Prentice Hall Series in Geographic Information Science

KEITH C. CLARKE, *Series Editor*

Getting Started with Geographic Information Systems

KEITH C. CLARKE

CD-ROM Included

Fourth Edition

Prentice Hall Series in
Geographic Information Science

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Fourth Edition

Keith C. Clarke
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Prentice Hall

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Preface

After six years and four editions, *Getting Started with Geographic Information Systems* remains a basic-level textbook for the beginning student in the expanding field of geographic information science. Books in GIS have tended to be rather advanced, for the specialist rather than the beginner. GIS is not just for the specialist, but for everyone. **Geographic information science** is the discipline that uses geographic information systems as tools to understand the world, by describing and explaining humankind's relationship to that world. The usual order of intellectual discovery has been reversed by GIS. In the past, geography students in their advanced studies met the tools of spatial description and analysis for the first time. Today, students from many disciplines and professionals find their way into the newly evolving academic discipline of geographic information science *through* their hands-on use of geographic information systems and through the medium of real-world problems. Geographic information systems are an important new entry point into fields where location in geographic space makes a difference, what might be called the *mapping sciences*.

Nevertheless, it is reassuring to find that as geographic information technologies have evolved, necessitating revision after revision of this book, the same old principles have reemerged to assert their significance as the roots of the new discipline. Much of this book is simply an old story retold, one that most geographers will find very familiar. Bernhard Varenius's 1650 *Geographica Generalis*, for example, contained much of the basic cartography in this book. Yet technology has brought change, and the evolution of the GIS field has now reached maturity, and the benefits to all are self-evident.

This book evolved from a tried and trusted approach to basic education. This approach is to first revisit the **basics**, such that all students will have the same foundation in underlying principles—both students who have covered them *and* those who skipped them during their grade school education. Next, the **scope** of the field is covered, and the critical underlying issues are highlighted in the context of the learned principles. Finally, the approach works toward the development of **critical thinking**, using the knowledge base and the basic concepts to develop educated thinking in context.

Getting Started with Geographic Information Systems uses these three stages of learning. In the early chapters, the basics of cartography, geodesy, and geography are covered. The following chapters cover the breadth and a little of the depth of GIS. In the course of this coverage, critical thinking is developed by visiting themes and challenges around issues and applications. Accuracy, data models, how data structure dictates capability, the demands of analysis—all are considered in context.

Chapter 1, *What Is a GIS?*, is an introduction to the concepts of GIS by the examination of alternative definitions, a glimpse at the historical context and heritage of the field, and a guide to the many information sources available, including those on the Internet and the World Wide Web. Chapter 2, *GIS's Roots in Cartography*, is a basic concepts chapter, introducing the cartographic necessities of map projections, coordinate systems, and geodesy. Chapter 3, *Maps as Numbers*, begins a consideration of map data representation, necessary for storage of the data within a GIS. The survey approach to data structures and formats is supplemented by consideration of how data structures both facilitate and limit GIS data use.

Chapter 4, *Getting the Map into the Computer*, also covers the basics of computer cartography and database systems, and getting maps into the computer in digital form, the process of geocoding. The broader issue introduced is the relationship between map accuracy and resolution, and the cartographic process of generalization. When an existing map is the source of data for a GIS, we often make faithful reproduction in the digital world of cartographic errors in the real world. Chapter 5, *What Is Where?*, is information rarely covered in GIS books: the database management capabilities of GIS and how they have evolved. Most database systems have a great deal in common. The attribute database is used as a vehicle to understand the concept of retrieval from a spatial database, a very different process indeed, and one right at the core of GIS power. Chapter 6, *Why Is It There?*, looks at data analysis, building from attribute data description and analysis toward spatial analysis. Here less depth is used because many curricula in geography already teach advanced methods of spatial analysis. A strength is the use of a real-world GPS data set. As my grandfather often said, it makes no sense to teach carpentry with blunt tools—you are just as likely to get cut. The same goes for GIS.

Chapter 7, *Making Maps with GIS*, is the last of the basic review chapters, in this case covering the map design component of cartography. So often, GIS is taught without a link to the substantial literature and body of experience on map design. With just a few of the basics, a GIS novice will be better able to understand when mistakes are being made. Chapter 8, *How to Pick a GIS*, is intended to allow the GIS novice to make an informed choice of systems, all too often the first step required in a GIS user's education. Although no coverage can be complete, the view here is that the educated shopper is the best consumer. Far more information is available to the sophisticated user; here the GIS novice gets the essentials. Chapter 9, *GIS in Action*, explores five original contributed case studies in GIS, one of them new to the fourth edition. The chapter highlights the full scope of GIS work, the inter- and multidisciplinary nature of the research in the field, and the many problems that are addressable (and created) by GIS. Chapter 10, *The Future of GIS*, speculates on future hardware, software, and issues, providing the GIS novice with a road map to the intellectual issues driving GIS research.

Each chapter includes four essential learning aids. First, each chapter's content is summarized in "bullet" form for easy use as classroom summaries and study guides. Next, each technical term is treated as a keyword, and definitions are given chapter by chapter. This assists in review, in learning concepts along with lectures, and in learning along with reading. A summary dictionary-style glossary is also provided at the end of the book. Finally, two sets of questions are included. The study questions are specific to the chapter and can serve as useful enrichment. Each chapter ends with exercises that can be completed using software on a PC. These exercises are generic enough that almost any GIS can be used to complete them. New to this edition, I include the labs developed for my class at UC Santa Barbara and the ArcView GIS software to complete them with.

The final feature of the book is a collection of interviews, included as sections called *People in GIS*. These sections are included because, first, it is hard to relate to a subject that does not have a human face, and, second, because the snippets of information each of these GIS users relate reinforce concepts highlighted elsewhere in the book. We are all, just because we are reading this book, people in GIS!

As with any book, there are many people to thank. Ray Henderson, my first editor at Prentice Hall and creator of the *Prentice Hall Series in Geographic Information Science*, originally talked me into writing this book. Dan Kaveney saw the project to completion,

and has now stuck with me through four editions and the whole GIS series, as has his assistant Margaret Ziegler. Applications were provided by Ellen Cromley, Sean Ahearn, Leal Mertes, Bryan Pijanowski, and Paula Messina. The interviewees, Nils Larsen, Mark Bosworth, Susan Benjamin, Assaf Anyamba, Michael Goodchild and Brenda Faber, gave generously of their time and energy. Assistance with some of the graphics came from David Lawson, Barbara Tempalski, Brett Gilman, Westerly Miller, Jeff Hemphill and many others. Susan Baumgart did a highly professional job of redrafting many of the original figures for the third edition.

The following people read and reviewed all or parts of the manuscript: Len Gaydos, Joshua Lerner, E. Lynn Usery, Robert Sechrist, William Lawrence, Thomas Hodler, Benjamin Richason III, Leland Dexter, Mark Jakubauskas, Steven Walsh, Robert Churchill, Michael Peterson, and others. Len Gaydos was kind enough to torture-test the book in the classroom at San Jose State University in the spring of 1996. Sarah Battersby worked on the laboratory exercises on the web site, and Jordan Hastings did the actual site creation. The cartoons at the beginnings of each chapter are the inspired work of Englishman Jon Paul Fahy. Thanks JP!

I received a great deal of feedback on previous editions, from the reviews in the GIS literature, to E-mail from instructors around the nation and the world, to student evaluations from my own class, Geography 176A, at UCSB. Despite the fact that I have acted upon almost all of the suggested improvements, I humbly ask again that you keep them coming! I am committed to ongoing update, correction and improvement of this book—something that is especially important in a field as volatile and fast-paced as GIS. I have also received positive feedback on the teaching materials that accompany this book on the World Wide Web at `http://www.prenhall.com/clarke`. Encouraged by this, I have refined and expanded these materials to include lecture notes, exams and quizzes; a series of HTML-based labs using the ArcView software can be found on the CD in the back of this book. The outstanding efforts to create the CD and the Web site were by Ann Ricchiazzi and Jordan Hastings, with content provided by Violet Gray for the third edition and Sarah Battersby for the fourth.

There is much new material in the fourth edition. The graphics are much improved by color, and there is a new case study plus the laboratory and Web material. I hope this makes the basic GIS class, especially in geography programs around the country, of increased value to students. Geographers now find their discipline in demand intellectually, and they have the opportunity to conduct work of increased relevance. This is possible because of the power that GIS has placed into the hands of the spatial analyst. The challenge to use the power well is as vivid as ever.

I dedicate this fourth edition to my father, Raymond Harry Clarke, who died in England in September of 2000, shortly after the third edition appeared. I will always remember our last trip together, to the Greenwich Observatory. He took the photograph there that I have used in Chapter 2. And last, of course, and yet again, I thank Margot, Chantal, Elizabeth, Anne, and Caroline. Not only did they put up with a husband and father who travels way too much, they also modeled for some of the photographs in the book.

Keith C. Clarke
Santa Barbara

Brief Contents

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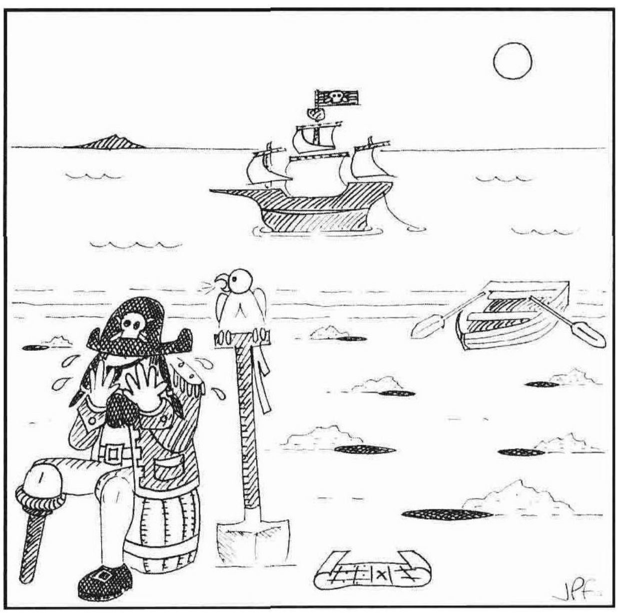
CHAPTER 1

What Is a GIS?

What in the world is a "GIS"?

—Item on the Internet's `comp.infosystems.gis` *FAQ list (FAQ = frequently asked question)*

GISs are simultaneously the telescope, the microscope, the computer, and the Xerox machine of regional analysis and synthesis of spatial data.
—(Ron Abler, 1988)



SQUAWK! "Who needs a GIS?" SQUAWK! "Who needs a GIS?"

1.1 GETTING STARTED

If you are getting started with geographic information systems (GISs), or perhaps are curious to know what a GIS is and what it can do for you—then this book is for you. Whatever your field of interest, the chances are strong that you will at least come across and probably use a GIS in some way in the years ahead. So getting started now is a good idea! Perhaps you have already checked into some of the sources of information about GIS covered in this chapter. If you have, you may have noticed that there are already a great many GIS textbooks. Why, you may ask, do I need another? What is different about *this* GIS book?

Getting Started with Geographic Information Systems is intended to supplement the many new GIS books, not by updating or adding to them, but by *gently easing new GIS users into their community of understanding* without that long, slow, expensive, and sometimes painful climb up the GIS learning curve. As your first book in GIS, this one will set the foundation for a more breadth-first tour through the discipline than what the more advanced books can offer. By keeping the text up to date, the author and editors are working hard to ensure that your first GIS experience is timely, pleasant, and constructive.

First, we get started with GIS definitions, outline the development of the field, and map out some of the sources of information that can teach you more about GIS. It should be clear at the outset that GIS is not a new "killer app," namely a "must-have" innovative and essential computer application like a spreadsheet, a word processor, or a database manager. GIS is partly a killer app, but the upward shift in capability that its users receive is not due to computer software alone. Instead, GIS has built on the collective knowledge of the academic fields of geography and cartography, with some geodesy, database theory, and mathematics thrown in for good measure. As Ron Abler's definition shows, GIS is not just one but *many* simultaneous technological revolutions. *Getting Started with Geographic Information Systems* introduces a distilled version of the theory and content from the fields of these technologies—the minimum necessary to get you started—and then offers some signposts pointing toward where the revolutions will lead next. If you choose to go further, there are plenty of paths forward.

Using GIS requires you to think like a geographic information scientist. *Geographic information science* is a new field, born by merging skills and theory across many different disciplines, and it has now reached maturity after years of development. Like all new fields, geographic information science requires some mental readjustment. The purpose of this book is to gently guide you, the reader, through this readjustment. Fortunately, because you are reading this book, the chances are that you are already used to thinking graphically, mapping out information, and building analytical solutions around these maps and graphics. If not, I hope that this text will serve both to get you started and to unleash a part of the brain you may never have used before—the spatial part—that holds real power as a new way of problem solving.

1.2 SOME DEFINITIONS OF GIS

Good science starts with clear definitions. In the case of geographic information systems, however, definitions have sometimes been as clear as mud. As a result, different definitions have evolved over the years as they were needed. It is no surprise, then, that "geographic information system" can be defined in many different ways. Which definition you choose depends on what you seek. Common to all the definitions is that one type of data, *spatial data*, is unique because it can be linked to a geographic map (Figure 1.1).

Spatial means "related to the space around us, in which we live and function." Our own definition of GIS can start with a simple description of the three parts of a GIS, which are (1) the database, (2) the spatial or map information, and (3) some way to link the two. Necessary parts are a computer, some software, and people to use the system. We also need an underlying problem or task for which the GIS will be used, such as choosing a site for a nature preserve, routing an ambulance to a house, or maintaining a set of data that citizens of a town can use to become informed. Then, of course, we need both understanding and experience, both of the system and of the problem. As you will quickly learn, the last two items are the hardest to come by.

1.2.1 A GIS Is a Toolbox

A GIS can be seen as a set of tools for analyzing spatial data. These are, of course, computer tools, and a GIS can then be thought of as a software package containing the elements necessary for working with spatial data. If we want to write a book, we might visit a computer store and buy a word processing package in a box to install on our computer. Similarly, if we seek to work with spatial data, one definition of a GIS is the software in the box that gives us the geographic capabilities we need.

Peter Burrough, in his pioneering textbook, defined GIS as "**a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes**" (Burrough, 1986, p. 6). The key word in this definition is "powerful." Burrough's definition implies that GIS is a tool for geographic analysis. This is often called the "toolbox definition" of GIS because it stresses a set of tools each designed to solve specific problems.

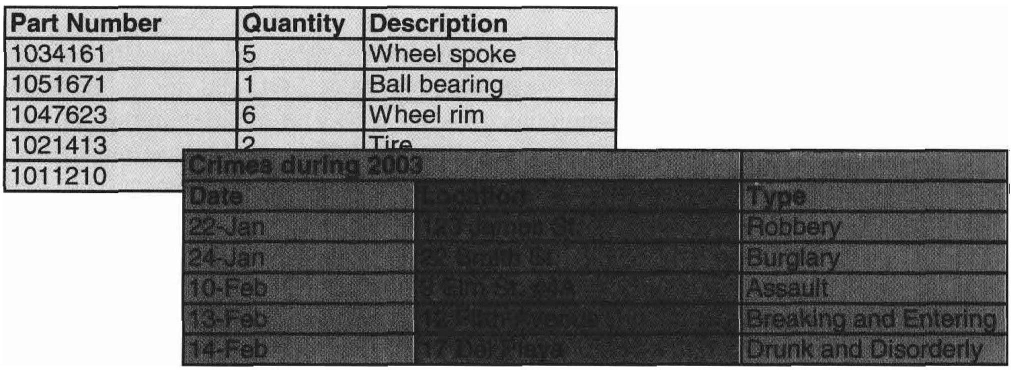


FIGURE 1.1: Two databases. A database contains columns (attributes) and rows (records). The bicycle parts list on the left is not spatial. The parts could be located anywhere. The list of crimes on the right is spatial because one of the attributes, the street address, locates the crimes on a map. This list could be used in a GIS.

If a GIS is a toolbox, a logical question is, What types of tools does the box contain? Several authors have tried to define a GIS in terms of what it does, offering a *functional definition* of GIS. Most agree that the functions fall into categories and that the categories are subtasks that are arranged sequentially as data move from the information source to a map and then to the GIS user and decision maker. Another GIS definition, for example, states that GISs are "**automated systems for the capture, storage, retrieval, analysis, and display of spatial data**" (Clarke, 1995, p. 13). This has been called a "process definition" because we start with the tasks closest to the collection of data and end with tasks that analyze and interpret the information. This book's chapters are structured around this sequence of functions, and each will be discussed in detail as the book progresses.

1.2.2 A GIS Is an Information System

Jack Estes and Jeffrey Star defined a GIS as "**an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working with the data**" (Star and Estes, 1990, p. 2).

This definition stresses that a GIS is a system for delivering answers to questions or queries, what might be called an *information system* sort of definition. This means that a GIS collects data, sifts and sorts them, and selects and rebuilds them to find precisely the right piece of information to answer a specific question. The reference to geographic coordinates is an important one, because the coordinates are literally how we are able to link data with the map. This theme is examined in detail in Chapter 2.

Another information system definition of a GIS is one that has stood the test of time remarkably well. As such, this definition is worth considerable thought. In 1979, during the infancy of the technology, Ken Dueker defined a GIS as "**a special case of information systems where the database consists of observations on spatially distributed features, activities or events, which are definable in space as points, lines, or areas. A geographic information system manipulates data about these points, lines, and areas to retrieve data for ad hoc queries and analyses**" (Dueker, 1979, p. 106).

The phrase "special case of information systems" implies that GIS has a heritage in information systems technology, which it indeed does. GIS did not invent database management, and there exists in computer science a 40-year tradition in this field all the way from the earliest spreadsheet programs, through relational database management, to the object-oriented database management of today. Information systems are used extensively in library science, in business, and around the Internet.

In Dueker's definition of GIS, the database itself consists of a set of observations, which implies a scientific approach to measurement. Scientists take measurements and record those measurements in some kind of system to help them analyze the data. The observations are *spatially distributed*; that is, they occur over space at different times and at different locations at the same time.

The observations are those of *features*, *activities*, and *events*. A *feature* is a term from cartography meaning an item to be placed on a map. *Point features*, such as an elevation bench mark (Figure 1.2), have only a location. *Line features* have several locations strung out along the line in sequence like a bead necklace, an example being

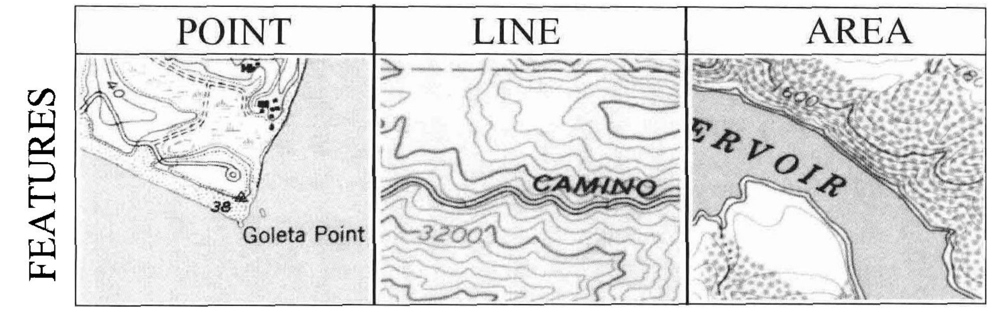


FIGURE 1.2: The Feature Model: Examples of a point feature (38 foot elevation bench mark), a line feature (road, contours), and area features (reservoir, vegetation).

a road or a stream. *Area features* consist of one or more lines that form a loop, such as the shoreline of a reservoir or lake, or the edge of a patch of vegetation. Traditionally, the source of geographic information is the map, and the information on a map consists of a set of graphic symbols, such as colors, lines, patterns, and shades.

"Activities" implies a link to the social sciences. Human activities create geographic patterns and distributions. They lead to the population map, census map, distribution of disease incidences, location of infrastructure, and so on—all related to how people live their daily lives. The "event" part of GIS implies that geographic data fall not only into space but also into time. Time gives us a fourth dimension and becomes a part of the data because events happen in time and features exist over a duration. The reservoir in Figure 1.2, for example, was created by damming a stream and so was not shown on a map made 100 years ago.

Dueker's GIS definition assumes that events also have expressions as points, lines, or areas in space and on the map. An example of a point event is the location of a traffic accident. A line activity could be the flow of electricity along a segment of a power cable. An area event could be the freezing of a body of water, such as the Central Park reservoir in New York City. The information element becomes useful to the GIS user because it exists, it has data associated with it, and it has cartographic reality as a feature on a map.

We use the information mapped in the GIS for doing exactly what an information system should do: solve problems, do queries, come up with the answer, or try out a possible solution. So we manipulate the data, not by hand, but digitally. We manipulate data about events or activities by using the digital map features that represent them as "handles." In other words, *the points, lines, and areas in this map database are used to manage the data*. Another key part of Dueker's GIS definition is that the queries must be ad hoc or context-specific queries. We don't have to know in advance when building a GIS exactly what we want to use it for. This means that GIS is a generic problem-solving tool; it is not something built just for that project or to get this week's assignment done. The value of GIS comes from its ability to apply general geographic methods to specific geographic regions.

Finally, in Dueker's definition a GIS can also do analysis. Usually, the purpose of having data in GIS form is so that an analyst can extract what is necessary to make predictions and explanations about geographic phenomena. A focus on GIS technology ignores the fact that the ultimate purpose of the system is to solve problems. Geographic information science goes beyond description, to include analysis, modeling, and prediction. The information systems definition, then, leads back to the role of a GIS as a problem solver. It begs the question: Is this just one more scientific method, or is this a new scientific approach?

1.2.3 GIS Is an Approach to Science

As a tool or as an information system, GIS technology has changed the entire approach to spatial data analysis. GIS has already been compared to not one but several simultaneous revolutionary changes in the way that data can be managed. The convergence of GIS with allied technologies, those of surveying, remote sensing, air photography, the global positioning system (GPS), and mobile computing and communications has fed a spectacular growth of these technologies.

As a result, the way of doing business—the standard operating procedure of geographic and spatial information handling—has rapidly restructured itself. First, the technology of GIS has become much simpler, more distributed, cheaper, and has crossed the boundary into disciplines such as anthropology, epidemiology, facilities management, forestry, geology, and business. Second, this mutation has led to a culling of the body of knowledge that constitutes geography so that it is suitable for use in these parallel fields as a new approach to science. Goodchild called this "geographical information science" (Goodchild, 1992). In the United States the preferred term is *geographic information science*.

Goodchild defined geographic information science as "**the generic issues that surround the use of GIS technology, impede its successful implementation, or emerge from an understanding of its potential capabilities**" (Goodchild, 1992). He also noted that this involved both research *on* GIS and research *with* GIS. Supporting the science are the uniqueness of geographic data, a distinct set of pertinent research questions that can only be asked geographically, the commonality of interest of GIS meetings, and a supply of books and journals. On the other hand, Goodchild noted that the level of interest depends on innovation, that it is hard to sustain a multidisciplinary (rather than interdisciplinary) science, and that at the core of the science, in geography, a social science tradition has to some extent an antipathy toward technological approaches.

This book is an effort to distill from the discipline of geography exactly those components that are derived from the areas of research outlined by Goodchild. As such, this book adopts Goodchild's approach. The chapters that compress the principles of cartography are Chapters 2 and 7; analytical cartography's contributions fall into Chapters 3–5; and spatial analysis is discussed in Chapter 6. Added to these are doses of general geography, database management, and applied GIS. This knowledge base constitutes the new and strengthening field of geographic information science.

1.2.4 GIS Is a Multibillion-Dollar Business

Groups monitoring the GIS industry estimate the total value of the hardware, software, and services conducted by the private, governmental, educational, and other sectors that handle spatial data to be billions of dollars a year. Furthermore, for the last half decade of the 1990s, and into the current decade, the industry has seen double-digit annual growth. Anyone who attends a national or international conference in the field can feel an overwhelming sense of rapid growth, sophistication, and the sheer magnitude of the transformation that GIS has led.

Largely responsible for this situation were the massive cost reductions in technology dating from about 1982, when computers moved out from behind glass windows as tended by people in white coats and onto the desktop. This decline in cost, aided by the success of the workstation as a tool in engineering settings, has led to a rapid increase in what is usually called the "installed base" of GIS. Just about every major academic institution in the United States and in many other countries now teaches at least one class in GIS. Most local, state, and federal government agencies use GIS, as do businesses, planners, architects, foresters, geologists, archeologists, and so on. This growth in pure numbers, added to the increase in sophistication of the systems, is what has led to the big business aspect of GIS.

However, other steps have been critical to the booming (and blooming) of GIS. First, the industry was founded on vast amounts of inexpensive federal government data, mostly data of the U.S. Census Bureau and the U.S. Geological Survey. Second, the community has been a successful advocate of the field and has rapidly developed an infrastructure for self-support, user groups, network conference groups, and so on. Third, the addition of graphical user interfaces and the addition of extremely useful features such as help screens and automatic installation routines have played an essential role. Fourth, GIS has merged successfully with parallel technologies and has benefited from the resultant multiplier effect.

The growth of GIS has been a marketing phenomenon of amazing breadth and depth and will remain so for many years to come. Clearly, GIS will continue to integrate its way into our everyday life to such an extent that it will soon be impossible to imagine how we functioned before. The GIS operations could become so transparent to the public that we would not even realize that GIS was there, just as we give no thought to the microprocessor that calculates our change at the cash register. Then again, many would argue that it already has done just this.

1.2.5 A GIS Plays a Role in Society

Many people doing research on GIS have argued that defining GIS narrowly, as a technology, as software, or as a science, ignores the role that GIS plays in changing the way people live and work. Not only has GIS radically changed how we do day-to-day business, but also how we operate within human organizations. Nick Chrisman (1999) has defined GIS as "**organized activity by which people measure and represent geographic phenomena then transform these representations into other forms while interacting with social structures**."

This definition has emerged from an area of GIS research that has examined how GIS fits into society as a whole, including its institutions and organizations, and how GIS can be used in decision making, especially in a public setting such as a town meeting, or on a community group Web site. This latter field is termed PPGIS, for Public Participation GIS.

Few people would doubt that as GIS has become part of the way of doing business within many organizations, such as planning offices or state planning agencies, the result has been a shifting in the work assignments, job descriptions, responsibilities, and even the power relationships of the organization. For example, when GIS is first introduced into a work environment, it is very important to have a "champion," someone who