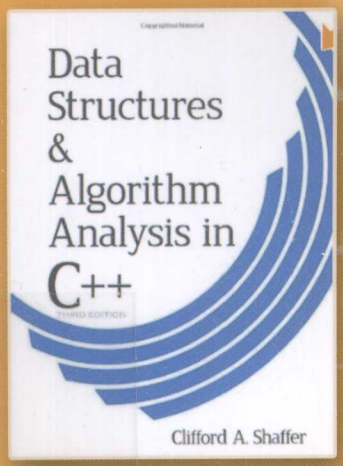
国外计算机科学教材系列

数据结构与算法分析

（C++版）（第三版）

Data Structures and Algorithm Analysis in C++

Third Edition



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[美] Clifford A. Shaffer 著

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内 容 简 介

本书采用程序员最爱用的面向对象 C++ 语言来描述数据结构和算法，并把数据结构原理和算法分析技术有机地结合在一起，系统介绍了各种类型的数据结构和排序、检索的各种方法。作者非常注意对每一种数据结构的不同存储方法及有关算法进行分析比较。书中还引入了一些比较高级的数据结构与先进的算法分析技术，并介绍了可计算性理论的一般知识。书中分别给出了 C++ 实现方法和伪码实现方法，便于读者根据情况选择。本书作者维护的网站上可下载相关代码、编程项目和辅助练习资料。

本书适合作为大专院校计算机软件专业与计算机应用专业学生的教材和参考书，也适合计算机工程技术人员参考。

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Preface

We study data structures so that we can learn to write more efficient programs. But why must programs be efficient when new computers are faster every year? The reason is that our ambitions grow with our capabilities. Instead of rendering efficiency needs obsolete, the modern revolution in computing power and storage capability merely raises the efficiency stakes as we attempt more complex tasks.

The quest for program efficiency need not and should not conflict with sound design and clear coding. Creating efficient programs has little to do with "programming tricks" but rather is based on good organization of information and good algorithms. A programmer who has not mastered the basic principles of clear design is not likely to write efficient programs. Conversely, concerns related to development costs and maintainability should not be used as an excuse to justify inefficient performance. Generality in design can and should be achieved without sacrificing performance, but this can only be done if the designer understands how to measure performance and does so as an integral part of the design and implementation process. Most computer science curricula recognize that good programming skills begin with a strong emphasis on fundamental software engineering principles. Then, once a programmer has learned the principles of clear program design and implementation, the next step is to study the effects of data organization and algorithms on program efficiency.

Approach: This book describes many techniques for representing data. These techniques are presented within the context of the following principles:

1. Each data structure and each algorithm has costs and benefits. Practitioners need a thorough understanding of how to assess costs and benefits to be able to adapt to new design challenges. This requires an understanding of the principles of algorithm analysis, and also an appreciation for the significant effects of the physical medium employed (e.g., data stored on disk versus main memory).
2. Related to costs and benefits is the notion of tradeoffs. For example, it is quite common to reduce time requirements at the expense of an increase in space requirements, or vice versa. Programmers face tradeoff issues regularly in all

phases of software design and implementation, so the concept must become deeply ingrained.

3. Programmers should know enough about common practice to avoid reinventing the wheel. Thus, programmers need to learn the commonly used data structures, their related algorithms, and the most frequently encountered design patterns found in programming.
4. Data structures follow needs. Programmers must learn to assess application needs first, then find a data structure with matching capabilities. To do this requires competence in Principles 1, 2, and 3.

As I have taught data structures through the years, I have found that design issues have played an ever greater role in my courses. This can be traced through the various editions of this textbook by the increasing coverage for design patterns and generic interfaces. The first edition had no mention of design patterns. The second edition had limited coverage of a few example patterns, and introduced the dictionary ADT and comparator classes. With the third edition, there is explicit coverage of some design patterns that are encountered when programming the basic data structures and algorithms covered in the book.

Using the Book in Class: Data structures and algorithms textbooks tend to fall into one of two categories: teaching texts or encyclopedias. Books that attempt to do both usually fail at both. This book is intended as a teaching text. I believe it is more important for a practitioner to understand the principles required to select or design the data structure that will best solve some problem than it is to memorize a lot of textbook implementations. Hence, I have designed this as a teaching text that covers most standard data structures, but not all. A few data structures that are not widely adopted are included to illustrate important principles. Some relatively new data structures that should become widely used in the future are included.

Within an undergraduate program, this textbook is designed for use in either an advanced lower division (sophomore or junior level) data structures course, or for a senior level algorithms course. New material has been added in the third edition to support its use in an algorithms course. Normally, this text would be used in a course beyond the standard freshman level "CS2" course that often serves as the initial introduction to data structures. Readers of this book should typically have two semesters of the equivalent of programming experience, including at least some exposure to C++. Readers who are already familiar with recursion will have an advantage. Students of data structures will also benefit from having first completed a good course in Discrete Mathematics. Nonetheless, Chapter 2 attempts to give a reasonably complete survey of the prerequisite mathematical topics at the level necessary to understand their use in this book. Readers may wish to refer back to the appropriate sections as needed when encountering unfamiliar mathematical material.

A sophomore-level class where students have only a little background in basic data structures or analysis (that is, background equivalent to what would be had from a traditional CS2 course) might cover Chapters 1-11 in detail, as well as selected topics from Chapter 13. That is how I use the book for my own sophomore-level class. Students with greater background might cover Chapter 1, skip most of Chapter 2 except for reference, briefly cover Chapters 3 and 4, and then cover chapters 5-12 in detail. Again, only certain topics from Chapter 13 might be covered, depending on the programming assignments selected by the instructor. A senior-level algorithms course would focus on Chapters 11 and 14-17.

Chapter 13 is intended in part as a source for larger programming exercises. I recommend that all students taking a data structures course be required to implement some advanced tree structure, or another dynamic structure of comparable difficulty such as the skip list or sparse matrix representations of Chapter 12. None of these data structures are significantly more difficult to implement than the binary search tree, and any of them should be within a student's ability after completing Chapter 5.

While I have attempted to arrange the presentation in an order that makes sense, instructors should feel free to rearrange the topics as they see fit. The book has been written so that once the reader has mastered Chapters 1-6, the remaining material has relatively few dependencies. Clearly, external sorting depends on understanding internal sorting and disk files. Section 6.2 on the UNION/FIND algorithm is used in Kruskal's Minimum-Cost Spanning Tree algorithm. Section 9.2 on self-organizing lists mentions the buffer replacement schemes covered in Section 8.3. Chapter 14 draws on examples from throughout the book. Section 17.2 relies on knowledge of graphs. Otherwise, most topics depend only on material presented earlier within the same chapter.

Most chapters end with a section entitled "Further Reading." These sections are not comprehensive lists of references on the topics presented. Rather, I include books and articles that, in my opinion, may prove exceptionally informative or entertaining to the reader. In some cases I include references to works that should become familiar to any well-rounded computer scientist.

Use of C++: The programming examples are written in C++, but I do not wish to discourage those unfamiliar with C++ from reading this book. I have attempted to make the examples as clear as possible while maintaining the advantages of C++. C++ is used here strictly as a tool to illustrate data structures concepts. In particular, I make use of C++'s support for hiding implementation details, including features such as classes, private class members, constructors, and destructors. These features of the language support the crucial concept of separating logical design, as embodied in the abstract data type, from physical implementation as embodied in the data structure.

To keep the presentation as clear as possible, some important features of C++ are avoided here. I deliberately minimize use of certain features commonly used by experienced C++ programmers such as class hierarchy, inheritance, and virtual functions. Operator and function overloading is used sparingly. C-like initialization syntax is preferred to some of the alternatives offered by C++.

While the C++ features mentioned above have valid design rationale in real programs, they tend to obscure rather than enlighten the principles espoused in this book. For example, inheritance is an important tool that helps programmers avoid duplication, and thus minimize bugs. From a pedagogical standpoint, however, inheritance often makes code examples harder to understand since it tends to spread the description for one logical unit among several classes. Thus, my class definitions only use inheritance where inheritance is explicitly relevant to the point illustrated (e.g., Section 5.3.1). This does not mean that a programmer should do likewise. Avoiding code duplication and minimizing errors are important goals. Treat the programming examples as illustrations of data structure principles, but do not copy them directly into your own programs.

One painful decision I had to make was whether to use templates in the code examples. In the first edition of this book, the decision was to leave templates out as it was felt that their syntax obscures the meaning of the code for those not familiar with C++. In the years following, the use of C++ in computer science curricula has greatly expanded. I now assume that readers of the text will be familiar with template syntax. Thus, templates are now used extensively in the code examples.

My implementations are meant to provide concrete illustrations of data structure principles, as an aid to the textual exposition. Code examples should not be read or used in isolation from the associated text because the bulk of each example's documentation is contained in the text, not the code. The code complements the text, not the other way around. They are not meant to be a series of commercial-quality class implementations. If you are looking for a complete implementation of a standard data structure for use in your own code, you would do well to do an Internet search.

For instance, the code examples provide less parameter checking than is sound programming practice, since including such checking would obscure rather than illuminate the text. Some parameter checking and testing for other constraints (e.g., whether a value is being removed from an empty container) is included in the form of a call to `Assert`. The inputs to `Assert` are a Boolean expression and a character string. If this expression evaluates to `false`, then a message is printed and the program terminates immediately. Terminating a program when a function receives a bad parameter is generally considered undesirable in real programs, but is quite adequate for understanding how a data structure is meant to operate. In real programming applications, C++'s exception handling features should be used to deal with input data errors. However, assertions provide a simpler mechanism for indi-

cating required conditions in a way that is both adequate for clarifying how a data structure is meant to operate, and is easily modified into true exception handling. See the Appendix for the implementation of **Assert**.

I make a distinction in the text between "C++ implementations" and "pseudocode." Code labeled as a C++ implementation has actually been compiled and tested on one or more C++ compilers. Pseudocode examples often conform closely to C++ syntax, but typically contain one or more lines of higher-level description. Pseudocode is used where I perceived a greater pedagogical advantage to a simpler, but less precise, description.

Exercises and Projects: Proper implementation and analysis of data structures cannot be learned simply by reading a book. You must practice by implementing real programs, constantly comparing different techniques to see what really works best in a given situation.

One of the most important aspects of a course in data structures is that it is where students really learn to program using pointers and dynamic memory allocation, by implementing data structures such as linked lists and trees. It is often where students truly learn recursion. In our curriculum, this is the first course where students do significant design, because it often requires real data structures to motivate significant design exercises. Finally, the fundamental differences between memory-based and disk-based data access cannot be appreciated without practical programming experience. For all of these reasons, a data structures course cannot succeed without a significant programming component. In our department, the data structures course is one of the most difficult programming course in the curriculum.

Students should also work problems to develop their analytical abilities. I provide over 450 exercises and suggestions for programming projects. I urge readers to take advantage of them.

Contacting the Author and Supplementary Materials: A book such as this is sure to contain errors and have room for improvement. I welcome bug reports and constructive criticism. I can be reached by electronic mail via the Internet at **shaffer@vt.edu**. Alternatively, comments can be mailed to

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The electronic posting of this book, along with a set of lecture notes for use in class can be obtained at①

http://www.cs.vt.edu/~shaffer/book.html.

① 本书已根据作者于2012年11月19日更新的勘误表进行了更正。——编者注

The code examples used in the book are available at the same site. Online Web pages for Virginia Tech's sophomore-level data structures class can be found at

http://courses.cs.vt.edu/~cs3114.

This book was typeset by the author using LaTeX. The bibliography was prepared using BibTeX. The index was prepared using **makeindex**. The figures were mostly drawn with **Xfig**. Figures 3.1 and 9.10 were partially created using Mathematica.

Acknowledgments: It takes a lot of help from a lot of people to make a book. I wish to acknowledge a few of those who helped to make this book possible. I apologize for the inevitable omissions.

Virginia Tech helped make this whole thing possible through sabbatical research leave during Fall 1994, enabling me to get the project off the ground. My department heads during the time I have written the various editions of this book, Dennis Kafura and Jack Carroll, provided unwavering moral support for this project. Mike Keenan, Lenny Heath, and Jeff Shaffer provided valuable input on early versions of the chapters. I also wish to thank Lenny Heath for many years of stimulating discussions about algorithms and analysis (and how to teach both to students). Steve Edwards deserves special thanks for spending so much time helping me on various redesigns of the C++ and Java code versions for the second and third editions, and many hours of discussion on the principles of program design. Thanks to Layne Watson for his help with Mathematica, and to Bo Begole, Philip Isenhour, Jeff Nielsen, and Craig Struble for much technical assistance. Thanks to Bill McQuain, Mark Abrams and Dennis Kafura for answering lots of silly questions about C++ and Java.

I am truly indebted to the many reviewers of the various editions of this manuscript. For the first edition these reviewers included J. David Bezek (University of Evansville), Douglas Campbell (Brigham Young University), Karen Davis (University of Cincinnati), Vijay Kumar Garg (University of Texas – Austin), Jim Miller (University of Kansas), Bruce Maxim (University of Michigan – Dearborn), Jeff Parker (Agile Networks/Harvard), Dana Richards (George Mason University), Jack Tan (University of Houston), and Lixin Tao (Concordia University). Without their help, this book would contain many more technical errors and many fewer insights.

For the second edition, I wish to thank these reviewers: Gurdip Singh (Kansas State University), Peter Allen (Columbia University), Robin Hill (University of Wyoming), Norman Jacobson (University of California – Irvine), Ben Keller (Eastern Michigan University), and Ken Bosworth (Idaho State University). In addition, I wish to thank Neil Stewart and Frank J. Thesen for their comments and ideas for improvement.

Third edition reviewers included Randall Lechlitner (University of Houstin, Clear Lake) and Brian C. Hipp (York Technical College). I thank them for their comments.

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I am thankful to Shelley Kronzek at Dover publications for her faith in taking on the print publication of this third edition. Much expanded, with both Java and C++ versions, and many inconsistencies corrected, I am confident that this is the best edition yet. But none of us really knows whether students will prefer a free online textbook or a low-cost, printed bound version. In the end, we believe that the two formats will be mutually supporting by offering more choices. Production editor James Miller and design manager Marie Zaczkiewicz have worked hard to ensure that the production is of the highest quality.

I wish to express my appreciation to Hanan Samet for teaching me about data structures. I learned much of the philosophy presented here from him as well, though he is not responsible for any problems with the result. Thanks to my wife Terry, for her love and support, and to my daughters Irena and Kate for pleasant diversions from working too hard. Finally, and most importantly, to all of the data structures students over the years who have taught me what is important and what should be skipped in a data structures course, and the many new insights they have provided. This book is dedicated to them.

Cliff Shaffer
Blacksburg, Virginia

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