Geographic Information: Science, Systems, and Society

This chapter sets the conceptual framework for and summarizes the content of the book by addressing several major questions:

- What exactly is geographic information (GI), and why is it important? What is special about it?
- What new technological developments are changing the world of GI?
- How do GI systems affect the lives of average citizens?
- What kinds of decisions make use of geographic information?
- What is a geographic information system (GI system), and how would you recognize one?
- What is geographic information science (GI science), and why is it important to GI systems?
- How do scientists and governments use GI systems, and why do they find them helpful?
- How do companies make money from GI systems?

LEARNING OBJECTIVES

After studying this chapter you will:

- Know definitions of many of the terms used throughout the book.
- Be familiar with a brief history of GI science and GI systems.
- Recognize the sometimes invisible roles of GI systems in everyday life, business, and government.
- Understand the significance of GI science and how it relates to GI systems.
- Understand the many impacts that GI systems and its underpinning science are having on society and the need to study those impacts.

1.1 Introduction: What Are GI Science and Systems, and Why Do They 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 through the lower levels of its 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. We reside on the Earth and interact with others through work, leisure, and family pursuits. Keeping track of all 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 more information about the same place, or to inform people who live nearby. In addition, geography shapes the range of options that we have to address things that happen, and once they are made, decisions have geographic consequences. For example, deciding the route of a new high-speed railroad may be shaped by topographic and environmental considerations, and the chosen route will create geographic winners and losers in terms of access. Therefore geographic location is an important component of activities, policies, strategies, and plans.

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

The focus of this book is on geographic information, that is, information that records *where* as well as *what* and perhaps also *when*. We use the abbreviation *GI* throughout the book. GI systems were originally conceived as something separate from the world they represent—a special kind of information system, often located on a user's desk, dedicated to performing special kinds of operations related to location. But today such information pervades the Internet, can be accessed by our smartphones and other personal devices, and is fundamental to the services provided by governments, corporations, and even individuals. Locations are routinely attached to health records, to Twitter feeds and photographs uploaded to Flickr, and to the movements of mobile phone users and vehicles. In a sense, then, the whole digital world has become one vast, interconnected GI system. This book builds on what users of this system already know—that use of GI services is integral to many of our interactions through the Internet. Later chapters will describe, for example, how storage and management of more and more data entail use of the Cloud, how Big Data and Open Data have become ubiquitous (but not necessarily useful), and how Web-based GI systems have become a fact of life.

Underlying these changes are certain fundamentals, however, and these have a way of persisting despite advances in technology. We describe them with the term *GI science*, which we define as the general knowledge and important discoveries that have made GI systems possible. GI science provides the structure for this book because as educators we believe that knowledge of principles and fundamentals—knowledge that will still be valid many years from now—is more important than knowledge of the technical details of today's versions of GI technology. We use the acronym *GISS*—geographic information science and systems—at various points in this book to acknowledge the interdependence between the underpinning science and the technology of problem solving.

At the outset, we also observe that GI science is also fundamentally concerned with solving applied problems in a world where business practices, or the realpolitik of government decision making, are important considerations. We also discuss the practices of science and social science that, although governed by clearly defined scientific principles, are imperfectly coupled in some fast-developing areas of citizen science.

1.1.1 The Importance of Location

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 and require rapid, concerted, and coordinated responses by a wide range of individuals and organizations—such as responding to the major emergencies created by hurricanes or earthquakes (see Box 1.1). Virtually all aspects of human life involve location. Environmental and social scientists recognize the importance of recording location when collecting data; major information companies such as Google recognize the importance of providing mapping and driving directions and prioritizing searches based on the user's location; and citizens are increasingly familiar with services that map the current positions of their friends. Here are some examples of major decisions that have a strong geographic element and require GI:

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

If location and GI are important to the solution of so many problems, what distinguishes those problems from each other? Here are three bases for classifying problems. First, there is the question of *scale*, or level of geographic detail. The architectural design of a building involves GI, 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

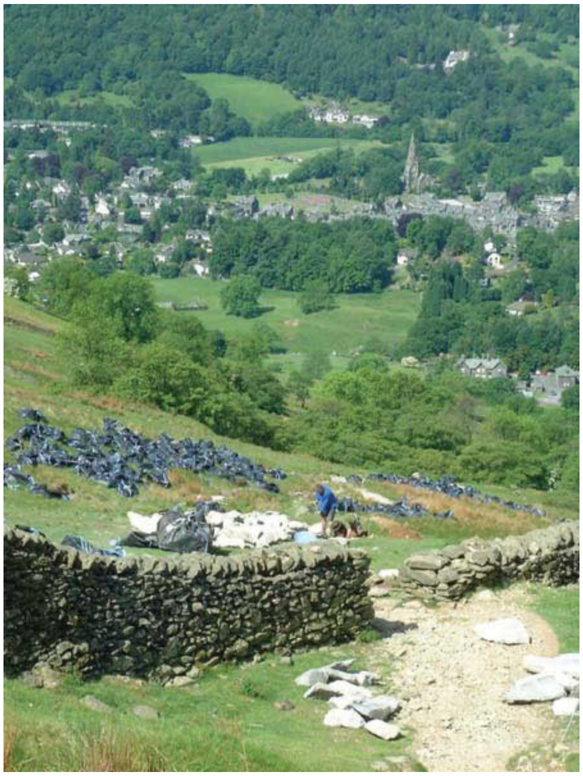


Figure 1.1 Maintaining and improving footpaths in national parks is a geographic problem.

Figure 1.2 Navigating tourist destinations is a geographic problem.

parcel, the vertical and subterranean extent of the building, 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 epidemics and the propagation of tsunamis across the Pacific Ocean (Box 1.1) are phenomena at a much broader and coarser scale.

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

Second, 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 at minimum cost to achieve such practical objectives as saving lives in an emergency, avoiding fines by regulators, or responding to civil disorder. Others are better characterized as driven by human curiosity. When GI is used to verify the theory of continental drift, to map distributions of glacial deposits, or to analyze the historic movements of people in anthropological or biosocial research (see Box 1.2 and Figure 1.5), there is no sense of an immediate problem that needs to be solved. Rather, the intent is to advance 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. Many of the tools and methods used by a retail analyst seeking a site for a new store are essentially the same as those used by a scientist in a government agency to ensure the protection of an endangered species, or a transport planner trying to ameliorate peak-hour traffic congestion in a city. Each requires the most accurate measurement devices, employs terms whose meanings have been widely shared and agreed on, produces results that are replicable by others, and in general follows all the principles of science that have evolved over the past centuries. The knowledge-exchange activities carried out between research organizations and the government and business sectors can be used to apply many of the results of curiosity-driven science to the practical world of problem solving.

The use of GI systems in support of science, routine application, and knowledge exchange reinforces the idea that science and practical problem solving are no longer distinct in their methods, as we will discuss later. As a consequence, GI systems are used widely in all kinds of organizations, from academic institutions to government agencies, not-for-profit organizations, and corporations. The use of similar tools and methods across so much of science and problem solving is part of a shift from the pursuit of curiosity within traditional academic disciplines to solution-centered, interdisciplinary teamwork.

Nevertheless, in this book we distinguish between uses of GI systems that focus on applications such as inventory or resource management, 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

Applications Box 1.1

The 2011 Tōhoku Earthquake and Tsunami

At 14.46 local time (05.56 GMT) on March 11, 2011, an undersea earthquake measuring 9.0 on the Richter scale occurred approximately 43 miles (70 kilometers) east of the Japanese coast of Tōhoku. This was the most powerful earthquake ever to have been scientifically documented in Japan, and the fifth most powerful earthquake in the world since modern record-keeping began in c. 1900. The earthquake moved Honshu (the main island of Japan) 2.4 m (8 ft) east and shifted the Earth on its axis by estimates of between 10 cm (4 in) and 25 cm (10 in). Of more immediate significance, the earthquake caused severe earth tremors on the main islands of Japan and triggered powerful tsunami waves that reached heights of up to 40.5 meters (133 ft) in Tōhoku Prefecture and traveled up to 10 km (6 mi) inland in Sendai.

Directly or indirectly, the earthquake led to at least 15,883 deaths and the partial or total collapse of over 380,000 buildings. It also caused extensive and severe structural damage in northeastern Japan (Figure 1.3B), including heavy damage to roads and railways, as well as fires in many areas and a dam collapse. In its immediate aftermath, 4.4 million households in northeastern Japan were left without electricity and 1.5 million without water. In the following days, the tsunami set in action events that led to cooling system failures, explosions, and major meltdowns at three reactors of the Fukushima Daiichi Nuclear Power Plant and the associated evacuation of hundreds of thousands of residents. The World Bank estimated the economic cost at US$235 billion, making it the costliest natural disaster in world history.

All of this happened to a very advanced economy in an earthquake-prone region, which was almost certainly the best prepared in the world for a natural disaster of this kind. GI systems had been used to assemble information on a full range of spatially distributed

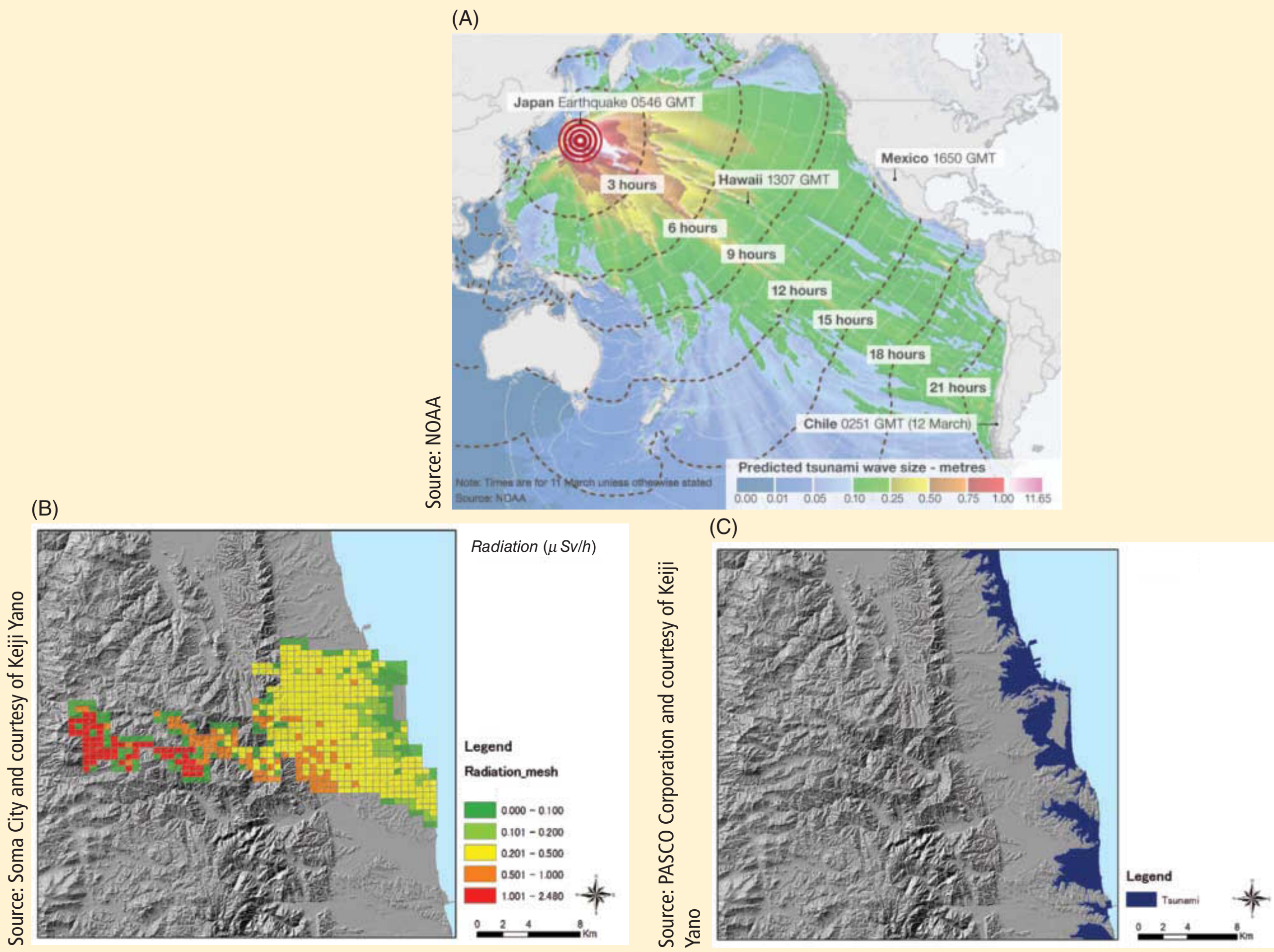


Figure 1.3 (A) The passage of the tsunami arising out of the Great East Japan (Tōhoku) earthquake of March 11, 2011. It had subsequent effects on Soma City in terms of (B) radiation (measured in μSv/h (micro Sievert per hour) and (C) tsunami inundation.

phenomena—including the human population, the built environment, and transportation infrastructure—in preparation for a major earthquake disaster and protection against many of its foreseeable consequences.

Yet the science of predicting the location, timing, and intensity of earthquakes has made little progress over the past century. A magnitude-9.0 earthquake is a very rare event and so did not fall within any disaster-management scenario prior to the event. For example, the Fukushima reactors had been built to withstand a magnitude-8.6 earthquake on the basis of historic occurrences plus a safety margin: but not an event of magnitude 9.0. However, even when major events are unforeseen, GI science and systems are integral to response and recovery in the short term (e.g., alerting populations to the imminent arrival of a tsunami, coordinating citizen reports of how localities have been affected, and organizing evacuation), the medium term (e.g., managing the disruption to industrial supply chains), and the long term (e.g., prioritizing repair and replacement of damaged transport infrastructure). All these actions take place in an organizational context. Early warning systems are very much an international effort. In terms of addressing effects after the event, the Tōhoku earthquake raised issues that were best addressed at the national level, whereas much of the implementation was best effected at local levels.

The three Ps of disaster management are prevention, preparedness, and protection. GI science and systems are integral to each of them.

evidence is found). Finding new locations for retailers, with its focus on design, is an example of a normative application of GI systems. But 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.

Design is concerned with improving the world—with decisions that when implemented achieve certain desired objectives, such as constructing new housing subdivisions, developing conservation plans, or defining sales territories. In recent years the term *geodesign* has become a popular way of referring to design decisions at geographic scales, supported by GI systems. All of us would like to design improvements to the world, and GI systems are valuable tools for doing so. Although most work with GI systems is considerably more mundane, it is always good to bear its grander potential in mind. As we show in Section 14.4, geodesign combines two important functions of GI systems—the ability to capture new ideas through sketching (creating/editing new features) and the ability to evaluate them and assess their impacts. A user might sketch a design for a new development, for example, and ask the GI system to predict its impacts on transportation, groundwater, and air pollution.

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

The third way in which problems can be distinguished is on the basis of their *time scale*, ranging in human terms from the dynastic (perhaps thousands of years; see Box 1.2) to the diurnal, but very much longer with respect to understanding geological or geomorphological change. At one end of the human time spectrum, some decisions are operational and are required for the smooth day-to-day functioning of an organization, such as how to control electricity inputs into grids that experience daily surges and troughs in usage. At slightly longer timescales, tactical decisions might include where to cut trees in next year's forest harvesting plan. Still other decisions are more infrequent and strategic in nature, such as those required to give an organization long-term direction, as when a retailer decides to expand or rationalize its store network (Figure 1.4). At the far end of the human time spectrum, Box 1.2 describes how the geographic

Figure 1.4 Many store location principles are generic across different retail markets, as with Tesco's investment in Ostrava, Czech Republic.

distributions of family names, past and present, can be used to indicate how settled (or otherwise) is the population of different places, and even the geography of the DNA of long-settled residents consequent on population movements in early human history (see Box 1.4).

Although humans like to classify time frames into hours, days, years, centuries, and epochs, the real world is somewhat more complex than this, and these distinctions may blur—what is theoretically and statistically a 1000-year flood in a river system 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. GI databases are often *transactional* (see Section 9.9.1), meaning that they are constantly being updated as new information arrives, unlike paper maps, which stay the same once printed.

Applications are discussed to illustrate particular principles, techniques, analytic methods, and management practices (such as risk minimization) as these arise throughout the book.

1.1.2 Spatial Is Special

The adjective *geographic* refers to the Earth's surface and near surface, at scales from the architectural to the global. This 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 GI systems 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. Techniques that are integral to GI systems have even been applied to the analysis of genome sequences on DNA. So the discussion of analysis

Applications Box 1.2

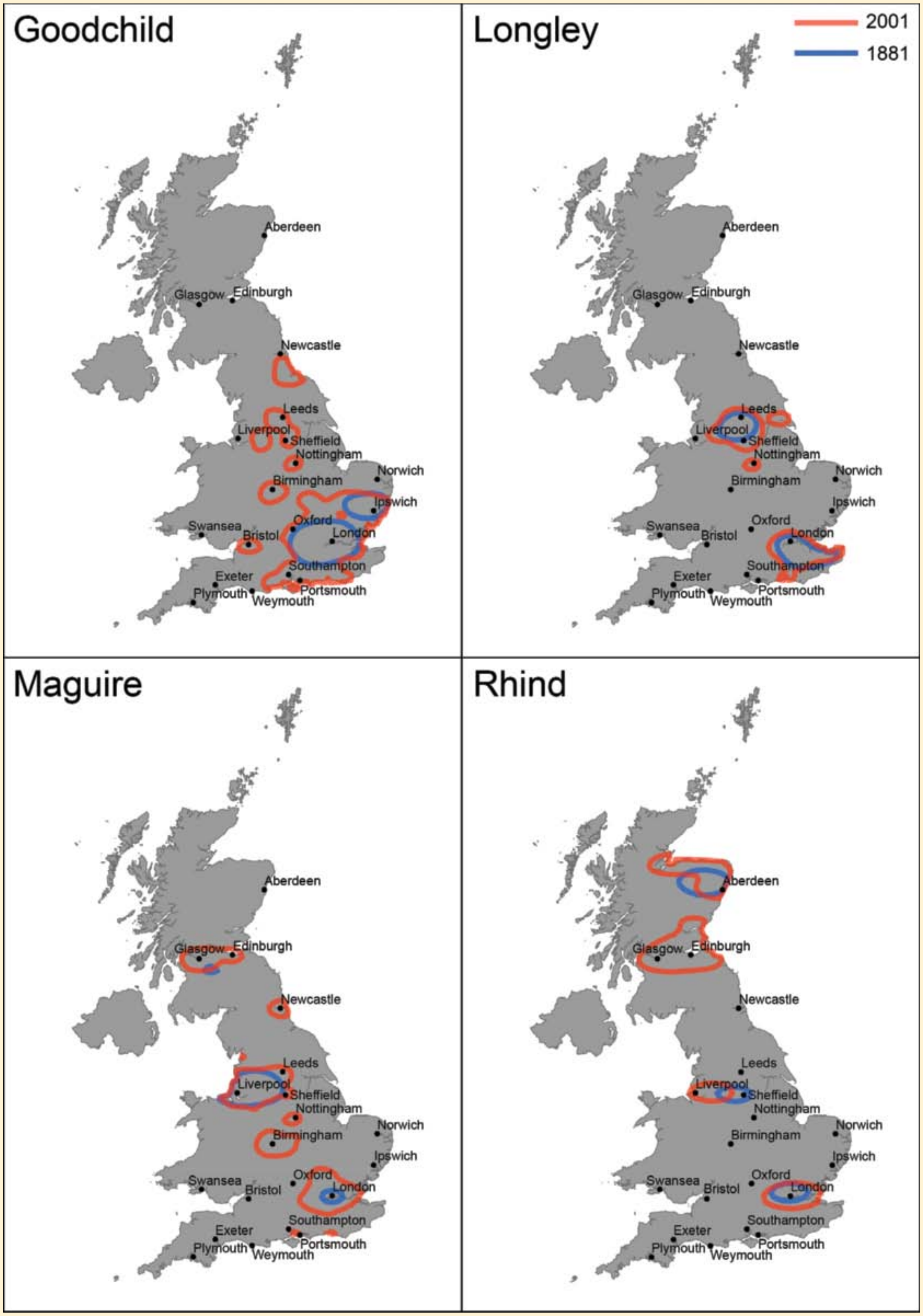
Researching Family Histories and Geo-Genealogy

As individuals, many of us are interested in *where*, in general terms, we came from at different points in recorded human history—for example, whether we are of Irish, Spanish, or Italian descent. More specific locational information can provide clues about the work and other lifestyle characteristics of our ancestors. Some of the best clues to our ancestry may come from our surnames (family names) because many surnames indicate geographic origins to greater or lesser degrees of precision (such clues are less important in some Eastern societies, where family histories are generally much better documented). Research at University College London uses GI systems to analyze historic and present-day lists of names to investigate the changing local and regional geographies of surnames across the world. Figure 1.5 illustrates how the bearers of four selected Anglo-Saxon names in Great Britain (the ancestors of the authors of this book) have mostly stayed put in those parts of the island where the names first came into common parlance at some point between the 12th and 14th centuries—although some have evidently migrated to urban centers.

It also turns out that the mix of names with similar geographic origins in any given area can provide a good indication of regional identity. Figure 1.6, derived from the PhD thesis of Jens Kandt, presents a regionalization of Great Britain on the basis of the present-day residences of bearers of different surnames. (This is essentially a geography of rural Britain. Note that the major urban areas have been excluded because they are characterized by mixes of names arising from urban–rural, interregional, and international migration over the last 200 or so years).

All of this is most obviously evident for Great Britain and many of the countries of Europe, where populations have remained settled close to the locations at which their names were first coined. But there is also evidence to suggest that the spatial patterning of names in former colonies, such as North America, Australia, and New Zealand, is far from random. Figure 1.7 illustrates this for the surname Singleton, which can be used to build evidence about the migration patterns of bearers of this name from their documented origins in northwest England.

Fundamentally, this is curiosity-driven research, driven by the desire among amateur genealogists to discover their roots. But the same techniques can be used to represent the nature and depth of affiliation that people feel toward the places in which they live. Moreover, the work of Sir Walter Bodmer and colleagues (Box 1.4) is highlighting probable links between surnames and genetics, rendering this curiosity-driven research relevant to the development of drug and lifestyle interventions.

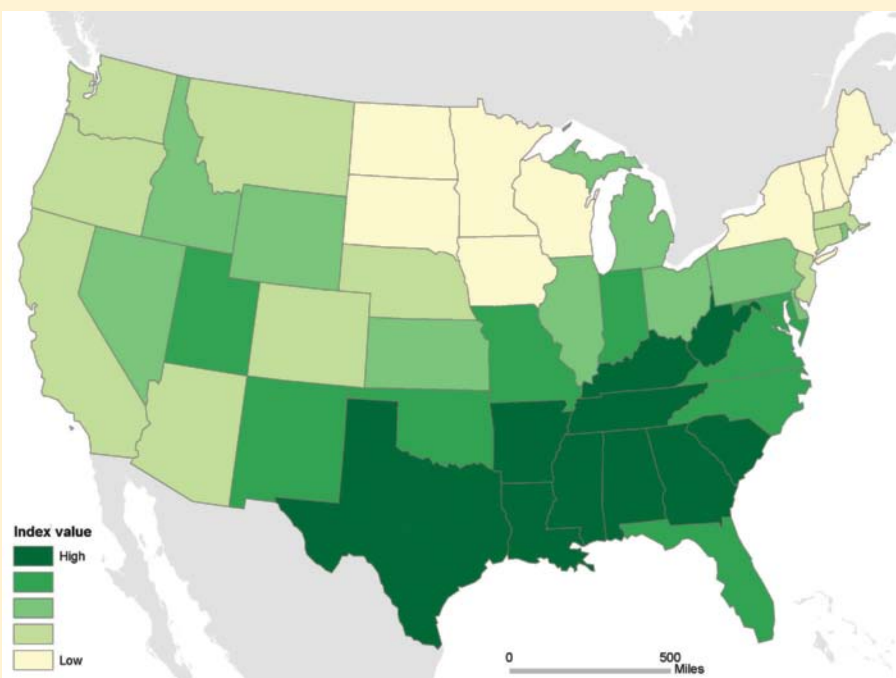


Courtesy: James Cheshire

Figure 1.5 The Great Britain Geography of the Longleys, Goodchilds, Maguires, and Rhinds. In each case the shorter (blue) line delineates the smallest possible area within which 95% of name bearers reside, based on 1881 Census of Population figures, and the outer (red) line encloses the smallest area that accommodates the same proportion of adult name bearers according to a recent address register.

Courtesy: Jens Kandt

Figure 1.6 A regionalization based on the coincidence of distinctive patterns of surnames, showing the southern part of Great Britain. Major urban areas do not fit into this regional pattern because their residents are drawn from a wide range of national and international origins.



Courtesy: Alex Singleton

Figure 1.7 The Singleton family name derives from a place in northwest England, and understandably the greatest concentration of this name today still occurs 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.

Technical Box 1.3

Some Technical Reasons Why Geographic Information Is Special and Why GI Science and Systems Have Developed

- It is multidimensional, because *two* coordinates must be specified to define a location, whether they be *x* and *y* or latitude and longitude; and a third coordinate is needed when elevation is important.
- It is voluminous because a geographic database can easily reach a terabyte in size (see Table 1.2).
- It may be collected by citizens, governments, or other organizations, and it may prove useful to pool information from these diverse sources.
- It may be represented at different levels of spatial resolution, for example, by using a representation equivalent to a 1:1 million-scale map or a 1:24,000-scale one (see Section 3.7).
- It may be represented in different ways inside a computer (see 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 4.8.
- It requires many special methods for its analysis (see Chapters 13 and 14).
- It may be transformed to present different views of the world, for example, to aid interpretation.

in this book is of *spatial* analysis (see Chapters 13 and 14), 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. In this book we have tended to avoid *geospatial*, preferring *geographic*, and we use *spatial* where we need to emphasize generality.

Although there are subtle distinctions between the terms *geographic(al), spatial,* and *geospatial,* for many practical purposes they can be used interchangeably.

People who encounter GI 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 GI spawned an entire industry, if geriatric information has not done so to anything like the same extent? Why are there unlikely to be courses in universities specifically in geriatric information science and systems? Part of the answer should be clear already: almost all human activities and decisions involve a location component, and the location component is important. Another reason will become apparent in Chapter 2, where we will see that working with GI 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, Evidence, Knowledge, and 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 1.1. There are no universally agreed-on definitions of these terms. 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 on 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, such as sensor measurements of 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 data set. The internal meaning of the data is irrelevant in such considerations. Data (the noun is the plural of datum) are assembled together in a

Table 1.1 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 data sets or scenarios
Information ↑	*Easy*	Contents of a database assembled from raw facts
Data	*Easy*	Raw geographic facts

database (see Chapter 9), and the volumes of data that are required for some typical applications are shown in Table 1.2.

The term *information* can be used either narrowly or broadly (and we use both in this book). 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 data sets, 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. GI systems are very useful for doing the latter because of the tools they provide for combining information from different sources.

GI systems do 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, as when an experienced hiker chooses not to set off into unfamiliar terrain having read about it and taken stock of the weather forecast. 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* and *tacit*. Knowledge is codifiable if it can be written down and transferred relatively easily to others. Tacit

Table 1.2 Potential GI database volumes in bytes 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 (2^{20})	Single data set in a small project database
1 gigabyte	1 000 000 000 (2^{30})	Entire street network of a large city or small country
1 terabyte	1 000 000 000 000 (2^{40})	Elevation of entire Earth surface recorded at 30 m intervals
1 petabyte	1 000 000 000 000 000 (2^{50})	Satellite image of entire Earth surface at 1 m resolution
1 exabyte	1 000 000 000 000 000 000 (2^{60})	A possible 3-D representation of the entire Earth at 10 m resolution
1 zettabyte	1 000 000 000 000 000 000 000 (2^{70})	One-fifth of the capacity (in 2013) of U.S. National Security Agency Utah Data Center

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.
- 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. We may hold conflicting information, but 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 different geographic settings, 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. It is given with some understanding of the likely consequences of various actions and assessment of which is or are most beneficial. Almost invariably, knowledge 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 GI Science and Systems

GI systems are computer-based tools for collecting, storing, processing, analyzing, and visualizing geographic information. They are tools that improve the efficiency and effectiveness of handling information about objects and events located in geographic space. They can be used to carry out many useful tasks, including storing vast amounts of GI in databases, conducting analytical operations in a fraction of the time they would take to do by hand, and automating the process of making useful maps. GI systems also process information, but there are limits to the kinds of procedures and practices that can be automated when turning data into useful information.

The question of whether and how such selectivity and preparation for purpose actually adds value, or whether the results add insight to interpretation in geographic applications, falls into the realm of GI science. This rapidly developing field is concerned with the concepts, principles, and methods that are put into practice using the tools and techniques of GI systems. It provides sound principles for the sample designs used to create data and the ways in which data can be turned into information that is representative of a study area. GI science also 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.

Like all sciences, an essential requirement of GI 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 themselves add to the existing body of knowledge
- Best attempts to attain 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)
- Generalization from partial representations that are developed for analytical purposes to the wider objective reality that they purport to represent

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 of knowledge about the world, including information both on how it *looks*—that is, its *forms*—and how it *works*—that is, 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 ecosystems,

Figure 1.8 Social processes, such as carbon dioxide emissions, modify the Earth's environment independent of location.

through the burning of fossil fuels, the felling of forests, and the cultivation of crops (Figure 1.8). Still 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. This is because knowledge about how it works 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, because 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 if we know both how slope stability is generally affected 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 a GI system as a problem-solving tool lies in its ability to combine the general with the specific, as in this example. A GI system designed to solve this problem would contain knowledge of local slopes, in the form of computerized maps, and the programs executed by the GI system would reflect general knowledge of how slopes affect the probability of mass movement under extreme weather conditions. The *software* of a GI system captures and implements general knowledge, whereas the *database* of a GI system represents specific information. In that sense, a GI system resolves the long-standing debate between nomothetic and idiographic camps by accommodating both.

GI systems solve the ancient problem of combining general scientific knowledge with specific information and give practical value to both.

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

(A)

(B)

Figure 1.10 Predicting landslides requires general knowledge of processes and specific knowledge of the area—both can be brought together in a GI system.

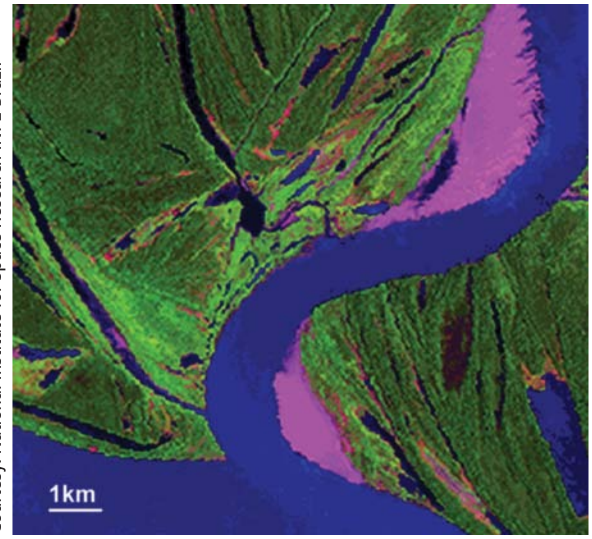


Figure 1.11 A classified Landsat image (at 30-meter resolution) of part of the Amazon region of Brazil.

This perspective is consistent with our understanding of *places* in the world as sites at which unique relations develop among people and the locations that they occupy and the accumulated effects of these relations over time. GI systems provide ways of generalizing about and between places, albeit in ways that acknowledge differences between them. Place-based methods in GI systems make it possible to think of geography as repetitive (where in the world is like this place?) while at the same time remaining sensitive to the unique context of unique places.

General knowledge about unique places comes in many forms. Classification is perhaps the simplest and most rudimentary and is widely used in 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. Such rules can be captured in the data model of a GI database (see Chapter 7).

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 laboratory that is available for understanding the effects of many factors on unique places in the social and environmental sciences, and considerable uncertainty is generated when we are unable to control for all conditions. These problems are compounded in the social 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, whereas market researchers use spatial interaction models, in conjunction with GI systems, to predict how many people will shop at each shopping center in a city, substantial errors will occur in the predictions—because people are in significant part autonomous agents. 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 GI systems 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. "Good" usually means "good enough for this specific application" in GI systems applications.

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, shortest distance, least time, greatest profit or 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 the design of GI systems. For discussion of the use of such mixed objectives see Section 15.4. This topic is taken up again in Chapter 16 in the context of estimating the return on investment of GI systems.

Often a problem will have *multiple objectives*, each of which is measured in a different way. 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

Today it is a truism to reflect that geographic information is everywhere and that we access and divulge it from many different sources and in many different contexts. A system is usually thought of as a *bounded* set of components, and in a world in which geographic information is transmitted and shared across physical, public/private, political, and institutional *networks*, it hardly seems to make sense to think in terms of bounded systems at all. However, although geographic information may be pervasive and ubiquitous, the notion of a networked system remains useful in understanding the components of the tools that in turn underpin GI science (Figure 1.12).

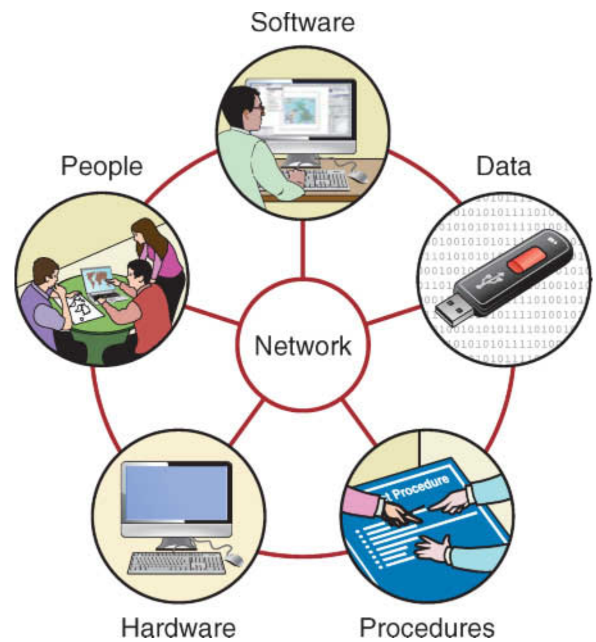


Figure 1.12 The six component parts of a GI system.

Today, almost all GI software products are designed as components of a network. *Cloud computing* (see Chapter 10) is a colloquial expression that is widely used in business to describe the supply of hosted services to industry and commerce, using computer infrastructure that is located remotely. Networks of large numbers of computers in different locations may be used for collection, storage, and analysis of data in real time. Cloud computing makes it possible to gain convenient, on-demand network access to a shared pool of computer hardware, software, data storage, and other services. Many of these components were previously colocated prior to the innovations of fast wide-area networks; powerful, inexpensive server computers; and high-performance virtualization of computer hardware.

In terms of hardware, the user's device is the *client*, connected through the network to a *server*, or a *server farm* in the Cloud, that is designed to handle 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 (as with a mobile phone application, for example). In Cloud computing applications, most or all of the computation is performed remotely.

Uptake and use of the Internet to link computers has been remarkably quick, diffusion being considerably faster than almost all comparable innovations (for

Table 1.3 World Internet usage and penetration statistics as of June 30 2012. (Source: www.internetworldstats.com)

World Region	2012 Population	Internet Users (Dec. 2000)	Internet Users (June 2012)	Penetration (% Population)	Growth 2000–12	Users % of all Table
Africa	1,073,380,925	4,514,400	167,335,676	15.6%	3,607%	7.0
Asia	3,922,066,987	114,304,000	1,076,681,059	27.5%	842%	44.8
Europe (inc. EU)	820,918,446	105,096,093	518,512,109	63.2%	393%	21.5
Middle East	223,608,203	3,284,800	90,000,455	40.2%	2,640%	3.7
North America (excl. Canada)	348,280,154	108,096,800	273,785,413	78.6%	153%	11.4
Latin America/ Caribbean	593,688,638	18,068,919	254,915,745	42.9%	1,311%	10.6
Oceania/Australia	35,903,569	7,620,480	24,287,919	67.6%	219%	1.0
WORLD TOTAL	7,017,846,922	360,985,492	2,405,518,376	34.3%	566%	100.0

example, the radio, the telephone, and the television). RealTimeStatistics.org estimated that in 2013 some 2.4 billion of the world's 7 billion population were Internet users, although stark variations in Internet availability and usage remain—see Table 1.3.

Many of the early Internet applications of GI systems remain in use, in updated form, today. They range from using GI systems on the Internet to disseminate information on the location of businesses (e.g., www.yell.com), to consolidated lists of available goods and services, to direct revenue generation through subscription services, to helping members of the public to participate in important local, regional, and national debates. The Internet has become very popular as a vehicle for delivering business GI system applications for several reasons. It provides an established, widely used platform and accepted standards for interacting with information of many types. It also offers a cost-effective way of linking 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.

Internet-enabled devices became portable in the early 2000s (see Section 10.3) with the wide diffusion of location-aware smartphones and other handheld devices and the availability of wireless networks in public places such as airports and railway stations. The subsequent innovation of 3G and 4G mobile broadband now routinely allows portable and in-vehicle devices to deliver *location-based services* (see Section 10.3.2) to users on the move. Users receive real-time geographic services such as mapping, routing, traffic congestion, and geographic yellow pages. These services are usually funded directly or indirectly through advertising, with Google perhaps the most obvious exponent of understanding the importance of location in delivering targeted advertising.

We now turn to consider the other components of a GI system. First, the user's *hardware* is the device that the user interacts with directly in carrying out GI system 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 more options and much more freedom because GI system functions can also be delivered through smartphones, notebooks, and in-vehicle devices.

The second component is the software programs that represent the world by running locally in the user's machine or remotely in the Cloud. Increasing numbers of users manipulate geographic information using executable *open-source software* code that is often freely available for download across the Web. Users can execute this code and also modify it if they wish. Other *open software* is also available for use as linked executable files, although the computer code that was used to generate it is not made available by its authors and so cannot be modified by other users. Both of these types of software may be made available by their authors in the interests of solving particular problems, or they may be made available as part of larger linked software libraries, such as the R project for statistical computing and graphics (www.r-project.org/). Some open software libraries have a focus on geographic problem solving and as such are described as GI systems—with the Quantum GIS Project (www.qgis.org/) providing perhaps the best contemporary example. The international "Geo for All" initiative (www.geoforall.org/) seeks to combine the potential of e-learning tools and open-source software to strengthen education in GI science, with particular emphasis on fast-changing needs in low-income countries.

Still other software is sold as closed commercial packages by established GI-system vendors, such as Autodesk Inc. (San Rafael, California; www.autodesk.com), Esri, Inc. (Redlands, California; www.esri.com), Intergraph Corp. (Huntsville, Alabama; www.intergraph.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 GI system produced and marketed by an academic institution rather than by a commercial vendor (for further information on GI system sources see Chapter 6).

Michael de Smith, along with two of the authors of this book, has produced an online guide (www.spatialanalysisonline.com) and book that is intended to raise awareness of the range of commercial and open software options that are available and the quality of the results that may be produced.

It is not always easy to compare the software solutions suggested by Internet searches.

The third component of a GI system is the data, which provide the foundations for digital representation of selected aspects of some specific area of the Earth's surface or near surface. 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 (e.g., installation of new underground pipes, creation of new customer accounts, and daily service-crew activities). As Open Data (see Section 17.4) become more freely available for download, the data that are downloaded for particular projects are frequently obtained from different sources, and thus the constituents of a GI database may have originally been assembled or collected for widely varying purposes and to widely varying standards. We discuss some of the implications of this in Chapters 5 and 17. The size of a project database may be as small as a few megabytes (a few million bytes, easily stored on a DVD) or as large as many terabytes (see Table 1.2).

Big Data is a term that has come to describe individual or linked data sets that are too large and complex to process using standard data-processing software or database-management tools on standard computer servers (see Box 17.2). Geographic databases are often big, not least of all because they include large numbers of location coordinates and sometimes many raster images. This poses significant challenges of data capture, storage, maintenance, sharing, visualization, and analysis. Scientists regularly encounter limitations in their abilities to manage and analyze Big Data in fields such as genomics (see Box 1.4) and meteorology. These discipline-specific problems are becoming more pervasive as more and more data are gathered using ubiquitous information-sensing mobile devices, remote sensing, radio-frequency identification (RFID) tagging, and wireless sensor networks. The world's technological per capita capacity to store information has roughly doubled every 40 months since the 1980s, and as of 2012, an average of 2.5 petabytes of data were created every day. This poses important management challenges for organizations that need to decide who should own Big Data initiatives that straddle their operation. The management and analysis of Big Data are closely associated with developments in Cloud computing.

Major GI applications also require management. An organization must establish procedures, lines of reporting, control points, and other mechanisms for ensuring that its GI activities meet its needs, stay within budgets, maintain high quality, avoid breaking the law, and generally meet the needs of the organization. These issues are explored in Chapters 16, 17, and 18.

Finally, a GI system is useless without the people who design, program, and maintain it, supply it with data, and interpret its results. The people of a GI system 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 GI community. Most important, they will have a capacity for critical spatial thinking, allowing them to filter the message of spatial data through the medium of a GI system.

1.5 The Disciplinary Setting of GI Science and Systems (GISS)

At this point we review the emergence of GI science, the ways in which it is used, and its relationship with other disciplines. We discuss the significance of its underpinning technologies to business as well as some of the issues arising from its use in government. It should already be apparent that computer science is important because GI systems are computer applications, and its perspective is addressed in Section 1.5.4. Similarly geography, the science and

Biographical Box 1.4

Sir Walter Bodmer, Human Geneticist

Sir Walter Bodmer (Figure 1.13A) is a German-born British human geneticist. He studied mathematics and statistics at Cambridge University, doing his PhD under the renowned statistician and geneticist Sir Ronald A. Fisher before joining Nobel-Prize-winning microbiologist Joshua Lederberg's laboratory in the Genetics Department of Stanford University in 1961. He was an early pioneer of the use of computing to study population genetics, and after a period as a faculty member at Stanford, he left to become the first Professor of Genetics at Oxford University in 1970.

Population genetics is the study of the changing distribution of gene variants (or alleles) under the influence of four important evolutionary processes: natural selection, genetic drift, mutation, and gene flow. Walter was one of the first to suggest the idea of identifying the physical and functional characteristics of the 20,000–25,000 genes of the human genome. This idea was subsequently pursued in the Human Genome Project, which in important respects remains the ultimate investigative analysis using Big Data.

Geography is central to study of the human genome, for the very good reason that most families remain settled in one part of the world for many generations. In 2005 Walter was appointed to lead a major (£2.3 million/ $3.8 million) project to examine geographic variations in the genetic makeup of the people of the British Isles. The aim of this project is to measure the genetic profiles of long-established families who can trace their recent ancestry to particular locations and to relate this to historical and archaeological evidence of invasion and settlement. The DNA samples of thousands of volunteers have been analyzed in ways that reveal the biological traces of successive waves of colonizers of Britain—such as the original ancient British settlers, the Anglo-Saxons, and the Vikings. The resulting genetic map (Figure 1.13B) shows, for example, that the Viking invasion of Britain was predominately by Danish Vikings, whereas the Orkney Islands were settled by Norwegian Vikings.

Walter was a pioneering advocate of public engagement with science and technology and remains very active in this field. He was elected a Fellow of the Royal Society in 1974 and was awarded the Society's Royal Medal in 2013 for seminal contributions to population genetics, gene mapping, and our understanding of familial genetic disease.

Check out the People of the British Isles project at www.peopleofthebritishisles.org.

Courtesy: Wellcome Trust POBI Project

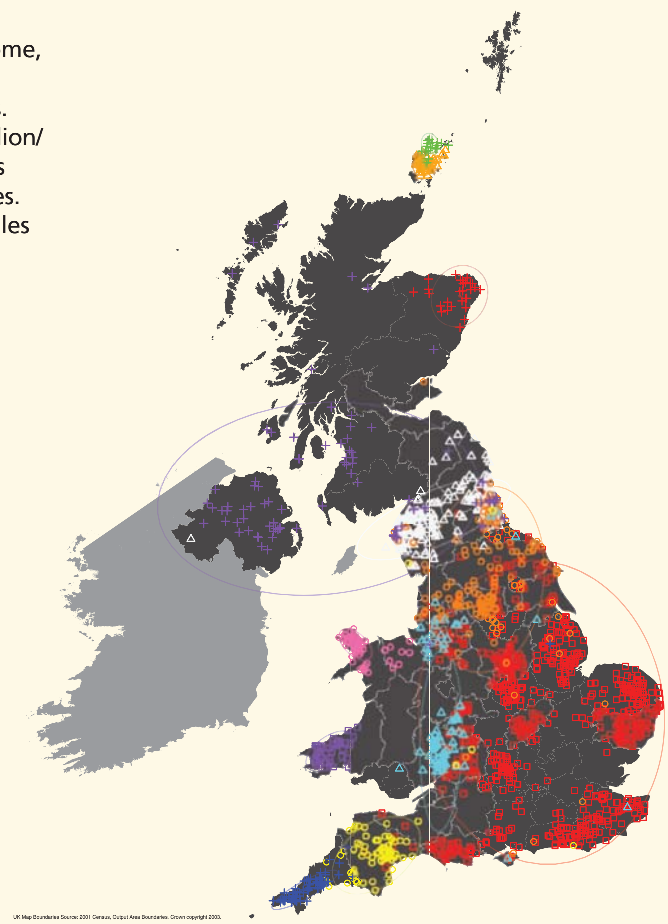


Figure 1.13 (A) Walter Bodmer, human geneticist; and (B) a genetic map of the United Kingdom, with different colors denoting the genetic groups of long-settled residents.

study of phenomena distributed over the surface and near-surface of the Earth, also provides much of the disciplinary context of GI science and is addressed in Section 1.5.5. Finally, we consider some of the ways in which the use of GI is embedded in society.

1.5.1 The Historical Perspective

Although the coining of the term "GI science" can be traced to Goodchild's paper published in 1992, greater controversy surrounds the emergence of GI systems because parallel developments occurred in North America, Europe, and Australia (at least). Until recently, it was convenient to think of geographic information handling as confined to a freestanding, self-contained, computer-based system, like many other pieces of equipment. Indeed, prior to the innovation of the Internet, or the intranets of large organizations, the system was a physically isolated system of computer hardware, software, and data, such as a desktop computer, with no connections to the rest of the world. It was the extraction of simple geographic measures that largely drove the development of the first GIS to be described as such, the Canada Geographic Information System or CGIS, in the mid-1960s. 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 was (and still is) notoriously difficult to measure accurately from a paper map (see Section 14.1.1). CGIS was planned and developed as a measuring tool, a producer of tabular information, rather than as a mapping tool.

The first GI system 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 (Dual Independent Map Encoding) program created digital records of all U.S. 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 software of the late 1970s.

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

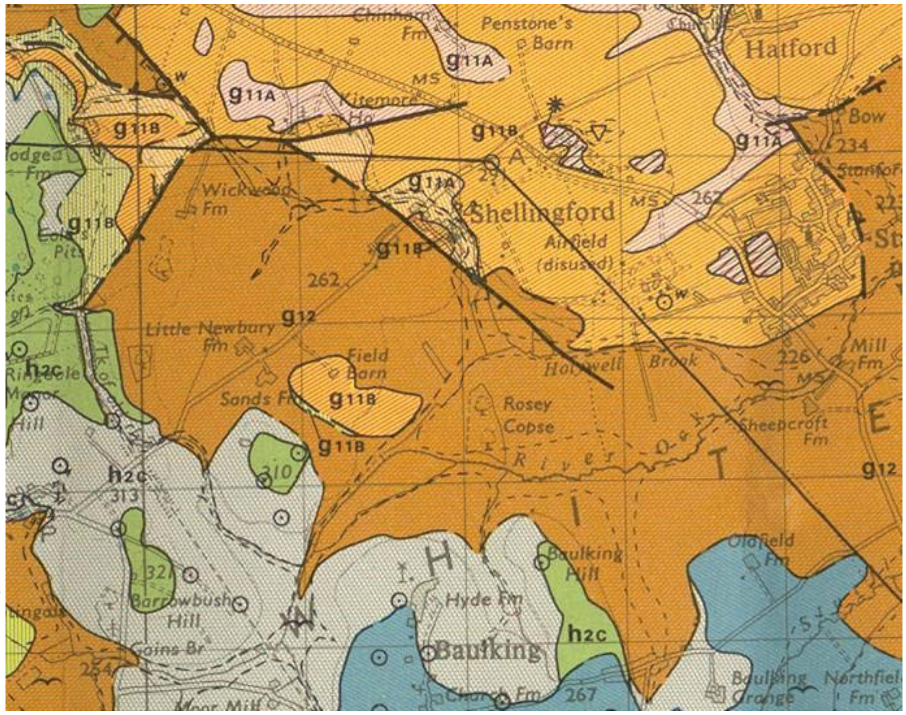
In a largely separate development during the latter half of the 1960s, cartographers and mapping agencies had begun to ask whether computers might be adapted to their needs and possibly to reducing the costs and shortening the time of map creation. The UK Experimental Cartography Unit (ECU) pioneered 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 1.14). National mapping agencies, such as Britain's Ordnance Survey, France's Institut Géographique National, and the U.S. Geological Survey and Defense Mapping Agency (now the National Geospatial-Intelligence Agency) began to investigate the use of computers to support the editing and updating 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 limits of the technology of the time ensured that it was not until 1995 that the first country (Britain) achieved complete and detailed digital map coverage in a database.

Remote sensing also played a part in the development of GI systems, 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, and although the early spy satellites used conventional film cameras to record images, digital remote sensing began to replace them in the 1960s. 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 positional control in use today (see Section 4.7). Military needs were also responsible for the initial development of the Global Positioning System (GPS; see Section 4.9 and Box 17.7).

Many technical developments in GI systems originated in the Cold War.

GI systems 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.

Figure 1.14 Section of the 1:63,360 scale geological map of Abingdon, UK—the first known example of a map produced by automated means and published in a standard map series to established cartographic standards.



At the time a modest computing system—far less powerful than today's personal computer—could be obtained for about $250,000 (about $750,000 in 2015 prices) and the associated software for about $100,000 ($300,000 today). Even at these prices, the benefits of consistent management using GI systems and the decisions that could be made with these new tools substantially exceeded the costs. The market for GI software continued to grow, computers continued to fall in price and increase in power, and the GI software industry has been growing ever since.

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

As indicated earlier, the history of GI systems is a complex story, much more complex than can be described in this brief history, but Table 1.4 summarizes developments from this early history to more recent commercial developments and the wide advent of Open Data and open-source software.

1.5.2 The Business Perspective

GI systems provide the underpinning technology for GI science, and many people play many roles in their development. Important activities range from software development to championing the importance of the spatial dimension in the activities of an organization through spatial data analysis. The business activities of many established companies are based on the collection of geographically referenced data or activities that build on this, such as value-added reselling of data, consulting, app development, training, system integration, software design, and so forth. Many new opportunities (particularly for start-up companies) are arising from use of open-source software or Open Data (see Section 1.5.3), where the underpinning costs of data or software 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 section looks at the diverse roles that people play in the business of GI systems, and is organized by the major areas of human activity associated with it.

1.5.2.1 The Software Industry

Many of the roots of the development of GI systems can be traced to the commercial development of off-the-shelf software packages that began in the 1980s. Today's commercial solutions are manifest in a wide range of forms. Thus, for example, the major software vendor Esri, Inc. (Redlands, California) today sells a family of GI system products under the ArcGIS brand name to service the disparate needs of its diverse user base. At its core are three niche desktop systems: Basic, for viewing spatial data, creating layered maps, and performing rudimentary spatial

Table 1.4 Major events that shaped the development of GI systems.

The Era of Innovation	
1963	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*.
1964	The Harvard Laboratory for Computer Graphics and Spatial Analysis is established under the direction of Howard Fisher. SYMAP, the first raster system for automated cartography, is created by Harvard researchers in 1966.
1967	The U.S. Bureau of Census develops DIME-GBF (Dual Independent Map Encoding—Geographic Base File), a data structure and street-address database for the 1970 U.S. Census.
1969	ESRI (Environmental Systems Research Institute) Inc. formed by Jack Dangermond, previously at the Harvard Lab, and his wife Laura.
1969	M&S Computing (subsequently renamed Intergraph Corp.) formed by Jim Meadlock and four others, who worked on guidance systems for Saturn rockets.
1969	Publication of *Design with Nature* by Ian McHarg; introduces many of the basic concepts of geographic analytics, including the map overlay process (see Section 13.2.4).
1972	Landsat 1 launched—the first of many civilian remote-sensing satellites.
1973	First digitizing of maps by a national mapping agency in a production system (Ordnance Survey, Great Britain).
The Era of Commercialization	
1981	ESRI ArcInfo launched—the first major commercial GI system based on the vector data structure and a relational database.
1985	The Global Positioning System gradually becomes a major source of data for navigation, surveying, and mapping.
1986	MapInfo Corp.'s software develops into first major desktop GI system. It defines a new standard for GI systems, complementing earlier software.
1986	The British Broadcasting Corporation (BBC) launches the Domesday machine to mark the 900th anniversary of the original Domesday Survey. Based on a microcomputer system with some GI system functionality, it held data and information provided by a million volunteers. The 21,000 GI files comprised maps, millions of words of text, and photographs of all of Britain, all cross-referenced and accessible by location and theme.
1988	TIGER (Topologically Integrated Geographic Encoding and Referencing), a follow-up from DIME, is described by the U.S. Census Bureau. Low-cost TIGER data stimulate rapid growth in U.S. business GI systems.
1992	The 1.7 GB Digital Chart of the World, sponsored by the U.S. Defense Mapping Agency (now NGA), is the first integrated 1:1 million-scale database offering global coverage.
1994	Executive Order 12906, signed by President Clinton, leads to creation of U.S. National Spatial Data Infrastructure (NSDI), clearinghouses, and the Federal Geographic Data Committee (FGDC).
1994	OpenGIS (subsequently Open Geospatial) Consortium of vendors and users established to improve interoperability between software.
1995	Complete conversion of the 240,000 topographic maps in the Great Britain national map coverage at 1:1,250, 1:2,500 and 1:10,000 scales into digital form.
1996	Innovation of Internet GI system products by Autodesk, ESRI, Intergraph, and MapInfo.
1996	MapQuest Internet mapping service launched.
1999	New generation of commercial satellites launched with submeter resolution capability (e.g., IKONOS and Quickbird).
The Era of Openness and Pervasive Use	
2000	The United States ceases the deliberate degradation (or "selective availability") of U.S. Global Positioning System (GPS) signals for national security purposes to encourage commercial and civilian applications using GPS technology.
2003	U.S. Federal e-government initiative provides "One-Stop" access to geospatial data and information (now part of geo.data.gov/geoportal/).

Table 1.4 (*continued*)

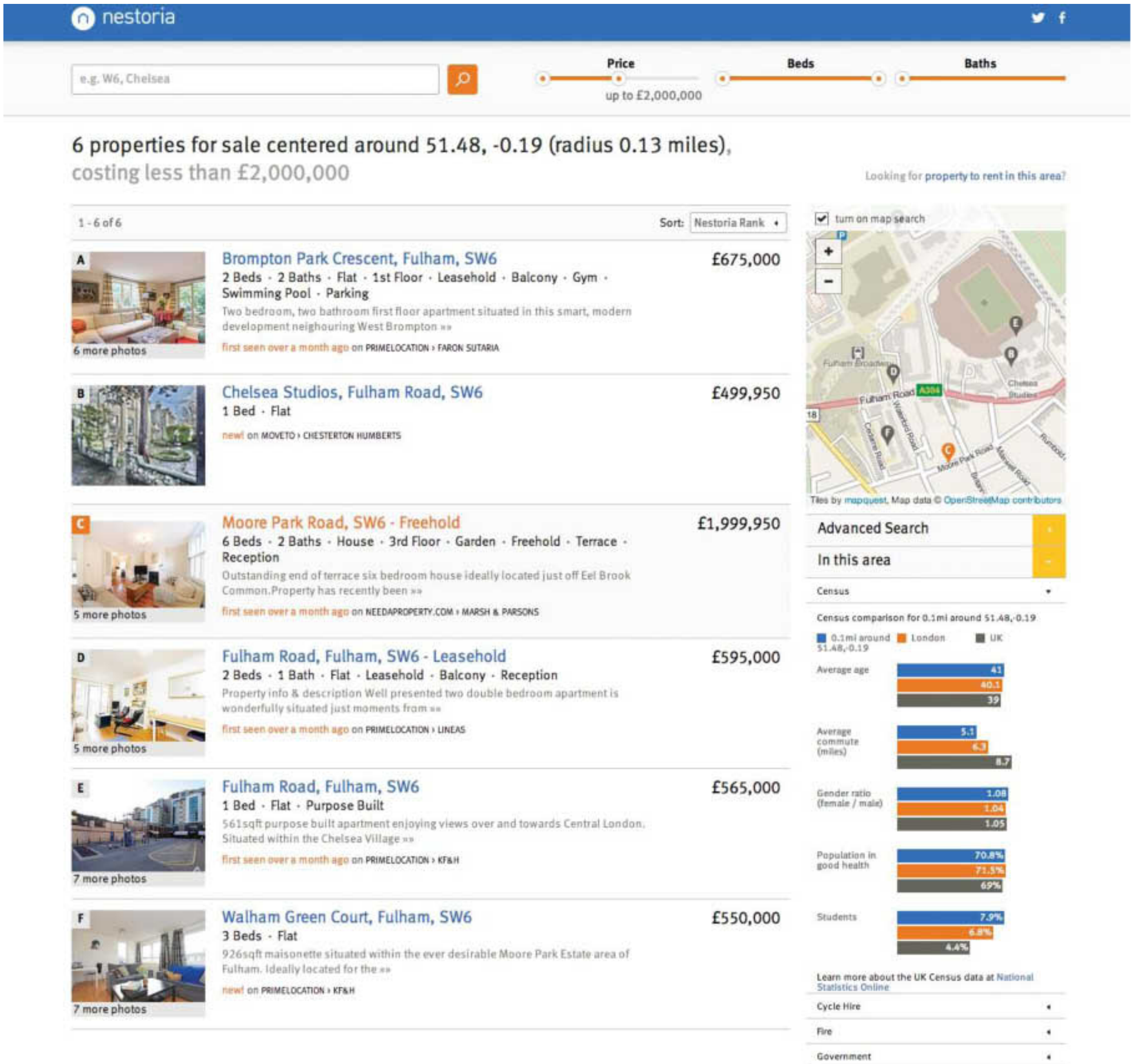
	The Era of Openness and Pervasive Use
2004	OpenStreetMap founded by Steve Coast to create citizen-enabled mapping for the UK. The OpenStreetMap Foundation is subsequently established to encourage the creation, development, and distribution of free geospatial data (notably through "mapping parties") to provide geospatial data for anybody to use and share.
2004	Biggest GI system user in the world, National Imagery and Mapping Agency (NIMA), renamed National Geospatial-Intelligence Agency to signify emphasis on geo-intelligence.
2005	Launch of Google Earth service, the first major virtual 3-D globe with 150 million downloads in first 12 months.
2006	Launch of Amazon Web Services (AWS) as a "cloud," a distributed utility computing service.
2007	Purchase by Nokia mobile phone company of NAVTEQ street data provider for $8.1 billion.
2007	Launch of first touch-screen iPhone, including GPS-enabled mobile mapping with touch-screen functions.
2008	TeleAtlas street data provider purchased by TomTom for $2.9 billion.
2009	Cost of RFID tags falls to the point that the "Internet of Things" becomes a widespread reality.
2009	Quantum GIS (QGIS; initially developed by Gary Sherman) launched. Developed through the Open Source Geospatial Foundation (OSGeo) and making extensive use of open-source plugins, this user-friendly multiple-operating-system software is available under public license.
2010	ESRI Inc. launches www.arcgis.com (trialed in 2009 as www.arcgisonline.com), a Cloud-based GI platform offering a range of GI services.
2010	Advent of the UK Open Government Licence, allowing public bodies to publish a range of previously copyright material for public use. These are compatible with Creative Commons licences and are contributing to the wider dissemination of geographically referenced Open Data by governments around the world (see Section 17.4).
2011	Google launches indoor maps (floor plans) to enhance Google Maps service.

analysis; Standard, which offers more advanced tools for manipulating spatial databases; and Advanced, which has further additional facilities for data manipulation, editing, and analysis. Other vendors specialize in certain niche markets, such as the utility industry, or military and intelligence applications. 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. Given the all-pervasive nature of GI systems and their linkage to other forms of software, it no longer makes much sense to guesstimate the global value of the GI system industry, but where such estimates are attempted, it seems clear that the industry continues to grow rapidly—for example, estimates of GI system sales in China, where GeoStar (www.geostar.com.cn/Eng/) is widely used, suggest that the value of the industry has increased 50-fold over the last decade. GI systems are a dynamic and evolving field, and their future continues to offer many exciting developments, some of which we will discuss in the final chapter.

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

1.5.2.2 The Data Industry

The acquisition, creation, maintenance, dissemination, and sale of GI data also account for a huge volume of economic activity. Traditionally, a large proportion of GI data have been produced centrally by national mapping agencies, such as the U.S. Geological Survey (USGS) or Great Britain's Ordnance Survey. In response to U.S. federal government policy, USGS supplies Open Data, defined as being priced at no more than the cost of reproduction of data. Elsewhere, some or all of available national mapping agency data are charged for to recoup the costs of their collection, although this is changing under various government Open Data initiatives. In Great Britain, for example, many Ordnance Survey mapping series have been made available free of charge since 2010; other, commercially valuable, data sets are not made available, however, because the government is unwilling to bear the projected $45 million cost of losing future revenue streams for highly detailed mapping products used by corporations such as utility companies. The innovation of free-to-view mapping services such as Google Maps (maps.google.com) and Microsoft Bing Maps and Virtual Earth, with their business model based on advertising revenues, is having profound implications for the provision of



Source: Nestoria

Figure 1.15 The Nestoria Website (www.nestoria.com) presents a consolidated view of available property for sale or rent, alongside Open Data about neighborhoods. It is funded by the realtors who supply the linked listings and who "pay by click" for users searching for property.

map data (see Chapter 18). Specialist mapping sites, such as those used in the real-estate industry, present a consolidated map view of all available properties for sale or rent, along with Open Data pertaining to neighborhood quality (Figure 1.15). 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 and have stimulated the growth of commercial firms such as CloudMade (cloudmade.com).

Open Data are revolutionizing the business model for GI applications.

Geographically referenced attribute data relating to customer transactions are collected by many organizations in pursuit of their day-to-day operational activities. Subject to legal data protection requirements, such data may be reused in pursuit of the tactical or strategic objectives of the organization, and many retailers, energy suppliers, and financial-service providers employ teams of analysts to devise better ways of servicing customers and increasing market share. Still other companies (including cell phone companies) fulfill the role of *value-added data resellers* of commercial and public-sector data. Important applications for such services are opening up, including improving public-service delivery. The GeoWeb (see Chapter 10) is creating fertile environments in which a very wide range of public- and private-sector data sources can be combined, analyzed, and displayed.

Private companies are now also licensed to collect fine-resolution data using satellites and to sell them to customers—as, for example, with GeoEye's (geofuse.geoeye.com) IKONOS satellite data (see Table 1.4). Other companies collect similar data from aircraft. Still other companies specialize in the production of good-quality data on street networks, a basic requirement of many delivery companies. TomTom (www.tomtom.com) is an example of this industry, employing over 1800 staff in producing, maintaining, and marketing good-quality street-network data worldwide.

1.5.2.3 GI Services

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 Cloud makes possible easy user access to 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 Inc. offers a geographic data management service, in which 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 a business information solutions division and acquired its own geodemographic system (called Tapestry) to service a range of business needs. This merging of the software and data industries comes together in the business of providing *GI systems as a service*, in which the Cloud is used as a remote platform on which software and data reside and GI system operations are performed.

1.5.3 The Government Perspective

Most government administration and decision-making activities have spatial implications, and governments—including the military and security services—remain by some margin the biggest users of commercial GI systems. Governments play an important role in many of the issues discussed throughout this book—including the development of data standards and interoperability, the creation of Web portals to disseminate GI (e.g., catalog.data.gov/dataset and data.gov.uk/), and the development of apps that automate key workflows such as zoning, property tax collection, or planning. Governments (such as those of Brazil and Spain) are also involved in the creation of open GI software.

One of the most profound changes concerning government and GI in recent years is in the ways in which government information is shared with citizens and external organizations in many parts of the world (see Chapter 17). Public-sector information (PSI) is defined by the wide range of information that government bodies collect, produce, reproduce, and disseminate across various areas of activity to fulfill their public-task functions. In terms of the nomenclature of Table 1.1, PSI is most conveniently thought of as information that has not been subjected to processing or any other manipulation beyond that necessary for its first use by government. Given the multiplicity of government functions, information that has been processed for one function (such as estimating local levels of homelessness or overcrowding) may be further refined and reused in the process of devising different measures for other functions (such as the composite measures of barriers to housing and public services used in various deprivation, or hardship, indices).

It is usual to think of PSI as having high fixed costs of assembly or collection and much smaller variable costs of copying and dissemination to users across the Web or through other media. It is also increasingly the case that the effort of rendering PSI into machine-readable or linked form can be absorbed into the fixed costs of information provision (see the star ratings schema discussed in Section 17.4.1). The small variable costs of disseminating some PSI have usually been absorbed in the United States, but this practice has been by no means universal, or even common, in other parts of the world. It is only in recent years that many governments worldwide have committed to greater availability of Open Data—which can be defined as data that can be used, reused, and redistributed freely by anyone, subject only at most to the requirement to attribute and share alike. Open Data are not necessarily free at the point of delivery, but any charge is usually no more than the cost of reproduction.

Open Data can be used, reused, and redistributed free of charge, subject only to Creative Commons or Open-Government licensing

The most obvious motivation for government supply of Open Data has been to improve transparency and accountability of government decision making, as well as to improve economic efficiency and to stimulate growth. It is often left to the private sector to spot opportunities for leveraging value and to lobby for new Open Data sources to be made available for the common good or commercial gain.

Open Data improve the transparency, accountability, and efficiency of decision making

The greater availability of PSI nevertheless raises a number of important issues for users of GI:

- Data are usually aggregated and cross tabulated to anonymize unit records, often using quite conservative procedures that mask important small-area variations.
- Government organizations are wary of the potential risk of *deanonymization*, that is, the combination of auxiliary data to link data to the individuals they characterize. GI systems provide the software environment in which such combination might take place
- Governments have traditionally emphasized data quality over timeliness, but are reluctant to extend quality-assurance procedures to rapidly delivered feeds of Open Data. There are likely to be issues with the provenance of Open Data as a consequence.
- Some of the core reference data produced by government provide the authoritative or definitive frameworks that are necessary to use other information—as, for example, with ZIP (post-) codes. Yet in many jurisdictions these are not open because they have considerable commercial value. There is considerable ongoing debate on whether government Open Data sources should build together into national (or international) information frameworks.

1.5.4 Computer-Science and Information-Science Perspectives

Computer scientists have been central to the development of GI technology, particularly in software development. Although sometimes mistakenly taken to be a branch of computer science, information science is a related but broad multidisciplinary area with a practical focus on the collection, classification, manipulation, storage, retrieval, analysis, movement, and dissemination of information. This brings with it concerns with database concepts, devising efficient algorithms for representing and accessing information, improving user interfaces, and developing computer architectures that are appropriate to different organizational settings. Like GI science and systems, these perspectives share concerns with the interactions between people, organizations, and computerized information systems.

All of this raises the question of whether GI is a fundamental part of computer science, or whether it merely presents a class of applications. The concepts underpinning spatiotemporal databases and computational geometry are core areas of computer science and information science that are directly relevant to GI technology, as are specific concerns with efficient computer processing, indexing schemes, database design, and computational geometry. Yet in each case, the treatment of such issues is more focused on the technical aspects of GI technology than the context to which it is applied.

Context is important from a geographic perspective, defined by its concern with the human and environmental properties of the Earth's surface and near surface (Section 1.1), at scales from the architectural to the global. These concerns bring special focus to issues such as the nature of geographic data, their representation in GI systems, the ways in which they are georeferenced, and the uncertainties that arise when working with real-world places. They are not the priority of computer-science and information-science perspectives when these emphasize technology at the expense of context. Thus although GI science can be viewed as a branch of information science, the special nature of GI ensures that many of the principles of GI science have only a tenuous relationship to the broader principles of information science, and the same can be said about computer science.

In recent years much attention has been devoted to what is often termed *data science*, the issues arising from society's increasing dependence on data. It has been argued that science is increasingly data driven (sometimes called the *Fourth Paradigm* for research) and is based on the vast quantities of data that are now becoming available from ground-based and space-based sensors of various kinds, from social media, and from a host of other sources. From this perspective, some application domains produce such vast quantities of data that new and specialized techniques for storing, accessing, processing, and visualizing data are necessary to handle these enormous data problems. It has even been argued that such research neither needs nor produces theory, but instead mines data for patterns that may be useful in solving humanity's problems. We hear about the *exaflood*, the flood of information in quantities of exabytes (Table 1.2) and talk of science "drinking from a fire-hose." Data science studies the principles and techniques involved in managing these vast quantities of information, which include acquiring, sharing, documenting, managing, and archiving them.

Insofar as a substantial proportion of these data include information about location, it is clear that the issues of GI science have significant overlap with those of data science. Yet we maintain that the special characteristics of GI demand that many of these issues be treated separately and that education in the generic principles of data science is not necessarily sufficient qualification. Moreover, the kinds of infrastructure concerns that are often raised to prominence in data science, ranging from systematic documentation of data (metadata) to archiving and sharing, have a long history of development in GI science and may already be more advanced within this specialized domain than in generic data science (see also Chapters 17 and 19).

1.5.5. The Geography Perspective

Geographers have long agonized over the content, coherence, and relevance of their discipline, and set against this background, it is perhaps surprising that they have nonetheless made time to investigate and innovate in the use of new research methods in their discipline. Throughout the period documented in Table 1.4, GI science and systems have developed and maintained a special relationship to the academic discipline of geography and other disciplines that deal with the Earth's surface, including geodesy, landscape architecture, planning, and surveying. Yet any special relationship is multifaceted, nuanced, and sometimes tense. This is even more so, given that the roots to much of geography lie in mapping for warfare, that the military remain heavy users of GI systems, and that commercial software applications are rarely open to full academic scrutiny in deference to business priorities.

The idiographic and nomothetic concerns of geography (Section 1.3) have recently been the focus of thinking about the representation of *place* and *place effects*. Place is a social construct of space by humans and is key to the way that they understand their surroundings. Thus, although space exists independent of the existence of people, it is human interactions and experiences that crystallize space into place through shared perceptions and recognition. Figure 1.16 shows one delineation of the place known as "Paris" (France) through mapping the extent of attribution of this label to photographs uploaded to Flickr, along with the more limited extents of other more localized places identified by users.

Geography also tells us that widely scattered places (for example, in Washington, California, Florida, or Vermont) share important social or physical similarities that are manifest in different ways and to differing degrees. GI systems provide a way of representing these similarities, using standardized quantitative measures and, hence, the repetition of place effects across space. Geodemographic classifications provide one prominent example of the assignment of dispersed locations to place-relevant typologies, independent of their locational proximity to one another (see Figure 1.17).

In both of these examples, absolute location is not the principal focus, but it is the relative locations of places and the connectivity and relations between them that are important.

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 by online communities of *volunteered geographic information* (VGI), discussed in Section 1.5.6 below. 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

Image courtesy: Linna Li; base map courtesy Openstreetmap

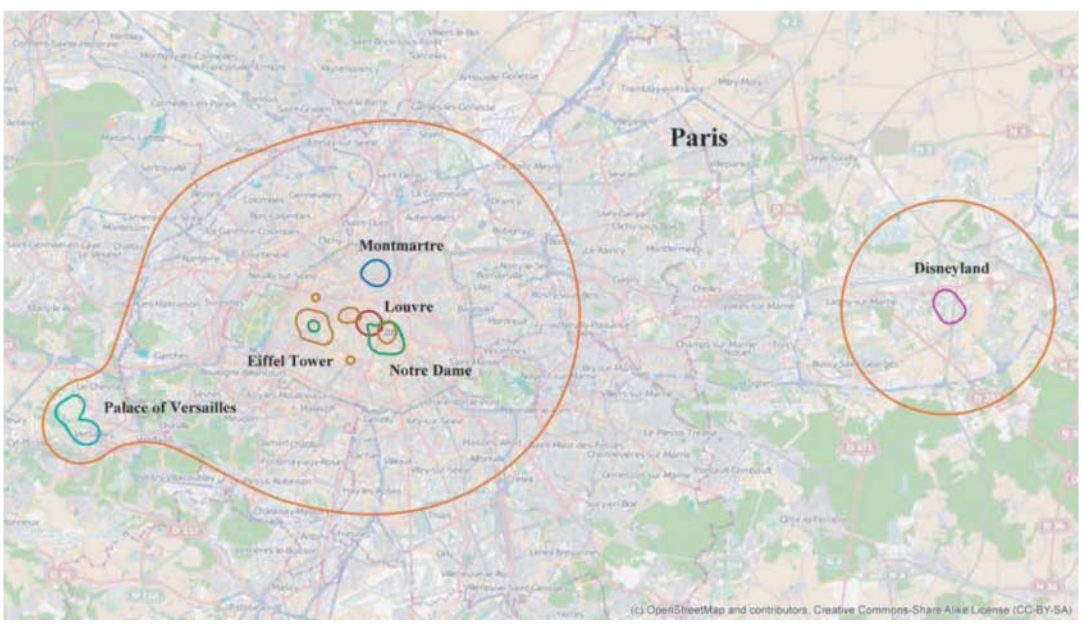
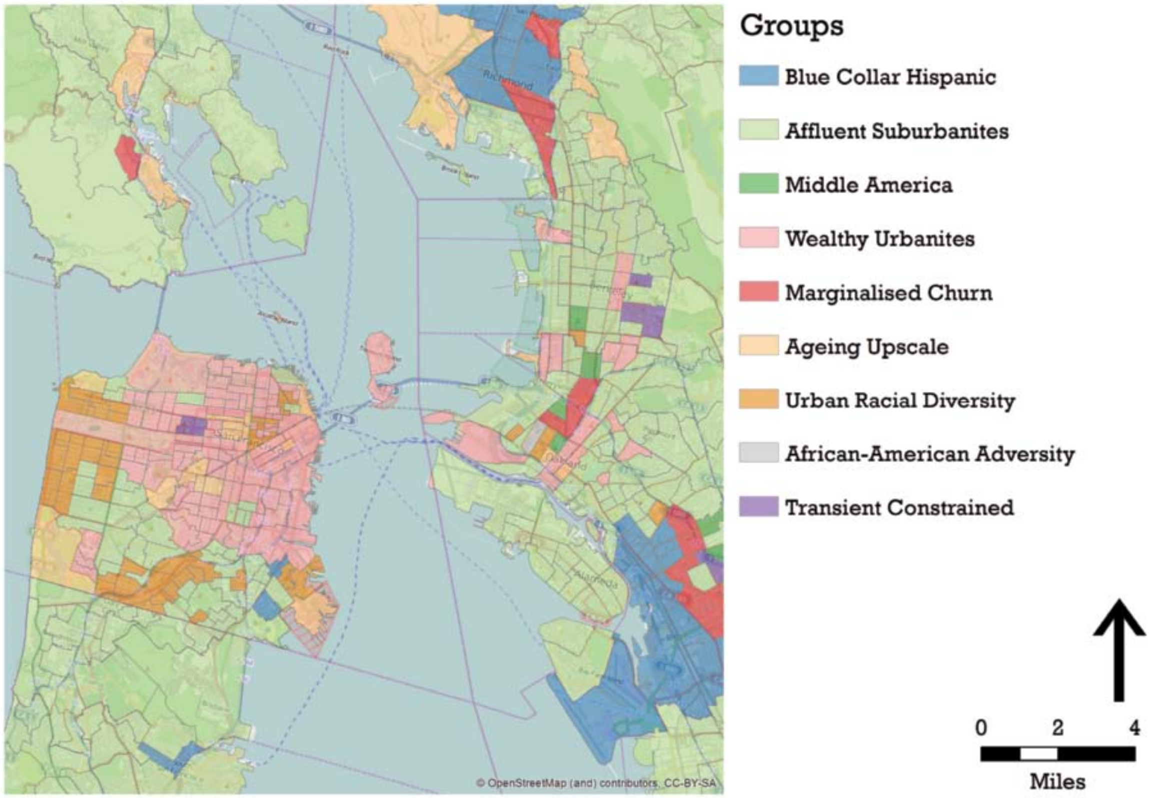


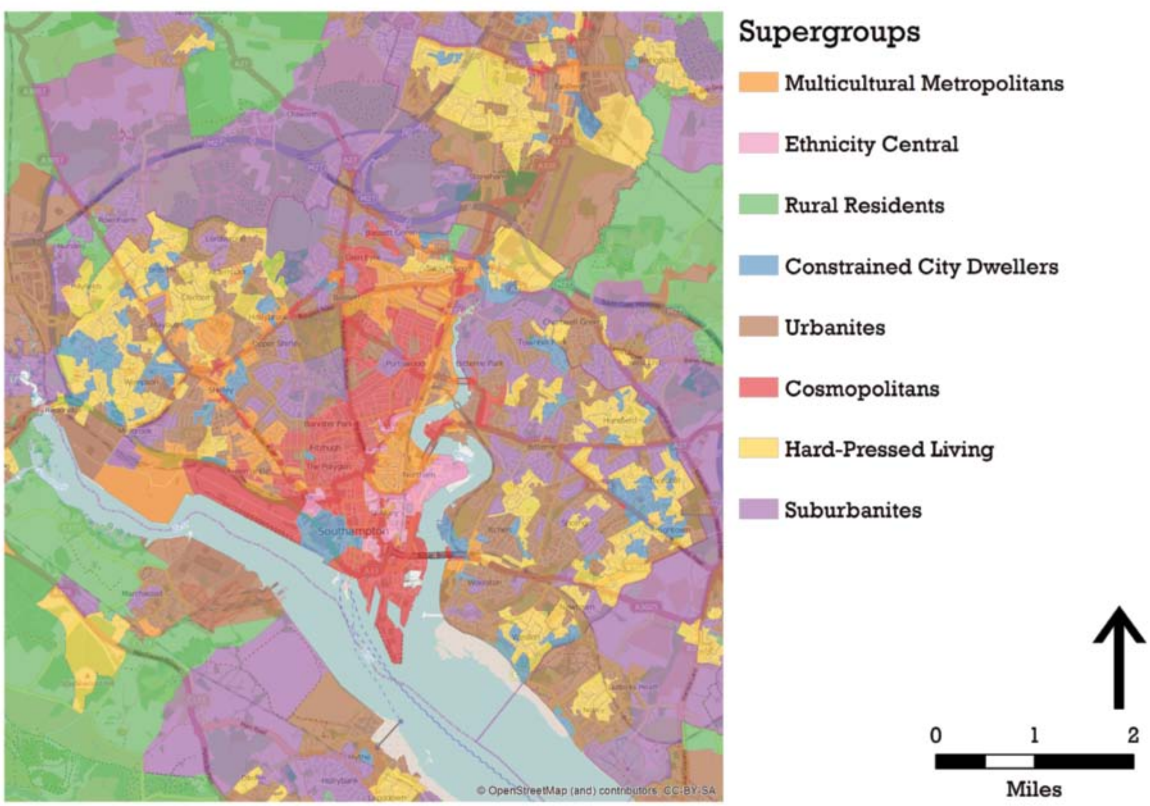
Figure 1.16 Delineation of the extent of Paris, France, and locations associated with it, based on the density of geotagged Flickr photos for each place name. Contours of the place surfaces are depicted by choosing a threshold value of point density visually (e.g., the threshold value for the contour of Louvre is 500 points per square kilometer).

(A)



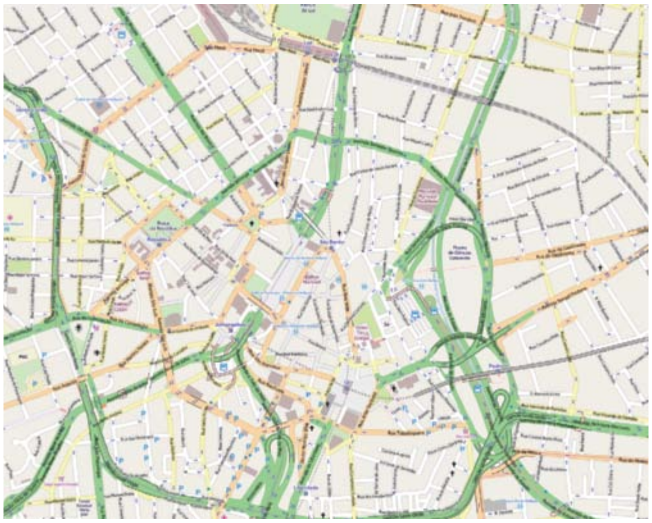
Courtesy: Alex Singleton

(B)



Courtesy: Chris Gale; contains National Statistics and Ordnance Survey data
© Crown Copyright and database right 2014

Figure 1.17 Geodemographic neighborhood classifications make it possible to quantify how similar one place is to another, subject to the availability of consistent data across a jurisdiction. (A) A classification based on 2010 U.S. Census data, showing part of San Francisco; and (B) the UK 2011 Output Area Classification, showing part of Southampton.



Source: OpenStreetMap

Figure 1.18 A crowd-sourced street map of part of São Paulo, Brazil.

(www.openstreetmap.org). Today, Wikimapia contains user-generated entries for more places than are available in any official list of place-names, whereas 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 1.18). This has converted many new users to the benefits of creating, sharing, and using geographic information, often through ad hoc collectives and interest groups. The creation, maintenance, and distribution of databases is no less than a "wikification of GI systems." Neogeography brings GI systems and some uses of spatial data infrastructures to the masses, while also presenting new challenges to citizen privacy and confidentiality. The empowerment of many nonexpert GI system users also brings with it the new challenges of ensuring that tools are used efficiently, effectively, and safely (see Chapter 17) and reemphasizes that technology can never offer more than a partial solution to the effective deployment of GI systems.

A core motivation for GI science is to better understand why GI systems applications are successful in practice. In this way, it should be possible to develop still better research practices for the future. Yet the applied nature of these endeavors and their core concerns with data, technology, and procedures inevitably distances any application from the investigator's direct experience. For some, this redefines the subject in ways that are inherently unacceptable in their reductionism; and no engagement with ever-more immersive technologies, richer data, or more sensitive analytical method can accommodate what are seen as failures inherent in empiricist methodology. In recent years protagonists of "critical GIS" have claimed some success in illustrating how better technology, data, and methods make it possible to go beyond simplistic depiction of raw data. Yet for others, the deployment of computer systems inherently implies greater conviction than is warranted about the attributes and behaviors of the subjects of research. If this is the case, the "critical" prefix can never be more than a sop that implies, but does not deliver, acceptable levels of humility when engaging with the subjects of research.

Some geographers remain suspicious of the use of GI systems in geography.

Still broader issues arise when research is sponsored, directly or indirectly, by vested interests of commerce or the military. The latter was thrown into sharp focus in 2013 in Joel Wainwright's *Geopiracy*—a critique of recent U.S. military funding of academic geography to fund expeditions to map the human terrain of other countries. The Bowman expeditions—named after Isaiah Bowman, an early Twentieth Century American geographer identified with both empiricism and empire building—attracted criticism from Mexican authorities for alleged nondisclosure of U.S. military funding. To some, this was an uncomfortable reminder of the role of mapping as a tool of warfare (see Box 11.1) and the historic role of military motivations in the development of geography. We discuss this further in Chapter 18.

1.5.6 The Societal Perspective

The history of the development of GI systems has been one in which a technology of problem solving has evolved from specialized (and expensive) standalone configurations of hardware, software, and data to a background technology that is very much part of the information-technology mainstream. Today, when most of us casually use computers to pose "Where?" questions, we are rarely if ever cognizant that we are "doing GIS." We rarely contemplate the costs that an organization, somewhere, incurs in providing the GI services that we consume—because the costs of using the geographically enabled search of online mapping systems, for example, are absorbed through the advertising and data-sharing revenues of corporations such as Google, Apple, or Microsoft, or the costs of real-time public-transit information systems are borne by the operator out of ticket revenues. Internet behemoths foist use of cookies on us as users that betray our locations and many characteristics of our online identities, and we may resent the sophistication of the resulting advertising that is targeted on us. It seems that opting out of default options of disclosure requires greater diligence and doggedness than in the pre-Internet era, and we discuss privacy and legal concerns in Chapter 17. But most of us accept this intrusiveness, most of the time,

Technical Box 1.5

The Top-Level Categories of the Geographic Information Science and Technology Body of Knowledge

Following are the 73 top-level categories of knowledge in the first edition (2006), and pointers (in brackets) to related chapters in this book where appropriate.

Knowledge Area: Analytical Methods (AM)

Unit AM1 Academic and analytical origins (13)

Unit AM2 Query operations and query languages (13 and 14)

Unit AM3 Geometric measures (13 and 14)

Unit AM4 Basic analytical operations (13 and 14)

Unit AM5 Basic analytical methods (13 and 14)

Unit AM6 Analysis of surfaces (14)

Unit AM7 Spatial statistics (13)

Unit AM8 Geostatistics (13)

Unit AM9 Spatial regression and econometrics (13 and 14)

Unit AM10 Data mining (13 and 14)

Unit AM11 Network analysis (14)

Unit AM12 Optimization and location-allocation modeling (14)

Knowledge Area: Conceptual Foundations (CF)

Unit CF1 Philosophical foundations (1)

Unit CF2 Cognitive and social foundations (1)

Unit CF3 Domains of geographic information (1)

Unit CF4 Elements of geographic information (2 and 3)

Unit CF5 Relationships (2 and 3)

Unit CF6 Imperfections in geographic information (5)

Knowledge Area: Cartography and Visualization (CV)

Unit CV1 History and trends (11 and 12)

Unit CV2 Data considerations (11 and 12)

Unit CV3 Principles of map design (11)

Unit CV4 Graphic representation techniques (11 and 12)

Unit CV5 Map production (11)

Unit CV6 Map use and evaluation (11)

Knowledge Area: Design Aspects (DA)

Unit DA1 The scope of GI system design (6)

Unit DA2 Project definition (16)

Unit DA3 Resource planning (16)

Unit DA4 Database design (9)

Unit DA5 Analysis design (13 and 14)

Unit DA6 Application design (1)

Unit DA7 System implementation (16)

Knowledge Area: Data Modeling (DM)

Unit DM1 Basic storage and retrieval structures (7)

Unit DM2 Database management systems (6)

Unit DM3 Tessellation data models (7)

Unit DM4 Vector and object data models (7)

Unit DM5 Modeling 3-D, temporal, and uncertain phenomena (7)

Knowledge Area: Data Manipulation (DN)

Unit DN1 Representation transformation (7 and 8)

Unit DN2 Generalization and aggregation (11 and 12)

Unit DN3 Transaction management of geospatial data (8)

Knowledge Area: Geocomputation (GC)

Unit GC1 Emergence of geocomputation (15)

Unit GC2 Computational aspects and neurocomputing (15)

Unit GC3 Cellular Automata (CA) models (15)

Unit GC4 Heuristics (14)

Unit GC5 Genetic algorithms (GA) (15)

Unit GC6 Agent-based models (15)

Unit GC7 Simulation modeling (15)

Unit GC8 Uncertainty (5)

Unit GC9 Fuzzy sets (5)

Knowledge Area: Geospatial Data (GD)

Unit GD1 Earth geometry (4)

Unit GD2 Land partitioning systems (4)

Unit GD3 Georeferencing systems (4)

Unit GD4 Datums (4)

Unit GD5 Map projections (4)

Unit GD6 Data quality (5)

Unit GD7 Land surveying and GPS (4)

Unit GD8 Digitizing (8)

Unit GD9 Field data collection (2, 8, 17)

Unit GD10 Aerial imaging and photogrammetry (8)

Unit GD11 Satellite and shipboard remote sensing (8)

Unit GD12 Metadata, standards, and infrastructures (10)

Knowledge Area: GIS&T and Society (GS)

Unit GS1 Legal aspects (18)

Unit GS2 Economic aspects (17)

Unit GS3 Use of geospatial information in the public sector (17)

Unit GS4 Geospatial information as property (17)

Unit GS5 Dissemination of geospatial information (17)

Unit GS6 Ethical aspects of geospatial information and technology (18)

Unit GS7 Critical GI systems (1)

Knowledge Area: Organizational and Institutional Aspects (OI)

Unit OI1 Origins of GIS&T (1)

Unit OI2 Managing GIS operations and infrastructure (16)

Unit OI3 Organizational structures and procedures (16)

Unit OI4 GIS&T workforce themes (1)

Unit OI5 Institutional and interinstitutional aspects (18)

Unit OI6 Coordinating organizations (national and international) (18)

either in ignorance or in implicit recognition of the convenience of the search engine and other services that such companies provide. Disclosure of online identity (of which location is an integral part) helps us to deal with the tyranny of small decisions in everyday life, even if GI service providers then try to use this to shape aspects of our identities as consumers in the interests of their advertising clients.

Choosing whether or not to use a particular search engine is an individual decision, but other GI applications are fundamentally underpinned by collective attitudes to creation and use. VGI is the collective harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals—such as street locations (e.g., www.openstreetmap.org), geotagged photographs (e.g., www.flickr.com), or locationally referenced restaurant reviews. The motivations for supply of such information are multifaceted and may ebb and flow over time—recent years have seen much talk of "Wiki fatigue"—but all such projects are dependent on funding models for creating and maintaining GI systems—for example through individual donations or corporate sponsorship.

The funding imperative holds in all other societal deployments of GI. Governments pay the cost of ensuring the availability of Open Data and public-sector information (PSI). The costs of creating open software are often borne by research-grant-awarding organizations or funding by universities using student-fee income (justified as enhancing the public-facing profile of the organization). We discuss these different funding models in greater detail in Chapter 18.

The diversity of motivations underpinning the creation, maintenance, and dissemination of GI and the software to analyze it leads to the following societal concerns (see also the contribution of Sarah Elwood, discussed in Box 10.4):

- The links between knowledge and power. The ways in which GI systems represent the Earth's surface, and particularly human society, have been observed to privilege certain people, phenomena, and perspectives, at the expense of others. Minority views, and the views of individuals, can be submerged in this process, as can information that differs from the official or consensus view. GI systems often force knowledge into forms that are more likely to reflect the view of the majority, or the official view of government, and as a result *marginalize* the opinions of minorities or the less powerful. Countering this outlook is the view that greater access to PSI (see Section 17.4), especially over the Web, has enlivened debate and has gone some considerable way toward leveling the playing field in terms of data access. Moreover, the near-ubiquitous availability of mapping services and virtual Earths with limited GI system functionality (e.g., maps.google.com, apple.com/ios/maps/, and www.microsoft.com/virtualearth) brings rudimentary mapping and analysis capabilities to almost anyone with an Internet connection.

- In principle it is possible to use GI systems for any purpose, and so in practice they may sometimes be 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. Although most would agree that the consequences of misuse of GI systems are not cataclysmic, there are nevertheless some similarities with the debates over the atomic bomb in the 1940s and 1950s: the scientists who develop and promote the use of GI systems surely bear some responsibility for how they are eventually used to the net benefit of humankind. The idea that a tool can be inherently neutral, and its developers therefore immune from any ethical debates, is now strongly questioned.
- The very success of GI systems 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 GI systems have become *too* successful in modeling socioeconomic distributions and that as a consequence GI systems have become a tool of the "surveillance society." And there are fears that many users of services such as social media do not understand the uses to which their data may be put and the ways that they may be linked to other sources. Geography provides a powerful means of linking rich data sources pertaining to individual behavior.
- There remains an underrepresentation of applications of GI systems in *critical* research that focuses on the connections between human agency and particular social structures and contexts. Some detractors of GI systems have also suggested that such connections are not amenable to digital representation in whole or in part. Applications of "critical GIS" (see Section 1.5.5) have been developed that investigate, for example, the compatibility between GI systems and feminist epistemologies and politics; yet for some, the "critical" prefix does not address fundamental concerns with empiricism and the use of technologies to analyze the subjects of critical research.
- Some view the association of GI systems with the scientific and technical project as fundamentally flawed. More narrowly, there is a view that GI systems 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 1.1.1). As such, the argument goes, GI systems can never be more than a positivist tool and a normative instrument and cannot enrich other more critical perspectives in social science and even core areas of science itself. This is a criticism not just of GI systems, but also of the application of the scientific method to the analysis of social systems.

1.6 GI Science and Spatial Thinking

GI 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 GI system user know that the results obtained are accurate? What principles might help a GI system 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 GI system design, and others are about the nature of GI and the methods used to analyze it. Taken together, we can think of them as questions that arise from the use of GI systems—that are stimulated by exposure to GI systems in their many guises. Many of them are addressed in detail in this book, and the book's title emphasizes the enduring importance of the science of problem solving.

Science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the world (and beyond). It also refers to a body of knowledge itself, of the type that can be rationally explained and reliably applied. The U.S. University Consortium for Geographic Information Science (www.ucgis.org) is an organization of roughly 70 research universities that engages in research agenda setting, lobbying for research funding, and related activities. In 2006 it developed and published *Geographic Information Science and Technology Body of Knowledge* (BoK) in collaboration with the Association of American Geographers (a revised second edition is under development). The *BoK* is intended to be a comprehensive summary of knowledge in the field, to be used to evaluate the content of courses and programs, to set standards for job descriptions, and many other uses.

Box 1.5 lists the top-level contents of the 2006 first edition, which is currently available from www.aag.org/galleries/publications-files/GIST_Body_of_Knowledge.pdf. Each of the top-level topics is elaborated in detail in the document.

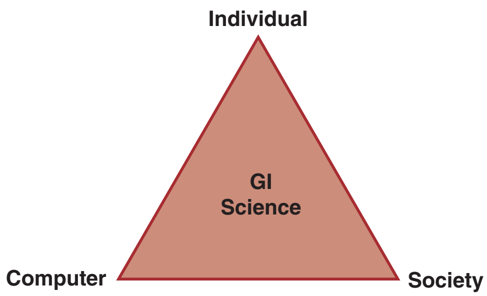


Figure 1.19 The remit of GI science, according to Project Varenius (www.ncgia.ucsb.edu/varenius/varenius.html).

One disarmingly simple way of viewing this taxonomy is in the framework of the Varenius project (www.ncgia.ucsb.edu/varenius/varenius.html; Figure 1.19). Here, GI science is viewed as anchored by three concepts: the individual, the computer, and society. These form the vertices of a triangle, and GI science lies at its core. The various terms that are used to describe GI-science 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 geovisualization 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.

1.7 GI Systems and Science in Society

GI science is often about using the software environment of GI systems to redefine, reshape, and resolve problems that are even older than the first GI systems. The need for methods of spatial analysis, for example, dates from the first maps, and many methods were developed long before the first GI system appeared on the scene in the mid-1960s. Another way to look at GI science is to see it as the body of knowledge that GI systems implement and exploit. Map projections (Chapter 4), for example, are part of GI science and are used and transformed through use of GI systems. A further area of great importance to GI systems is cognitive science, particularly the scientific understanding of how people think about their geographic surroundings. If GI systems 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.

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

Yet if there are enduring qualities to the body of knowledge that constitutes GI science, so there is also profound change in the setting in which it is applied. Astonishing improvements in our technical capacity to create and manipulate digital information have profoundly changed the ways in which GI systems are understood and used, both in business and in government. But perhaps the most profound changes of all have taken place in society at large. Just as a GI "system" is no longer a readily identifiable and clearly bounded "thing," so the notion of a "GI system user" has become a similarly anomalous conception—for the simple reason that we are now all consumers of GI and applications that use it. Other changes characterize the environment in which GI science is applied, given our vastly improved abilities to identify and monitor the movements of objects and (consenting) individuals, the rise of citizen science, and the availability of vast arrays of data that make it possible to devise rich yet comparable depictions of unique places.

We wonder where this will all end. Resolving the "Where?" question places unending demands on society's evolving information infrastructures and, in turn, begs many more questions concerning the sourcing, assembly, maintenance, and deployment of GI. How might the quality and reliability of volunteered geographic information be ascertained? How can users best understand the standards by which the information that they rely on has been created? How might user interfaces be improved to render GI intelligible to all relevant users? What are the obligations of governments to supply Open Data that are timely, comprehensive, and safe to use? What issues arise when commercial spatial data infrastructures (such as Google Earth) are reused for scientific or policy purposes? And what rights does the citizen have to privacy, or to be forgotten?

These are some of the key questions of GI science that we address in this book. They have profound implications for the ways in which we interact with one another and the ways in which we interact with places. For billions of casual users, GI systems have become an integral part of the information technology mainstream, yet this begs important questions about the roles, functioning, and status of pervasive GI technologies in society.

Although we continue to refer to "GI systems," an emphasis throughout much of this book is on this new societal vision of the emerging globally connected "GI system." As the software and procedures that are used to manipulate and analyze data continue to evolve, GISS provides focus to the way that better system design advances science and vice versa. Much of this book is about the more enduring principles of GI science, which are applied through society's use of geographic information, using the standards and procedures that are integral to GI system design.

The title of the first three editions of this book, which appeared between 2001 and 2011, was *Geographic Information Systems and Science*. Our revision of the title, as well as the content, of this fourth edition is designed to emphasize the enduring importance of scientific principles against a background of improvements in GI system design. Over this period, GI systems have evolved from isolated, monolithic software to society's resource of choice when the question "Where?" arises in any of its many guises. We believe strongly that effective users of GI systems 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.

Questions for Further Study

1. Examine the geographic data available for the area within 80 km (50 miles) of either where you live or where you study. Use it to produce a short (2500-word) illustrated profile of either the socio-economic or the physical environment. (See, for example, www.data.gov/ or data.gov.uk/data)
2. What are the distinguishing characteristics of the scientific method? Discuss the relevance of each to the history of GI systems.
3. Has society-wide use of GI systems transformed the research agenda for GI science? Give reasons for your answer.
4. Locate a subset of the issues identified in Box 1.5 in two triangular "GI science" diagrams like that shown in Figure 1.17—one for themes that predominantly relate to developments in science and one for themes that predominantly relate to developments in technology. Further details on each of the themes is available in the online *BoK*. If time is available, give short written reasons for your assignments. Compare the distribution of issues within each of your triangles to assess the relative importance of the individual, the computer, and society in the development of GI science and of GI technologies.

Further Reading

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Foresman, T. W. (ed.). 1998. *The History of Geographic Information Systems: Perspectives from the Pioneers.* Upper Saddle River, NJ: Prentice Hall.

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