

**FUNDAMENTALS  
OF  
GEOGRAPHIC  
INFORMATION  
SYSTEMS**

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**SECOND EDITION**

**MICHAEL N. DEMERS**

# **FUNDAMENTALS OF GEOGRAPHIC INFORMATION SYSTEMS**

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**Michael N. DeMers**

*New Mexico State University*



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# PREFACE

The availability of off-the-shelf geographic information systems (GIS) continues to expand at an ever-increasing rate. At least in part this seems to have resulted from a growing awareness of the inherent geographic nature of some of the most important problems facing society today. This may come as no surprise to professional geographers, but to those without formal geographic education the ascendancy of this burgeoning technology seems to have come about only recently. In fact, the geographic roots of GIS follow a lineage of nearly 2,500 years of geographic exploration, research, and theory building. In the early 1960's this body of knowledge began to be formalized as a set of computer tools to input, store, edit, retrieve, analyze, and output natural resources information for the Canadian government. This first GIS, the Canada Geographic Information System, inaugurated efforts around the world to formalize and automate geographic principles to solve spatial problems related to managing natural resources. After nearly 40 years of development, the GIS is now a mainstay for solving geographic problems not only for natural resources, but for a myriad of physical and human endeavors: from crime and disease analysis and prevention to emergency vehicle routing and business and industrial location analysis; from urban and regional planning to scientific research and spatial data exploration; and from utilities inventory and management to military simulations. The potential applications of geographic information systems are enormous and still growing.

As a tool-kit for answering geographic questions the GIS currently provides a relatively robust set of computer algorithms. But as our application needs increase and our knowledge of geographic concepts grow, the need for even more advanced tools increases. Recognizing this increased need for advanced tools and new theory development, the GIS industry pays a premium for graduates who know not only how to use the existing software in complex and innovative ways, but how to push the technology beyond its current bounds. This new method of inquiry, known as geographic information science, demonstrates that a knowledge of the various GIS software packages is no longer sufficient if the industry is to expand. It acknowledges that many algorithms commonly used in GIS are either approximations of geographic reality or are workarounds stemming from a lack of understanding of the underlying geographic principles driving spatial patterns and dynamics.

This textbook is designed to provide some of the basics required not only to operate currently available GIS technology to solve everyday geographical problems, but also to encourage spatial thinking in the broader context. A fundamental premise of GIS is that its users, as well as its designers and developers, must be able to identify and isolate the spatial components of their knowledge domains. Before spatial models can even be considered, much less implemented, we must be able to recognize that geographic space is the underlying fabric upon which all spatial models are embroidered. While this may

seem to be commonly accepted in theory, in practice it is not always so well recognized. For example, it is not uncommon for business owners to be unaware that the potential for customers is generally greater among those who live near the business than for those who live farther away. This is a fundamental concept involved in economic placement theory—a type of modeling commonly applied within GIS. Even for those that recognize that there is an important spatial component inherent within their academic disciplines, their education frequently delays the explicit inclusion of that spatial component until late in the student's academic course work, thus limiting their exposure to severely restrained amounts and types of spatial data and spatial concepts.

Fortunately, this situation is changing, with new sub-fields developing that not only acknowledge but which focus on the importance of geographic space within their subject. The new sciences of landscape ecology and conservation biology, for example, often contain an explicit spatial component. Health care professionals are now examining the spread of disease vectors, the placement of health care facilities, and the importance of spatial interactions as they affect overall health of patients. Agriculture is now attempting to link ground-based data with remotely sensed data to examine the potential to increase the efficiency of applications of fertilizers, water, and pesticides under the heading of "precision agriculture." Even the U.S. Department of Justice's newly formed Crime Mapping Research Center is a direct result of the acknowledged need for mapped data in the analysis of crime statistics for reducing crime and apprehending criminals. Within that context, a new field of study called *geographic profiling* has developed to analyze the spatial behavior of serial criminals, allowing criminologists to predict the locations of future criminal events. Investigative journalists are beginning to use GIS as a method of answering questions about everything from the differential affects of storm damage to the impact of terrain and weather on military operations. The GIS literature within wildlife science is still another example of the exponential growth of GIS models applied to and developed by practitioners in other subject disciplines.

Although there are many additional examples of how spatial thinking has led directly to the use of GIS in a wide variety of fields, there are many more potential applications yet to be discovered by people trained in geographic information systems and geographic information science. For those whose career goals are primarily to become GIS technicians, it is important to understand how the GIS is to be used for modeling so that the databases allow the users to perform the necessary tasks. Applications specialists need to understand both the spatial nature of the data they will most often encounter as well as the limitations of the data structures and data models used by the GIS to allow them to do so. Finally, GIS designers and developers need to know what spatial analytical needs are not being met, the limitations of existing algorithms and data models, and how the users can best interact with the software. They must also be well versed in software development techniques and computer science.

This presents quite a diverse audience for those reading this book and/or taking perhaps their first course in geographic information systems. But while I have attempted to include some basic material of interest to all of these groups, I have focused on the primary task of the GIS—analysis and decision making. Analysis is what links the technician who must perform the analytical functions, the applications specialists who need the analyses performed, and the

developers who must make this happen. The text is meant as an overview of the discipline at a basic level, not as an encyclopedia of existing knowledge or as an examination of new theory. My intent is to provide a set of basic concepts upon which students will, through the pursuit of additional course work and practical experience, develop new applications, new theory, and new software.

For this second edition I have tried to incorporate as many of the suggested changes we received from readers and reviewers of the first edition to improve readability and the ability to convey the basic concepts. I have made some adjustments in the organization of the text without completely reworking its basic structure. Among the most requested changes is the inclusion of more graphics. I have added close to 40 new graphics to try to link the concepts to a visual learning device. I've also tried to improve or replace some of the graphics that were described as less than useful. All of the changes, whether major or minor, have been in response to the needs expressed by both instructors and students.

As you read through the book, whether as part of a formal GIS course or independently, try to examine each concept as it applies to your own career goals. Look for the spatial components and how they are represented and modeled. Think beyond the text itself by combining your own interests and background to extend the basic ideas to satisfy your own needs. Be creative. Much of what you read here may not be true in the future. You, and many others like you, will change the way the science, the technology, and the applications will appear in the next decade.

Finally, I invite all of you to become geographers, if not by vocation then by avocation. GIS is about geography and about thinking geographically. Beyond being an essential component of GIS, geography also opens new avenues of examining and analyzing the world around us. More importantly, it provides us with a totally new appreciation of everyday life and the environment in which we live it.

### Acknowledgments

I am deeply grateful to the many students, faculty, and reviewers who have suggested changes for the second edition. Unfortunately, there are far too many of you to mention. Please know that I took all your suggestions to heart and that I am grateful to you for helping to make this second edition better than the first. Some of you made substantial efforts on behalf of the second edition, and I would like to thank you by name. First, Dr. Keith Rice (University of Wisconsin, Stevens Point) provided some of the most precise pedagogic insights. He is joined by Dr. Lin Liu (University of Cincinnati), Dr. Donna Peuquet (Pennsylvania State University), and Dr. Elizabeth Wentz (and her students at Arizona State University). Dr. David Cowen (University of South Carolina) was not the only one but was certainly the most vociferous in his recommendation that more graphics be included. While at New Mexico State University, Dr. Howard Holt and Mr. Damian Kessler provided many needed changes and spotted some of the hard to find errors that slipped past me in the first edition. To these colleagues, and to the editorial and production personnel at Wiley, I owe a substantial debt.

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**UNIT 1**

**INTRODUCTION**





## CHAPTER 1

# Introduction to Automated Geography



This is a book about geography. Specifically it is about **Geographic Information Systems (GIS)**—a fundamental set of automated ideas and concepts rooted in over 2500 years of exploration and geographic research (Dobson, 1995) and designed to provide answers to questions based on mapped data. As a practicing geographer I have long been intrigued by the idea of geographer as explorer. Visions of Alexander von Humbolt or some Indiana Jones-like figure chopping his way through the tropical vegetation in search of some ancient ruins have filled me with wonder about the world in which we all live. I've been thrilled to picture myself as *Professor Challenger*, the Arthur Conan Doyle (1989) character from the book *The Lost World*, seeking out proof of the existence of live dinosaurs. The early explorers shared this wonder as they searched for new lands, new people, and new resources. As more of these lands were discovered, geographers began to use new tools to investigate the **spatial** distribution of people, plants, animals, and natural resources. They employed new methods of mapping and more efficient ways of examining the maps that others had produced. Geographic exploration became more than going to new places and describing what explorers saw. Instead, it became a way of trying to decide why the patterns explorers saw existed and what impacts those patterns might have on the health and well-being of both the people and fragile environments in which they dwelled.

Today, with very few exceptions, much of the search has been explored by conventional means. The machete and the pith helmet have been replaced by satellites and computers. Long, hazardous journeys through deserts and tropical rainforests, have been supplanted by computerized maps and statistical data—quantitative measures of unexplored terrain. They provide a different window into new worlds as well as old, much as the microscope and the telescope provided new eyes for the biologist and the astronomer. We can now see deeper and farther than we could before, allowing us to map more of what is present on the landscape and to ask questions that could not have been imagined. Questions of where things were on the earth have been replaced by those that ask why they are there and how that knowledge could be applied to predict future distributions and patterns. These predictions allow us to plan for the