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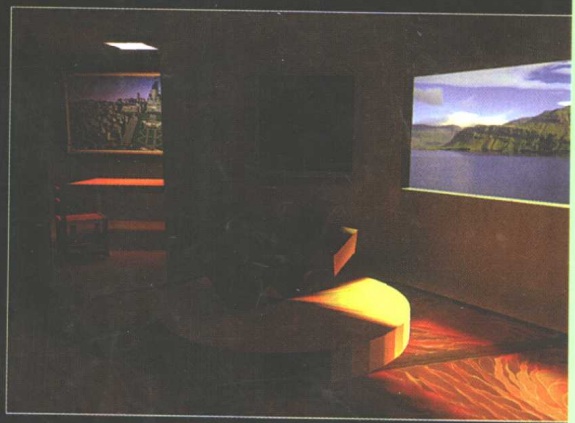
计算机图形学的算法基础

（英文版 · 第2版）

David F. Rogers



Procedural Elements *for* Computer Graphics

SECOND EDITION

（美）David F. Rogers 著

机械工业出版社
China Machine Press

McGraw Hill Education

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出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，计算机学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅擘划了研究的范畴，还揭橥了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的计算机产业发展迅猛，对专业人才的需求日益迫切。这对计算机教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短、从业人员较少的现状下，美国等发达国家在其计算机科学发展的几十年间积淀的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀计算机教材将对我国计算机教育事业的发展起积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章图文信息有限公司较早意识到“出版要为教育服务”。自1998年始，华章公司就将工作重点放在了遴选、移译国外优秀教材上。经过几年的不懈努力，我们与Prentice Hall，Addison-Wesley，McGraw-Hill，Morgan Kaufmann等世界著名出版公司建立了良好的合作关系，从它们现有的数百种教材中甄选出Tanenbaum，Stroustrup，Kernighan，Jim Gray等大师名家的一批经典作品，以“计算机科学丛书”为总称出版，供读者学习、研究及庋藏。大理石纹理的封面，也正体现了这套丛书的品位和格调。

“计算机科学丛书”的出版工作得到了国内外学者的鼎力襄助，国内的专家不仅提供了中肯的选题指导，还不辞劳苦地担任了翻译和审校的工作；而原书的作者也相当关注其作品在中国的传播，有的还专诚为其书的中译本作序。迄今，“计算机科学丛书”已经出版了近百个品种，这些书籍在读者中树立了良好的口碑，并被许多高校采用为正式教材和参考书籍，为进一步推广与发展打下了坚实的基础。

随着学科建设的初步完善和教材改革的逐渐深化，教育界对国外计算机教材的需求和应用都步入一个新的阶段。为此，华章公司将加大引进教材的力度，在“华章教育”的总规划之下出版三个系列的计算机教材：针对本科生的核心课程，剔抉外版菁华而成“国外经典教材”系列；对影印版的教材，则单独开辟出“经典原版书库”；定位在高级教程和专业参考的“计算机科学丛书”还将保持原来的风格，继续出版新的品种。为了保证这三套丛书的权威性，同时也为了更好地为学校和老师们服务，华章公司聘请了中国科学院、北京大学、清华大学、国防科技大学、复旦大学、上海交通大学、南京大学、浙江大学、中国科技大学、哈尔滨工业大学、西安交通大学、中国人民大学、北京航空航天大学、北京邮电大学、中山大学、解放军理工大学、郑州大学、湖北工学院、中国国家信息安全测评认证中心等国内重点大学和科研机构在计算机的各个领域的著名学者组成“专家指导委员会”，为我们提供选题意见和出版监督。

“经典原版书库”是响应教育部提出的使用原版国外教材的号召，为国内高校的计算机教学度身订造的。在广泛地征求并听取丛书的“专家指导委员会”的意见后，我们最终选定了这30多种篇幅内容适度、讲解鞭辟入里的教材，其中的大部分已经被M.I.T.、Stanford、U.C. Berkley、C.M.U.等世界名牌大学采用。丛书不仅涵盖了程序设计、数据结构、操作系统、计算机体系结构、数据库、编译原理、软件工程、图形学、通信与网络、离散数学等国内大学计算机专业普遍开设的核心课程，而且各具特色——有的出自语言设计者之手、有的历三十年而不衰、有的已被全世界的几百所高校采用。在这些圆熟通博的名师大作的指引之下，读者必将在计算机科学的宫殿中由登堂而入室。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证，但我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。教材的出版只是我们的后续服务的起点。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方法如下：

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PREFACE

In the preface to the first edition I wrote "Computer graphics is now a mature discipline." Little did I or anyone else anticipate the developments of the last dozen years. Then, ray tracing was an active research topic — now there are freely available programs for personal computers; radiosity was just on the horizon — today commercially rendering systems commonly use this technique; texture was a software application — today hardware texture acceleration is common place; color image quantization algorithms were certainly available in the computer graphics community, but today downloading an image from the World Wide Web depends on color image quantization. The list goes on. Computer graphics is thoroughly integrated into our daily lives, across fields as diverse as advertising, entertainment, medicine, education, science, engineering, navigation, etc. In fact, most computer programs, including the most popular operating systems, have a graphical user interface.

The present volume represents a major rewrite of the first edition. As a result, it is nearly twice the size of the original volume. Major new additions include a discussion of graphical user interfaces, an expanded discussion of line, circle and ellipse drawing and image compression algorithms. New clipping algorithms for lines and polygons are presented. In particular, the Liang–Barsky and Nicholl–Lee–Nicholl clipping algorithms are now discussed along with the classical Cohen–Sutherland, midpoint, Cyrus–Beck and Sutherland–Hodgman clipping algorithms.

The chapter on visible surface algorithms now includes sections on the Appel, haloed line and A-buffer algorithms, along with discussions of the binary space partitioning (BSP), octree and marching cubes algorithms. The discussion of the visible surface ray tracing algorithm is considerably expanded.

The rendering chapter is significantly enhanced. It now includes expanded discussions of physically based illumination models, transparency, shadows and textures. More recent advances in ray tracing, for example, cone, beam, pencil and stochastic ray tracing, are included along with a detailed discussion of the fundamentals of radiosity. The section on color is expanded to include uniform color spaces and a more detailed discussion of gamma correction. Sections on color image quantization and color reproduction for print media are included.

The book is suitable for use by professional programmers, engineers and scientists. A course in computer graphics at either the senior undergraduate or first year graduate level that emphasizes rendering techniques will benefit from the book. Combining it with its companion volume, *Mathematical Elements for Computer Graphics*, allows increasing the scope of the course to include manipulative transformations and curves and surfaces. The book retains the detailed worked examples from the first edition as well as presenting new ones — a total of 90 worked examples. An adequate background is provided by college level mathematics and knowledge of a higher-level programming language.

No computer graphics book is complete without algorithms. There are three types of algorithms presented in the book. The first is a narrative description often presented in list form; the second is a detailed procedural description of the algorithm, while the third is a more formal presentation using pseudocode. Although many books now present algorithms in C, I resisted this temptation. I believe that actually implementing an algorithm yields better understanding and appreciation of the nuances of the algorithm which no book can cover. Furthermore, as the algorithm is implemented additional efficiencies specific to the implementation language frequently suggest themselves. For those algorithms presented in pseudocode, the actual implementation is relatively straightforward.

No book is ever written without the assistance of many individuals. Thanks are expressed to my colleagues who read various parts of the manuscript. John Dill and his students read all of Chapter 3 on clipping and made many valuable comments. Paul Heckbert read both the sections on color image quantization and textures. Both sections are much the better for his comments. Maureen Stone lent her expertise on color reproduction. Eric Haines commented extensively on the ray tracing sections. I particularly enjoyed the ensuing discussions. John Wallace read the section on radiosity and set me straight on one or two key points. However, any errors are mine alone.

Special thanks are due my colleagues François Sillion and Peter Kipfer at the iMAGIS project in Grenoble, France, who created the cover image to an impossibly short deadline using hierarchical radiosity software developed under the direction of François Sillion and George Drettakis. You enthusiastically made all the changes that I requested! It was great working with you.

My editor of more than two and a half decades, B.J. Clark, has now left for other pastures. Without his initial faith in a young academic who wanted to do a book on computer graphics, and his gentle encouragement over the years, none of this would have happened. Thanks are due Fred Eckardt and his crew at Fine Line Illustrations for their efforts in creating the line art. They even trusted me with the original files. The production crew at McGraw-Hill — Kari Geltemeyer, Laurie Entringer and Heather Burbridge — did an outstanding job.

Last, but certainly not least, a very special thanks is due my wife Nancy for not only her long term patience with my need to write, but especially for the outstanding job of copy editing, proof reading and typesetting. I think you now qualify as a TEXpert.

David F. Rogers

PREFACE TO THE FIRST EDITION

Computer graphics is now a mature discipline. Both hardware and software are available that facilitate the production of graphical images as diverse as line drawings and realistic renderings of natural objects. A decade ago the hardware and software to generate these graphical images cost hundreds of thousands of dollars. Today, excellent facilities are available for expenditures in the tens of thousands of dollars and lower performance, but in many cases adequate facilities are available for tens of hundreds of dollars. The use of computer graphics to enhance information transfer and understanding is endemic in almost all scientific and engineering disciplines. Today, no scientist or engineer should be without a basic understanding of the underlying principles of computer graphics. Computer graphics is also making deep inroads into the business, medical, advertising, and entertainment industries. The presence in the boardroom of presentation slides prepared using computer graphics facilities as well as more commonplace business applications is considered the norm. Three-dimensional reconstructions using data obtained from CAT scans is becoming commonplace in medical applications. Television as well as other advertising media are now making frequent use of computer graphics and computer animation. The entertainment industry has embraced computer graphics with applications as diverse as video games and full-length feature films. Even art is not immune, as evidenced by some of the photos included in this book.

It is almost a decade now since the appearance of the companion volume to this book, *Mathematical Elements for Computer Graphics*. During that time significant strides in raster scan graphics have been made. The present volume concentrates on these aspects of computer graphics. The book starts with an introduction to computer graphics hardware with an emphasis on the conceptual understanding of cathode ray tube displays and of interactive devices. The following chapters look at raster scan graphics including line and circle drawing, polygon filling, and antialiasing algorithms; two- and three-dimensional clipping including clipping to arbitrary convex volumes; hidden-line and hidden-surface

algorithms including ray tracing; and finally, rendering, the *art* of making realistic pictures, including local and global illumination models, texture, shadows, transparency, and color effects. The book continues the presentation technique of its predecessor. Each thorough topic discussion is followed by presentation of a detailed algorithm or a worked example, and where appropriate both.

The material in the book can be used in its entirety for a semester-long first formal course in computer graphics at either the senior undergraduate or graduate level with an emphasis on raster scan graphics. If a first course in computer graphics based on the material in the companion volume *Mathematical Elements for Computer Graphics* is presented, then the material in this book is ideal for a second course. This is the way it is used by the author. If broader material coverage in a single-semester course is desired, then the two volumes can be used together. Suggested topic coverage is: Chapter 1 of both volumes, followed by Chapters 2 and 3 with selected topics from Chapter 4 of *Mathematical Elements for Computer Graphics*, then selected topics from Chapter 2 (e.g., 2-1 to 2-5, 2-7, 2-15 to 2-19, 2-22, 2-23, 2-28), Chapter 3 (e.g., 3-1, 3-2, 3-4 to 3-6, 3-9, 3-11, 3-15, 3-16), Chapter 4 (e.g., 4-1, part of 4-2 for backplane culling, 4-3, 4-4, 4-7, 4-9, 4-11, 4-13), and Chapter 5 (e.g., 5-1 to 5-3, 5-5, 5-6, 5-14) of the present volume. The book is also designed to be useful to professional programmers, engineers, and scientists. Further, the detailed algorithms and worked examples make it particularly suitable for self-study at any level. Sufficient background is provided by college level mathematics and a knowledge of a higher-level programming language. Some knowledge of data structures is useful but not necessary.

There are two types of algorithms presented in the book. The first is a detailed procedural description of the algorithm, presented in narrative style. The second is more formal and uses an algorithmic 'language' for presentation. Because of the wide appeal of computer graphics, the choice of an algorithmic presentation language was especially difficult. A number of colleagues were questioned as to their preference. No consensus developed. Computer science faculty generally preferred PASCAL but with a strong sprinkling of C. Industrial colleagues generally preferred FORTRAN for compatibility with existing software. The author personally prefers BASIC because of its ease of use. Consequently, detailed algorithms are presented in pseudocode. The pseudocode used is based on extensive experience teaching computer graphics to classes that do not enjoy knowledge of a common programming language. The pseudocode is easily converted to any of the common computer languages. An appendix discusses the pseudocode used. The pseudocode algorithms presented in the book have all been either directly implemented from the pseudocode or the pseudocode has been derived from an operating program in one or more of the common programming languages. Implementations range from BASIC on an Apple IIe to PL1 on an IBM 4300 with a number of variations in between. A suit of demonstration programs in available from the author.

A word about the production of the book may be of interest. The book was computer typeset using the TEX typesetting system at TYX Corporation

of Reston, Virginia. The manuscript was coded directly from handwritten copy. Galleys and two sets of page proofs were produced on a laser printer for editing and page makeup. Final reproduction copy ready for art insertion was produced on a phototypesetter. The patience and assistance of Jim Gauthier and Mark Hoffman at TYX while the limits of the system were explored and solutions to all the myriad small problems found is gratefully acknowledged. The outstanding job done by Louise Bohrer and Beth Lessels in coding the handwritten manuscript is gratefully acknowledged. The usually fine McGraw-Hill copyediting was supervised by David Damstra and Sylvia Warren.

No book is ever written without the assistance of many individuals. The book is based on material prepared for use in a graduate level course given at the Johns Hopkins University Applied Physics Laboratory Center beginning in 1978. Thanks are due the many students in this and other courses from whom I have learned so much. Thanks are due Turner Whitted who read the original outline and made valuable suggestions. Thanks are expressed to my colleagues Pete Atherton, Brian Barsky, Ed Catmull, Rob Cook, John Dill, Steve Hansen, Bob Lewand, Gary Meyer, Alvy Ray Smith, Dave Warn, and Kevin Weiler, all of whom read one or more chapters or sections, usually in handwritten manuscript form, red pencil in hand. Their many suggestions and comments served to make this a better book. Thanks are extended to my colleagues Linda Rybak and Linda Adlum who read the entire manuscript and checked the examples. Thanks are due three of my students: Bill Meier who implemented the Roberts algorithm, Gary Boughan who originally suggested the test for convexity discussed in Sec. 3-7, and Norman Schmidt who originally suggested the polygon splitting technique discussed in Sec. 3-8. Thanks are due Mark Meyerson who implemented the splitting algorithms and assured that the technique was mathematically well founded. The work of Lee Billow and John Metcalf who prepared all the line drawings is especially appreciated.

Special thanks are due Steve Satterfield who read and commented on all 800 handwritten manuscript pages. Need more be said!

Special thanks are also due my eldest son Stephen who implemented all of the hidden surface algorithms in Chapter 4 as well as a number of other algorithms throughout the book. Our many vigorous discussions served to clarify a number of key points.

Finally, a very special note of appreciation is extended to my wife Nancy and to my other two children, Karen and Ransom, who watched their husband and father disappear into his office almost every weeknight and every weekend for a year and a half with never a protest. That is support! Thanks.

David F. Rogers

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