Introducing Geographic Information Systems with ArcGIS®

Includes CD-ROM

Foreword by Jack Dangermond
With an afterword by Michael F. Goodchild

Michael Kennedy

Introducing Geographic Information Systems with ArcGIS®

Featuring GIS Software from Environmental Systems Research Institute

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University of Kentucky

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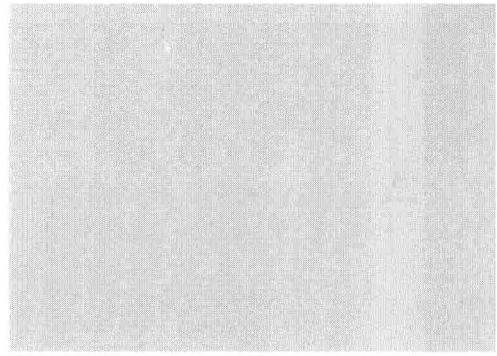

Dedicated to the memory of Evan Kennedy, who had every gift but that of years.

Foreword

by Jack Dangermond

Introducing Geographic Information Systems with ArcGIS offers a unique approach to GIS instruction. In it, Michael Kennedy recreates his time-tested methods of teaching GIS in the classroom in a step-by-step guidebook to GIS. Students on a journey to learn GIS with Professor Kennedy may feel like he is taking the journey with them, offering them his sage advice each step of the way. Professor Kennedy cares deeply for his students, and the detail of this care and years of teaching GIS come through in this book. In it, he walks students through the multitude of questions that come up daily in the classroom. His goal is to help students understand GIS concepts and learn GIS skills. It takes a master teacher to map GIS knowledge, making it clear to students and enabling them to gain confidence in their growing skills.

Once GIS students have learned the basics, the next step is to learn how to analyze spatial data and identify problems and create solutions. Learning to analyze spatial data moves students beyond exploration, beyond locating places on maps, and helps them create maps that guide better decisions.

All of us learn GIS skills in different ways. Some people are visual learners, some are auditory learners, and some need a hands-on approach. As the learning styles of students in general vary, so do the learning needs of students of GIS. Some students will need classroom study with conversations and time to process information about GIS concepts, spatial data, geodatabases, map projections, attribute tables, feature classes, datasets, and building maps, while others need only a guidebook with clear graphic illustrations. So, a variety of approaches to teaching GIS will help ensure that the increasing number of students worldwide have opportunities to gain GIS skills in ways that best suit their needs.

GIS is becoming part and parcel of the daily work lives of most people in many fields, from architects to zoologists, from academia to the business world, from city planning to national and international spatial data portals. Teachers are now taking on the essential task of opening the door for students to learn GIS. In *Introducing Geographic Information Systems with ArcGIS*, Professor Kennedy opens such a doorway for students to learn the skills basic to understanding GIS and to prepare students to make our communities better places.

Preface[1]

The purpose of Introducing Geographic Information Systems with ArcGIS is threefold.

1. To acquaint the reader with the central concepts of GIS and with those topics that are required to understand spatial information analysis.
2. To provide the person who works the exercises either (a) a considerable ability to operate important tools in the ArcGIS software or (b) a demonstration of other capabilities of the software.
3. To lay a basis for the reader to go on to the advanced study of GIS or to the study of the newly emerging field of GIScience, which might be described as the scientific examination of the technology of GIS and the fundamental questions raised by GIS.

Introducing Geographic Information Systems with ArcGIS is meant to serve as a text book for a standard one-semester course. It is suitable for a university, college, technical school, or advanced high school course, meeting for three hours per week. Between two and five additional hours per week are required for laboratory work, depending on the capabilities and computer experience of the students. The text may also be used for self-study.

The book, and any course taught from it, depend on having ESRI's ArcGIS Desktop and Workstation software, version 9.0, 9.1, or higher, available. The assumption is that the students will have access to full the ArcInfo package offered to colleges and universities under the generous site license agreement that ESRI offers to educational institutions. For more information about this program, point your browser at: http://www.esri.com/industries/university/education/faqs.html. However, if ArcInfo is not available, many of the exercises can be done with the ArcView level of ArcGIS, available to students with a free, one-year license.

While the author is impressed with the ArcGIS software (and with the aims of ESRI of being a force for conservation, preservation, and sustainable development worldwide), this book is not meant as a promotional text for ESRI. Like all large software packages, ArcGIS has its shortcomings, limitations, and bugs. When these arise in the process of working through the exercises, they are candidly pointed out to the reader. All bugs have been reported to ESRI, and most have been repaired or are scheduled for repair. By the way, the ESRI support staff is excellent: responsive and friendly.

[1]If this text is used in a classroom/laboratory setting, this preface is for the instructor and may be skipped by students. If you are using the book to learn GIS on your own you should probably read it.

The function of GIS software is to make a computer think it's a map—a map with characteristics that let the user analyze it, display its elements in a variety of ways, and use it for decision making. This text is oriented more toward preparing the student for doing analysis with GIS, rather than display, mapping, or standard data processing.

Contents of Introducing Geographic Information Systems with ArcGIS

- Part I: Basic Concepts of GIS
  - Chapter 1: Some Concepts that Underpin GIS (and introduction to ArcCatalog)
  - Chapter 2: Characteristics and Examples of Spatial Data (and introduction to ArcMap)
  - Chapter 3: Products of a GIS: Maps and Other Information
  - Chapter 4: Structures for Storing Geographic Data (and introduction to ArcToolbox and Workstation)
  - Chapter 5: Geographic and Attribute Data: Selection, Input, and Editing (and introduction to ArcScene and ArcGlobe)
- Part II: Spatial Analysis and Synthesis with GIS
  - Chapter 6: Analysis of GIS Data by Simple Examination
  - Chapter 7: Creating Spatial Data Sets Based on Proximity, Overlay, and Attributes
  - Chapter 8: Spatial Analysis Based on Raster Data Processing (and introduction to Spatial Analyst)
  - Chapter 9: Other Dimensions, Other Tools, Other Solutions (and introductions to 3-D Analyst, Historical Data, Address Geocoding, Network Analyst, and Linear Referencing)

In my view, the pedagogical theme of a first course should be breadth, with depth in vital areas. The text covers virtually all the general GIS capability that ArcGIS has to offer. Vector and raster storage, analysis, and synthesis are, of course, discussed extensively, with many examples and exercises for the student. Other areas receive less attention, such as 3-D GIS, time and GIS, network analysis (path finding and allocation), surface creation, spatial analysis, statistical and numerical analysis, model builder, GIS & GPS, and so on. In some later instances, the exercises are primarily demonstrations of the capabilities of the ESRI software, but, in my opinion, a student in a first course needs to get at least a glimpse of almost all of what GIS can do. Omitted from the text is most of customization, programming, and the more esoteric capabilities of geodatabases, which I believe belong in a second course. Also not included is GIS on the Internet and the issues related to large, enterprise implementations of GIS. To mention it again: the thrust of the text is to lay a foundation from which the reader can move toward doing analysis and synthesis with GIS.

The emphasis in terms of data structure is on geodatabases. However, extensive use is made of shapefiles and coverages, since most existing GIS data sets are in these formats. The student will become comfortable with switching and converting among the various formats. Another reason for using all three formats is that, at this stage of ArcGIS development, there are operations that can be done with coverages that cannot be performed with geodatabases.

ArcMap, ArcCatalog, ArcToolbox, ArcScene, and ArcGlobe are all explored in considerable detail. ArcInfo Workstation is introduced. Enough of command-line ArcInfo Workstation is used to make the student aware of its existence and its capability to perform operations that are cumbersome or impossible with the point and click software. This is a book that creates knowledge for the student that is realistic and at least touches on virtually all the ArcGIS capabilities and products.

In the four years the text has been under development, most of the exercises in the book have been performed by scores of students. All of the exercises have been tested and they work, both from a technical and pedagogical standpoint.

In terms of time required to do the exercises, most students will require:

Chapter 1—3:00 to 5:00 hours

Chapter 2—3:45 to 5:45 hours

Chapter 3—4:30 to 6:30 hours

Chapter 4—3:30 to 5:30 hours

Chapter 5—4:45 to 6:45 hours

Chapter 6—4:00 to 6:00 hours

Chapter 7—5:15 to 7:15 hours

Chapter 8—5:00 to 7:00 hours

Chapter 9—4:45 to 6:45 hours

Theory and Practice

Of the myriad of GIS textbooks available, some are long on theory but don't train the student, while the rest are pretty much manuals on how to use software, but don't promote an understanding of what lies behind the mechanics. So frequently GIS is taught either with texts that teach only theory and leave it to the instructor to select software and data to illustrate points or taught with manuals and demonstrations.

The book is unusual, if not unique, in that it serves both as a general introduction to GIS (serving an education function) and a manual on ArcGIS software (serving a training function). This is accomplished by dividing each chapter into an

- Overview section, and a
- Step-by-Step section

The Overview section is descriptive. It is a top-down discussion of theory and ideas relating to GIS.

The Step-by-Step section is prescriptive. It operates in a sequential fashion—do this, then this, then this. Here the student learns about and practices ArcGIS. There are more than 60 exercises in the book, not counting the 9 review exercises. Almost 60 percent of the book consists of step-by-step instructions on how to use ArcGIS software.

All the data sets for the exercises are on the CD-ROM that accompanies the book.

Teaching with This Book

The contents of the following folders on the CD must be available for downloading by students:

- IGIS-Arc—the primary source of data sets for the exercises
- IGIS-Arc_AUX—a source for datasets occasionally needed for exercises
- IGIS_with_ArcGIS_FastFactsFile_Checklists—a combination chapter summary and set of Fast Facts File prompts
- IGIS_with_ArcGIS_Selected_Figures—full-color versions of some figures in the text that suffer from black-and-white reproduction

If you are an instructor, you should consider copying the four folders above from the CD-ROM to a location on a network where the students can access their contents.

Exercises are roughly put into categories of length or difficulty, with such notes as "Warm-up" (least effort), "Project" (greater effort), and "Major Projects" (most effort).

Some warnings:

Do not use any of the sample databases on the CD-ROM for anything other than tutorial purposes. Most of the data is old. Much of it has been modified for instructional purposes.

For students who aren't paying attention, the exercises will get harder and harder because it is expected that they will learn (or be able to quickly find) how to perform operations that they have performed before. The "hand holding" diminishes as the chapter numbers increase.

Exercise 5-8 is a cooperative exercise for eight to twenty-four students. Preparation and management on the part of the instructor is a really good idea.

If you, as an instructor, are quite sure that your students will not need more than the most basic knowledge about coverages and shapefiles, you can have them skip considerable portions of Chapter 4. You should read the sections on coverages yourself and, perhaps in lecture sessions, supplement the student's knowledge of the coverage concepts that apply to geodatabases.

If you serve ArcGIS, or even just its license manager, over a network, you should thoroughly test the process. Also, in Chapter 8, the unsupported CellTool is used. Students may not be able to install it, so someone from network services will have to be involved.

More Resources for the Instructor

If you are an instructor who is using this text, you are encouraged to register on the website www.wiley.com/college/kennedy. There you will find advice on how to use the book to its fullest potential. Included there are answers to the questions posed in the text, sample assignments with blanks for the students to complete, test data for some assignments, and suggestions of how to use the text—avoiding some pitfalls that lurk, especially when the datasets are served across a network. The Instructor's Guide there can be a valuable resource for those teaching with this text. Also look at the folder IGIS_with_ArcGIS_Instructor's_Guide on the CD-ROM.

Concepts, Devices, and Techniques that Underlie the Philosophy of the Book

How can one textbook touch on almost all of GIS when it takes thousands of pages of manuals to do this? Two ways:

- There are few figures, and, compared to the standard computer manual, there are few screen shots. When a student follows the instructions, he or she sees the proper screens. When a figure can be better understood by the use of color, the figure is available on the CD-ROM in the folder IGIS_with_ArcGIS_Selected_Figures. Such figures are designated in the text reference with three asterisks. For example, "See Figure 8-4***."
- As the student progresses through the later chapters, the exercises do not contain detailed instructions. The students are expected to be able to do steps that were explained in detail earlier. For example, in early chapters, detailed instructions are given for finding or changing a property of a data set or data frame. In later chapters, the students will simply be told to take that action. When students can't either remember or find out how to perform an action that has been previously detailed, teachers should take it as a clue that the students are simply going through the motions of executing the software tools and that learning is not really taking place.

I believe that students learn best by doing—while observing and recording what it is they are doing. Students are asked to develop a Fast Facts File in which they record what it is they have learned about the software. This is a computer file that they keep open during their work sessions, both for adding new material and ascertaining how to do a particular procedure that they have used previously but cannot remember. They periodically revise and augment this file. Then, at the end of the course, they have their own reference manual for the software. I have used this technique for some years now, and it pays dividends. Some students who have graduated and now work in the GIS field tell me they take their Fast Facts File with them and maintain it in their new positions. One failure of other workbooks and web-based courses is that, while students can go through the exercises and even pass a test at the end, they simply cannot operate the software when handed a new exercise. Now with ten-plus years of teaching GIS with the Overview-Step method behind me, insisting that students make a Fast Facts File to provide themselves a guide through the very complex GIS software, I'm convinced that the not-always-popular-with-the-students Fast Facts File is more than worth the trouble.

The exercise material is project oriented; students learn the software as needed for the particular project at hand. So rather than learning everything about labeling features at one time or everything about selecting, the students learn as they complete projects and record what has been learned in their Fast Facts Files, which are later reorganized. At the risk of losing adoptions and sales, please let me candidly point out that this textbook does not serve very well as reference material. The idea behind the book is to make things click in the students' brains, to promote comprehension of concepts, not to serve as a reference guide to the software. However, the diligent students—indeed even those who follow the instructions—will emerge from the course with their own reference guides, done in a style suitable for each student: the Fast Facts File. Some students resist creating the file, so I make it count for 5 percent of their grade. Further, the Fast Facts File will be a reference document that the learners can maintain and upgrade in future months and years. A student of mine of a decade ago came to my class to give a guest lecture. He was in charge of the GIS program of a state unit. He brought his Fast Facts File with him to show to the class. Over the years, he had updated it many times.

The text is workbook-like in that there are blanks in the text which the students are asked to complete, showing that they have performed and comprehended a particular section. This also serves as a mechanism

for letting the instructors know how students are progressing. The Web site www.wiley.com/college/kennedy contains forms with these blanks, in context, so an instructor can copy and paste the material into assignment sheets. Student progress can be monitored using these assignments.

The text is set up so students can work at their own pace, respecting different learning styles and speeds of the students. For example, some students create entries in their Fast Facts Files with each step. Others make two passes through the material.

In a few places in the text, students are asked to record the names of menu choices or tabs in windows. Of course this information could have been printed for them, but having them write it in reinforces the words and the concepts behind them in the students' minds. It is also a modest protection against software changes (e.g., addition of menu or tab items).

The last exercise in each chapter is a checklist that can serve the students in development of the Fast Facts File. The students are given prompts that they fill in. The prompts appear in the text and also on the CD-ROM in the folder IGIS_with_ArcGIS_FastFactsFile_Checklists so they are available in machine readable form to the students. This allows students to copy the prompts into their Fast Facts Files and complete them.

The book simulates a teacher: sometimes a lecturer, standing in front of students, imparting information or giving directions. More often the instructor is a colleague, sitting beside the student, making suggestions, prompting, and, occasionally, making mistakes that he or she and the student rectify. One might describe the tone of the book as conversational. I believe the most important thing, after correctness, is engaging the student. I believe economy in writing is important. But sometimes additional words can set a tone. I actually use several tones in the text to provide variety. I change pace. I change style. I change attitude. I change the level of formality.

The writing style, for the most part, is informal—to convey the idea that the author is closely involved with the student, guiding her or him. Humor is used, but sparingly. Irony is used, but sparingly.

The ArcGIS software is so complex that there is no way to explore it "depth first." We must look at an overview. The book attempts to teach, or at least demonstrate, the major capabilities of ArcGIS. As you can tell from the weight of ESRI manuals, compared with the size of this text (which also serves as a general GIS theory text), I could hardly cover even a large portion in detail. However, the student will come away with considerable facility with the software and will know how to find and use additional capabilities.

Finally, I believe it is important to emphasize that computer is not a black box. An educated GIS professional should have some understanding of what makes a computer tick. So there is some general material on computers and representation of information, especially as they impact answers from a GIS.

Acknowledgments

This book was something of a family affair. My daughter Heather Kennedy provided help with the 3-D material[2]. My son Alex Kennedy carefully worked all the exercises in all chapters, making corrections and providing insightful observations. He also helped collect some of the GPS data.

Jack Dangermond, for his encouragement in general and writing the Foreword in particular, and ESRI for allowing use of numerous datasets and figures. In fact, this text was originally conceived of as a new edition of *Understanding GIS—The Arc/Info Method (UGIS-tiam)* reworked for the ArcGIS point-and-click version of the software, beginning with ArcGIS 8.x. It has clearly grown way beyond that first idea, with the addition of textual matter dealing with GIS itself, discussion of other capabilities of the software besides vector-based GIS site selection (such as a discussion of Spatial Analyst, the addition of material on several of the other important extensions to the software, and the major emphasis on geodatabases). Teachers who in the past used *UGIS-tiam* (last published almost a decade ago) will, however, recognize the site selection problem of that text (a laboratory to do research in "Aquaculture") as the Wildcat Boat Testing Facility of this text, albeit highly modified.

I am indebted to Dr. Michael Goodchild for writing the Afterword. As mentioned before, the aim of this textbook is to provide a general introduction to GIS and prepare students to use ArcGIS primarily for analysis. Some of those students will want to go on to study GIScience, and I commend Dr. Goodchild's Afterword to them.

Many colleagues and friends contributed to bringing this book to fruition. In particular, I want to thank:

Christian Harder, founding publisher, *ESRI Press*, for suggesting and encouraging the development of the text.

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The staff of ESRI technical support—friendly and helpful people too numerous to mention.

[2]She is author of *Data in Three Dimensions: A Guide to ArcGIS 3D Analyst* (Onward Press, 2004, ISBN 1-4018-4886-9) and editor of *The ESRI Press Dictionary of GIS Terminology* (2001, ISBN 1-879102-78-1)

Jim Harper and Amy Zarkos of John Wiley and Sons, who facilitated the editing process in spite of the author's frequent lack of organization and tardiness.

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Teaching assistants Chris Blackden and Amber Ruyter worked through the exercises and helped both students and me over rough spots.

Scores of students at UK had early drafts of the text inflicted on them. In particular Rebecca McClung, who reviewed the text exhaustively and helped prepare the index, and Travis Searcy, who combed through the later chapters.

I also wish to thank:

Taylor and Francis (and CRC Press) for allowing me to use portions of my textbook *The Global Positioning System and GIS* (ISBN 0-415-28608-5)

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I'm appreciative of the University of Kentucky and its College of Arts and Sciences and Department of Geography, for providing the opportunity to develop the text.

Introduction

A geographic information system (GIS) software package is basically a computer program designed to make a computer think that it's a map. This new sort of map is a dynamic entity, designed to assist people in making decisions. Such decisions might be as simple and short range as determining an efficient way to get from place A to place B. Or as complex as designing a light rail transportation system for a city or delineating flood planes. The difference between a paper map and a GIS map is that the latter exhibits "intelligence." You can ask it a question and get an answer.

Geographic information systems are transforming all the activities and disciplines that formerly used maps as the basis for decision making. It's about time. Most fields of human endeavor have long since been heavily impacted by the digital computer; in fact it's hard to think of one that hasn't. Fifty years have gone by since computers began changing accounting, census taking, physical sciences, and communication, to name a few. Even the field of music has been altered. Most of these "nonspatial" fields already couched their problems in terms of discrete symbols (such as A, r, 5, and $) that are easily converted to the binary language (using only the symbols 0 and 1) that the computer understands. The spatial fields such as geography, planning, and land use management, had to stick with maps because, while maps also use symbols, they are not so neat and tidy as to fit on the key of a keyboard. A symbol for a road might be three feet long! Determining how to efficiently represent the real-world environment in the memory of a computer turned out to be quite a challenge. So until a decade or so ago, those who relied on maps usually could not use computers effectively as the primary source of data from which to work.

Why has computer-based GIS come to influence how decisions are made about land use planning, navigation, resource allocation, and so on? First, the shortcomings of maps for decision making are many. Second, computers have become greatly faster, bigger (in terms of memory size), and cheaper. And, third, we have developed sophisticated data structures and learned how to efficiently program computers to represent the huge, almost infinitely detailed environment that we live in. So those of you who are just now beginning to learn about GIS are not pioneers, but if you enter the field now, I bet that in a decade you will feel like a pioneer because the field is growing so rapidly. You are off on a great adventure!

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