assimilation of digitized satellite photographs with GPS tracks supplied by volunteers (see Figure 1.20). This has converted many new users to the benefits of creating, sharing, and using geographic information, often through ad hoc collectives and interest groups. As such, Web 2.0 simultaneously facilitates crowd sourcing of VGI while making basic GIS functions increasingly accessible to an ever broader community of users. The creation, maintenance, and distribution of databases is no less than a "wikification of GIS." Neogeography provides both a partial response to the earlier social critiques of GIS, in that it brings GIS and some use of spatial data infrastructures to the masses, and a reinforcement of them, in that many Web 2.0 applications present new challenges to citizen privacy and confidentiality. The empowerment of many nonexpert GIS users also brings with it the new challenges of ensuring that tools are used efficiently, effectively, and safely, and reemphasizes that Web 2.0 can never be more than a partial technological solution to the effective deployment of GIS.

We wonder where all this discussion will lead. We have chosen a title for this book that includes both systems and science, and certainly much more of it is about the broader concept of geographic information than about isolated, monolithic software systems per se. We believe strongly that effective users of GIS require some awareness of *all* aspects of geographic information, from the basic principles and techniques to concepts of management and familiarity with applications. We hope this book provides that kind of awareness. On the other hand, we have chosen not to include GIStudies in the title. Although the later chapters of the book address many aspects of the social context of GIS, including issues of privacy, the context to GIStudies is rooted in social theory. GIStudies need the kind of focused attention that we cannot give, and we recommend that students interested in more depth in this area explore the specialized texts listed in the references.

Questions for Further Study

1. Examine the geographic data available for the area within 50 mi (80 km) of either where you live or where you study. Use it to produce a short (2500-word) illustrated profile of either the socioeconomic or the physical environment. (See, for example, www.geodata.gov/gos; www.geographynetwork.com; eu-geoportal.jrc.it; or www.magic.gov.uk.)
2. What are the distinguishing characteristics of the scientific method? Discuss the relevance of each to GIS.
3. We argued in Section 1.4.3.1 that the Internet has dramatically changed GIS. What are the arguments for and against this view?
4. Locate each of the issues identified in Box 1.7 in two triangular "GIScience" diagrams like that shown in Figure 1.18—one for themes that predominantly relate to the developments in science and one for themes that predominantly relate to developments in technology. Give short written reasons for your assignments. Compare the distribution of issues within each of your triangles in order to assess the relative importance of the individual, the computer, and society in the development of GIScience and of GI technologies.

Further Reading

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