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, 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

At the end of 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. Largely, we humans are confined in our activities to the surface and near-surface of the Earth. We travel over it and in the lower levels of the atmosphere, and 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, most (perhaps all) decisions have geographic consequences, e.g., adopting a particular funding formula creates geographic winners and losers, especially when the process entails zero sum gains. Therefore geographic location is an important attribute of activities, policies, strategies, and plans. Geographic information systems 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.

Because location is so important, it is an issue in many of the problems society must solve. Some of these 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 September 11 2001 in New York (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 and recommend where best to site retail outlets.

■ 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 1.3).

■ 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 1.4).

■ 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.

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 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 building, the slope of the land, and its accessibility using normal and emergency infrastructure. The global diffusion of the 2003 severe acute respiratory syndrome (SARS) epidemic, or 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 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 are often seen 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, use 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 certainly reinforces this 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 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.

Applications Box 1.1

September 11 2001

Almost everyone remembers where they were when they learned of the terrorist atrocities in New York on September 11 2001. Location was crucial in the immediate aftermath and the emergency response, and the attacks had locational repercussions at a range of spatial

Figure 1.1 GIS in the Office of Emergency Management (OEM), first set up in the World Trade Center (WTC) complex immediately following the 2001 terrorist attacks on New York (Courtesy ESRI)
(geographic) and temporal (short, medium, and long time periods) scales. In the short term, the incidents triggered local emergency evacuation and disaster recovery procedures and global shocks to the financial system through the suspension of the New York Stock Exchange; in the medium term they blocked part of the New York subway system (that ran underneath the Twin Towers), profoundly changed regional work patterns (as affected workers became telecommuters) and had calamitous effects on the local retail economy; and in the

Figure 1.2 GIS usage in emergency management following the 2001 terrorist attacks on New York: (A) subway, pedestrian and vehicular traffic restrictions; (B) telephone outages; and (C) surface dust monitoring three days after the disaster. (Courtesy ESRI)
long term, they have profoundly changed the way that we think of emergency response in our heavily networked society. Figures 1.1 and 1.2 depict some of the ways in which GIS was used for emergency management in New York in the immediate aftermath of the attacks. But the events also have much wider implications for the handling and management of geographic information, that we return to in Chapter 20.

At some points in this book it will be useful to distinguish between applications of GIS that focus on design, or so-called normative uses, and applications 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 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 10.6). Others are tactical, and concerned with medium-term decisions, such as where to cut trees in next year’s forest harvesting plan. Others are strategic, and are required to give an organization long-term direction, as when retailers decide to expand or rationalize their store networks (Figure 1.7). These terms are explored in the context of logistics applications of GIS in Section 2.3.4.6. 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 possibly arrive a year after the previous one! Other problems that interest geophysicists, geologists, or evolutionary biologists may occur on time scales 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 Sections 10.2.1 and 10.9.1), meaning
that they are constantly being updated as new information arrives, unlike maps, which stay the same once printed.

Chapter 2 contains a more detailed discussion of the range and remits of GIS applications, and a view of how GIS pervades many aspects of our daily lives. Other applications are discussed to illustrate particular principles, techniques, 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, and it 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 non-geographic 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 as the National Geospatial-Intelligence Agency in late 2003 by the US President and the Web portal for US Federal Government data is called Geospatial One-Stop. In this book we have tended to avoid geospatial, preferring geographic, and spatial where we need to emphasize generality (see Section 21.2.2).

People who encounter GIS for the first time are sometimes driven to ask why geography is so important — why 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 hasn’t 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

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**Figure 1.3** Maintaining and improving footpaths in National Parks is a geographic problem

**Figure 1.4** Navigating tourist destinations is a geographic problem

**Applications Box 1.2**

**Where did your ancestors come from?**

As individuals, many of us are interested in where we came from — socially and geographically. 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 19th century (Figure 1.5). This tells us quite a lot about migration, 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

Figure 1.5 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)
the characteristics of international emigrants (for example to North America, Australia, and New Zealand: Figure 1.6), or the regional naming patterns of immigrants to the US from the Indian sub-continent or China. In all kinds of senses, this helps us understand our place in the world. Fundamentally, this is curiosity-driven research: it is interesting to individuals to understand more about their 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 that live there. But it is not central to resolving any specific problem within a specific timescale.

Figure 1.5 (continued)
1.2 Data, information, evidence, knowledge, 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 knowledge 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 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 with their various meanings, because the differences between them can often be significant, and what follows draws upon many sources, and thus provides the basis for the use of these terms throughout the book. Data clearly refers to the most mundane kind of information, and wisdom to the most substantive.

Data consist of numbers, text, or symbols which are in some sense neutral and almost context-free. Raw geographic facts (see Box 18.7), 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

activities and decisions involve a geographic component, and the geographic component is important. Another reason will become apparent in Chapter 3 – 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.
Some technical reasons why geographic information is special

- It 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, e.g., using a representation equivalent to a 1:1 million scale map and a 1:24,000 scale one (see Box 4.2).
- 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 5.7.
- 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.

such considerations. Data (the noun is the plural of \textit{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 \textit{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 \textit{anything} which can be digitized, that is, represented in digital form (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 \textit{purpose}, or data that have been given some degree of \textit{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 (Section 18.3).

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

\textit{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: \textit{codified} and \textit{tacit}. Knowledge is codifiable if it can be written down and transferred relatively easily 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:

- Knowledge entails a knower. Information exists independently, but knowledge is intimately related to people.

<table>
<thead>
<tr>
<th>Table 1.1</th>
<th>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</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 megabyte</td>
<td>1 000 000</td>
</tr>
<tr>
<td>1 gigabyte</td>
<td>1 000 000 000</td>
</tr>
<tr>
<td>1 terabyte</td>
<td>1 000 000 000 000</td>
</tr>
<tr>
<td>1 petabyte</td>
<td>1 000 000 000 000 000</td>
</tr>
<tr>
<td>1 exabyte</td>
<td>1 000 000 000 000 000 000</td>
</tr>
</tbody>
</table>
### Table 1.2 A ranking of the support infrastructure for decision making

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

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.

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 half-way 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.

**Wisdom** is even more elusive to define than 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 The science of problem solving

How are problems solved, and are geographic problems solved any differently 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 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 such knowledge 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 US 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 longstanding debate, lasting

![Figure 1.8 Social processes, such as carbon dioxide emissions, modify the Earth’s environment](image-url)
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 only useful in solving specific problems if it can be combined effectively with knowledge of form. For example, we can only assess the impact of soil erosion on agriculture in New South Wales if we know both how soil erosion is generally impacted by such factors as slope and specifically how much of New South Wales has steep slopes, and where they are located (Figure 1.10).

One of the most important merits of GIS as a tool for problem solving 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’s slopes, in the form of computerized maps, and the programs executed by the GIS would reflect general knowledge of how slopes affect soil erosion. 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, and is widely used in geographic problem solving. In many parts of the USA and other countries efforts have been made to limit development of wetlands, in the interests 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).

**Figure 1.10** Predicting landslides requires general knowledge of processes and specific knowledge of the area – both are available in a GIS (Reproduced with permission of PhotoDisc, Inc.)

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. Rules are used by the US Forest Service
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 relatively 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 to make the most accurate prediction possible. These objectives are all expressed in tangible 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 an example of the use of such mixed objectives see Section 16.4.

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.

1.4 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. This may well be so, but what exactly is this technology called GIS, and how does it achieve its objectives? In what ways is GIS more than a technology, and why does it continue to attract such attention as a topic for scientific journals and conferences?

Many definitions of GIS have been suggested over the years, and none of them is entirely satisfactory, though many suggest much more than a technology. Today, the label GIS is attached to many things: amongst them, a software product that one can buy 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.

Nevertheless, certain definitions are particularly helpful (Table 1.3). As we describe in Chapter 3, GIS is much more than a container of maps in digital form. This can be a misleading description, but it is a helpful definition 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 clearly 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, a definition that 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, the definition that 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 (see Section 2.3.4.4), an interesting definition that 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, a definition that speaks to the problems associated with manual analysis of maps, particularly the extraction of simple measures, of area for example.

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

1.4.1 A brief history of GIS

As might be expected, there is some controversy about the history of GIS since parallel developments occurred in North America, Europe, and Australia (at least). Much of the published history focuses on the US contributions. We therefore do not yet have a well-rounded history of our subject. What is clear, though, is that the extraction of simple measures largely drove the development of the first real GIS, the Canada Geographic Information System or CGIS, in the mid-1960s (see Box 17.1). 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 (Section 14.3). 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 US 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 US streets, 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—a project that led eventually to the ODYSSEY GIS 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, and possibly to reducing the 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 US 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, to 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 was not until 1995 that the first country (Great 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, and 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, and this development led directly to the methods of