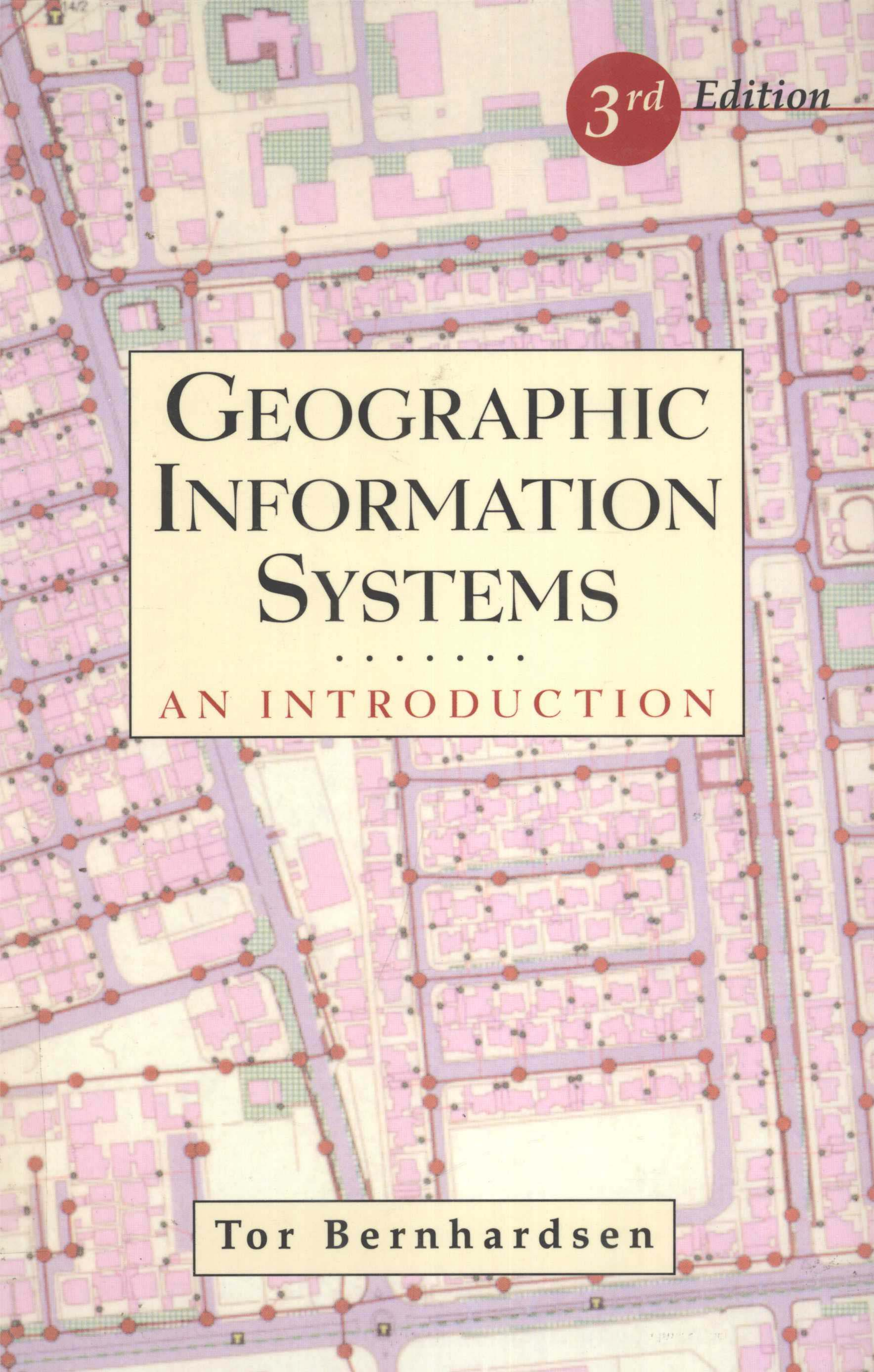

3rd Edition

GEOGRAPHIC INFORMATION SYSTEMS

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AN INTRODUCTION

Tor Bernhardsen

Geographic Information Systems
An Introduction

Third Edition

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Arendal, Norway

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FOREWORD

In approaching global problems, the people of the world are benefiting from more than 50 years of major developments in the science and technology used for studying the Earth, its human population, and the natural and cultural resources that make up the global environment. Especially important among these have been the rapid developments in remote sensing of the Earth environment, in computer science and technology, in global electronic communications, and in the gathering of spatial information about the Earth and its inhabitants into vast new electronic storehouses. In sum, as we enter the twenty-first century, we are in the fortunate position of having both the technical and the political means of bringing the people of the world together to deal with the world's problems; we must seize this opportunity.

One of these newly developed technologies, and one of the most important components of any approach to global problem solving, is geographic information systems (GIS) technology. Developed in just the last 30 years or so, GIS technology already represents a billion dollar industry worldwide, growing at perhaps 25% per year and serving about one million persons on a daily basis in more than 100 countries.

GIS has been used on problems at widely varying scales and for geographic areas ranging from a few hectares or a single city block up to those encompassed by the global databases just now beginning to become available for extensive use. GIS has been applied by a number of disciplines to a correspondingly wide range of problems. Governments, nongovernmental organizations, businesses, and educational institutions all now use GIS technology. Members of the general public will continue to become GIS users in the years just ahead. The fact that GIS technology has proven its value to its users is indicated by the rapid growth in its use, the rapid growth in expenditures for GIS technology, and the very large amounts of resources now being devoted throughout the world to creating digital data for use in GISs of various kinds.

Another indication of the value of GIS technology is that the number of GIS educational programs is growing faster than the use of the technology. For this important educational enterprise to succeed, sound textbooks in GIS technology and science are needed. This volume is just such a textbook. Until just a few years ago there were few introductory textbooks dealing with GIS technology. Those who learned the technology learned chiefly or exclusively through experience. Fortunately, that is now changing. I think this book is well designed, solidly constructed, and finely crafted; those who depend on it as they set out to explore our spatial world will be well served.

In my own work in the GIS field over the last 30 years or so, I have become convinced of the importance of providing GIS technology that works for its users. Many persons, especially those new to the field, can be overwhelmed by the enormous amount of information about GIS available. Students and others new to the GIS field need the guidance of textbook authors with extensive experience in the field, discernment, and careful judgment—authors who can separate the sound and essential from the ephemeral, authors who can indicate what actually works. That experience is reflected in these pages.

It is also important to realize that a GIS is considerably more than just technology; most of the problems with GIS now have more to do with the people and the procedures they use (system design, applications programming, effective use of GIS in solving real problems, funding new systems, GIS planning and implementation, and so on) than with computer hardware and software. The reality is that although one can now buy a reliable GIS hardware/software system and can often obtain a great deal of GIS data through purchase or conversion, there is no similarly reliable way to create the organizational structures and experienced staff necessary to support an effective GIS.

Some years ago, in thinking about how GIS use could best be developed throughout the world, I made a list of the traits that I thought GIS technical advisers would require if they were to be successful in spreading GIS use into new disciplines, new organizations, and new areas in the world. The list of intellectual and personal traits was a formidable one, chiefly because I believe that GIS technology can be applied to so many kinds of problems and in so many situations. The list, in turn, led me to reflect on how one could possibly find, recruit, and train and educate such people. How does one go about developing people with boundless enthusiasm and extraordinary patience, coupled with the appropriate technical, scientific, managerial, and political skills; those who are technicians as well as humanitarians; persons sympathetic to the ills of humankind and not afraid to wade in and try to improve things even when, often, they will not be successful?

In the end, I have concluded that such persons will, naturally and inevitably, be drawn to GIS technology, bringing with them the many skills and abilities they have already acquired elsewhere. When they understand just what GIS technology is capable of doing for many kinds of problem solving, they will embrace it and take it with them wherever they go. Books like this one will foster that process and so contribute to the improvement of the world in which we live.

I hope that the readers of this book will profit from what it has to teach them. If we are to solve many of the problems facing us—in the cities, in the wild areas of the Earth, in the atmosphere and the oceans—problems of the Earth as a whole, we shall need the help of skilled users of GIS technology. If readers can master what is in this volume, they will be well started on this enterprise.

Jack Dangermond

PREFACE

It is no more than three years since the previous edition of this book was published; however, technological developments in the field of GIS occur rapidly. In addition, there is always room for improvement. In this third edition I have attempted to maintain the original philosophy that the book should be at the introductory level while at the same time covering all relevant aspects linked to GIS. No major changes have been made in the chapter structure or in the choice of material. However, technological references have been updated and slightly extended. I have attempted to simplify the more difficult and obscure material, while going into greater depth with some of the material, such as georeferencing systems and geometric operations on geodata. The standardization work being carried out by such organizations as the International Standardization Organization (ISO), Open GIS Consortium (OGC), Federal Geographic Data Committee (FGDC), and others has lately become a central theme in the GIS world, and I have attempted to incorporate this material more actively in the text. Moreover, as in earlier editions I have supplemented the text with simple, but I hope instructive, illustrations.

It is not possible to write this kind of book without assistance from others. In this connection I would particularly like to thank the following from the National Mapping Authority, Norway: Bjoern Geirr Harsson for his contribution to Chapter 6, "Georeferencing Systems," Morten Borrebæk for his contribution to Chapter 3, "From the Real World to GIS," and Chapter 19, "Standards and Geospatial Infrastructure," as well as Hans Roenning for his contribution to Chapter 9, "Remote Sensing."

I would like to thank Mahala Mathiassen for her excellent translation to English of all the new material in this edition. I would also like to thank James Harper of my publisher John Wiley & Sons for his pleasant and professional cooperation. Finally, I would like to thank my wife and family for support and great patience while I spent much of my time working on the book.

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CONTENTS

CHAPTER 1

Geographical Information Systems and Geographical Information

1.1 Basic Concepts

Society is now so dependent on computers and computerized information that we scarcely notice when an action or activity makes use of them. Over the past few decades we have developed extremely complex systems for handling and processing data represented in the only form acceptable to computers: strings of zeros and ones, or bits (binary digits). Yet is has proved possible to represent not only numbers and letters, but sound, images, and even the contents of maps in this simple, universal form. Indeed, it may be impossible to tell whether the bits passing at high speed down a phone line or stored in minute detail on a CD-ROM (compact disk—read-only memory) represent a concerto by Mozart or the latest share prices. Unlike most of its predecessors, computer technology for processing information succeeds in part because of its ability to store, transmit, and process an extremely wide range of information types in a generalized way.

Computerization has opened a vast new potential in the way we communicate, analyze our surroundings, and make decisions. Data representing the real world can be stored and processed so that they can be presented later in simplified forms to suit specific needs. Many of our decisions depend on the details of our immediate surroundings and require information about specific places on the Earth's surface. Such information is called *geographical* because it helps us to distinguish one place from another and to make decisions for one place that are appropriate for that location. Geographical information allows us to apply general principles to the specific conditions of each location, allows us to track what is happening at any place, and helps us to understand how one place differs from another (Figure 1.1). Geographical information, then, is essential for effective planning and decision making in the modern society.

We are used to thinking about geographical information in the form of maps, photos taken from aircraft, and images collected from

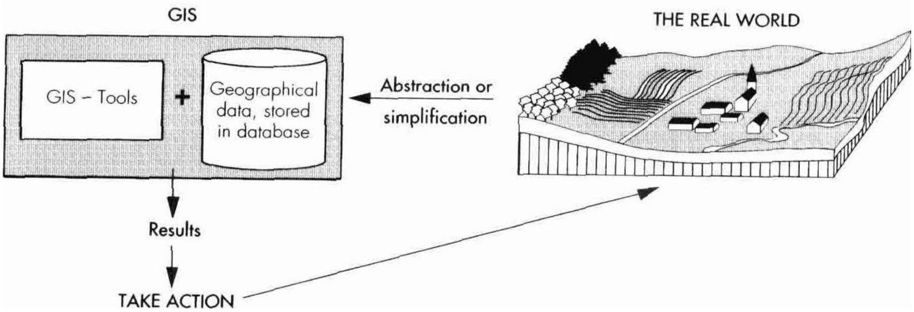

Figure 1.1
GIS is intended to be a means of improving everyday life. It is therefore important that the information that results from data processing be applied to guide the real world in the right direction.

satellites, so it may be difficult at first to understand how such information can be represented in digital form as strings of zeros and ones. That problem is one of the central issues of this book, and the fact that many alternatives exist is one of the reasons why that book is as long as it is. If we can express the contents of a map or image in digital form, the power of the computer opens an enormous range of possibilities for communication, analysis, modeling, and accurate decision making (Figure 1.2). At the same time, we must constantly be aware of the fact that the digital representation of geography is not equal to the geography itself—any digital representation involves some degree of approximation.

Since the mid-1970s, specialized computer systems have been developed to process geographical information in various ways, which include the following:

- Techniques to input geographical information, converting the information to digital form
- Techniques for storing such information in compact format on computer disks, compact disks (CDs), and other digital storage media
- Methods for automated analysis of geographical data, to search for patterns, combine different kinds of data, make measurements, find optimum sites or routes, and a host of other tasks
- Methods to predict the outcome of various scenarios, such as the effects of climate change on vegetation
- Techniques for display of data in the form of maps, images, and other formats
- Capabilities for output of results in the form of numbers and tables

The collective name for such systems is *geographical information systems* (GISs). The acronym GIS has come to signify much more than a software system that processes, stores, and analyzes geographical data.

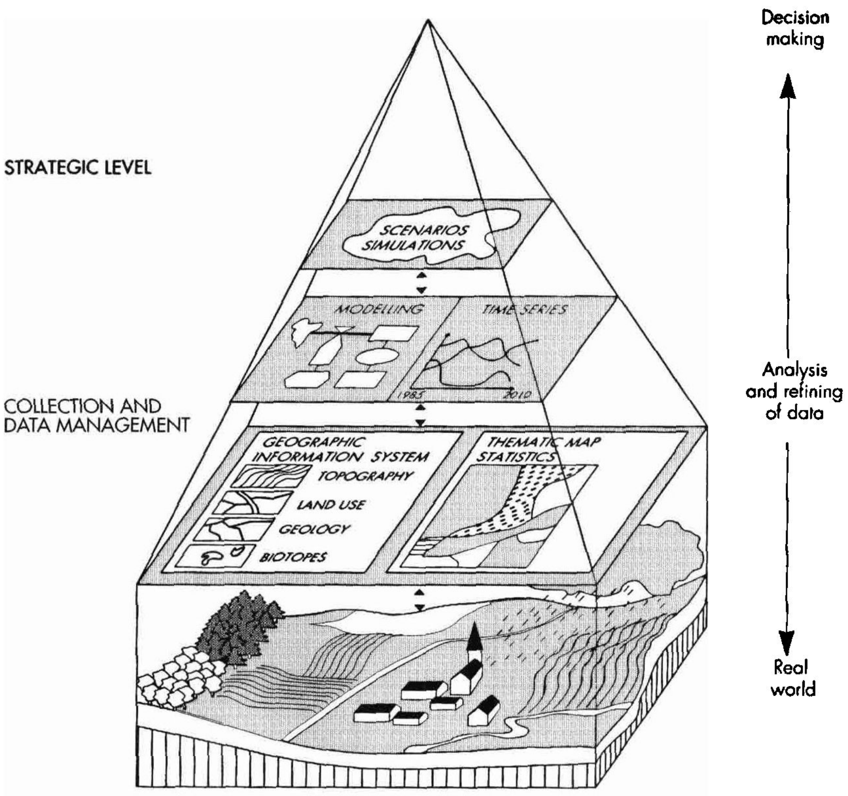

Figure 1.2
By use of geographical information systems, a simplified world can be brought into the computer. Different techniques can be applied to analyze and simplify the data, and the foundation is laid for the decision-making pyramid. Today, geographical information systems are in the process of filling the upper half of the pyramid. (Figure freely adapted from Grossman 1983.)

GIS is a "hot" application area for digital technology. Its software industry has been growing at more than 20% a year for many years, and recent figures for total annual sales of GIS software exceed $800 million. The term *GIS* has come to be associated with any activity involving digital geographical data; we now talk about GIS data, GIS decisions, and even GIS systems.

Although it is very easy to purchase the constituent parts of a GIS (the computer hardware and basic software), the system functions only when the requisite expertise is available, the data are compiled, the necessary routines are organized, and the programs are modified to suit the application. A computer system can function at what may appear to be lightning speed, yet the entire time span of a GIS project can stretch to months and even years. These facets of an overall GIS are interlinked (Figure 1.3). In general, procurement of the computer hardware and software is vital but simple. The expertise required is often underestimated, the compilation of data is expensive and

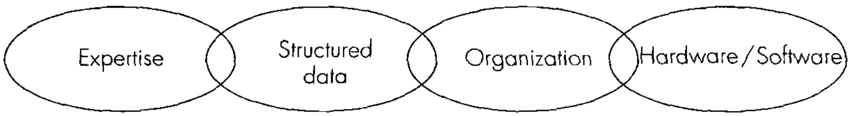

Figure 1.3
A GIS system cannot be bought off the shelf. The system has to be built up within an organization. When planning to introduce GIS, it is important that equal attention be given to all four links in the GIS chain.

time-consuming, and the organizational problems can be most vexing. These facets of an overall GIS are discussed in detail later.

Traditionally, geographical data are presented on maps with the use of symbols, lines, and colors. Most maps have a legend in which these elements are listed and explained—a thick black line for main roads, a thin black line for other roads, and so on. Dissimilar data can be superimposed on a common coordinate system. Consequently, a map is both an effective medium for presentation and a bank for storing geographical data. But herein lies a limitation. The stored information is processed and presented in a particular way, usually for a particular purpose. Altering the presentation is seldom easy. A map provides a static picture of geography that is almost always a compromise between many differing user needs. Nevertheless, maps are a substantial public asset. Surveys conducted in Norway indicate that the benefit accrued from the use of maps is three times the total cost of their production.

As compared with maps, GIS has the inherent advantage that data storage and data presentation are separate. As a result, data may be presented and viewed in various ways. Once they are stored in a computer, we can zoom into or out of a map, display selected areas, make calculations of the distance between places, present tables giving details of features shown on the map, superimpose the map on other information, even search for the best locations for retail stores! In effect, we can produce many useful products from a single data source (Figure 1.4).

GIS defined

The term *geographical information system* (GIS) is now used generically for any computer-based capability for the manipulation of geographical data. A GIS includes not only hardware and software, but also the special devices used to input maps and to create map products, together with the communication systems needed to link various elements. The hardware and software functions of a GIS are as follows:

- Acquisition and verification
- Compilation

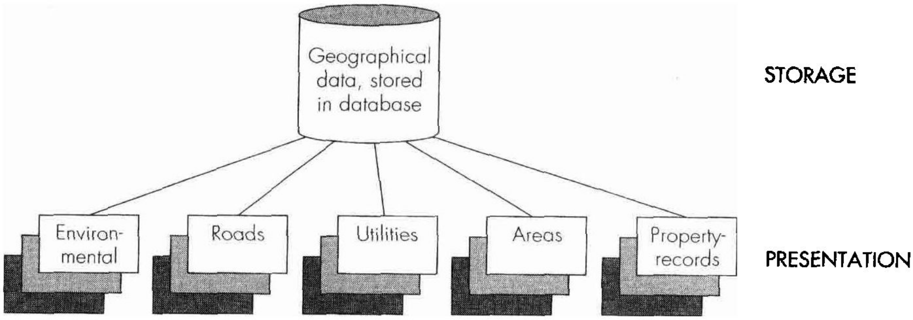

Figure 1.4
A map can be both a presentation medium and a storage medium, with resulting limitations. With GIS, storage and presentation are separated, thereby enabling a wide variety of products to be created from the same basic data.

- Storage
- Updating and changing
- Management and exchange
- Manipulation
- Retrieval and presentation
- Analysis and combination

These actions and operations are applied by a GIS to the geographical data that form its database.

All of the data in a GIS are georeferenced, that is, linked to a specific location on the surface of the Earth through a system of coordinates. One of the commonest coordinate systems is that of latitude and longitude; in this system location is specified relative to the equator and the line of zero longitude through Greenwich, England. But there are many other systems as well, and any GIS must be capable of transforming its georeferences from one system to another.

Geographical information attaches a variety of qualities and characteristics to geographical locations (Figure 1.5). These qualities may be physical parameters such as ground elevation, soil moisture level, or atmospheric temperature, as well as classifications according to the type of vegetation, ownership of land, zoning, and so on. Such occurrences as accidents, floods, or landslides may also be included. We use the general term *attributes* to refer to the qualities or characteristics of places and think of them as one of the two basic elements of geographical information, along with locations.

In some cases, qualities are attached to points, but in other cases they refer to more complex features, either lines or areas, located on the Earth's surface; in such cases the GIS must store the entire mapped shape of the feature rather than a simple coordinate location. Examples of commonly mapped features are lakes, cities, counties, rivers, and streets, each with its set of useful attributes. When a feature is used as a reporting zone for statistical purposes, a vast amount of