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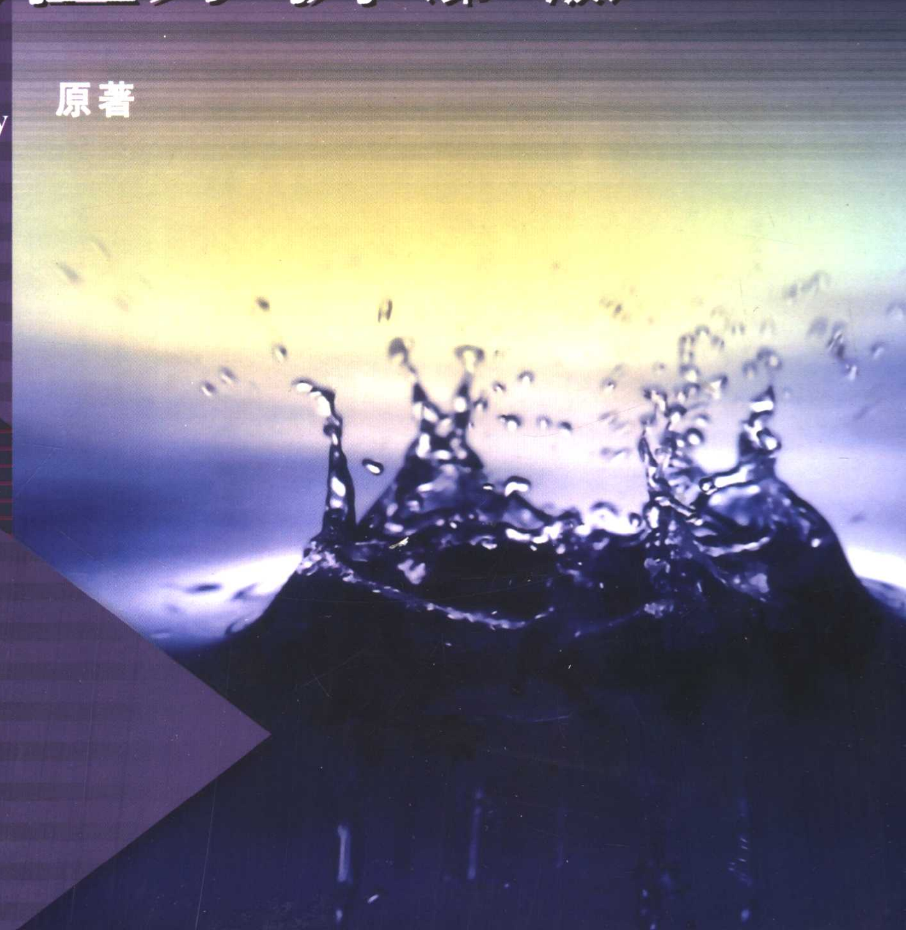
Applied Numerical Analysis

(Seventh Edition)

应用数值分析（第7版）

□ Curtis F. Gerald
□ Patrick O. Wheatley
原著
□ 白峰杉 改编



高等教育出版社
Higher Education Press

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图字：01-2005-5788号

图书在版编目(CIP)数据

应用数值分析：第7版／(美)杰拉尔德(Gerald, C.F.), (美)惠特利(Wheatley, P.O.)著. 白峰杉改编.—北京：高等教育出版社，2006.1(世界优秀教材中国版理科类系列教材) 书名原文：Applied Numerical Analysis, Seventh Edition

ISBN 7-04-016730-1

Ⅰ.应… Ⅱ.①杰…②惠…③白… Ⅲ.数值计算-高等学校-教材 Ⅳ.O241

中国版本图书馆CIP数据核字(2005)第144579号

出版发行	高等教育出版社	购书热线	010-58581118
社　　址	北京市西城区德外大街4号	免费咨询	800-810-0598
邮政编码	100011	网　　址	http://www.hep.edu.cn http://www.hep.com.cn
总　　机	010-58581000	网上订购	http://www.landraco.com http://www.landraco.com.cn
经　　销	蓝色畅想图书发行有限公司	畅想教育	http://www.widedu.com
印　　刷	北京未来科学技术研究所有限责任公司印刷厂		
开　　本	787×1092　1/16	版　　次	2006年1月第1版
印　　张	35	印　　次	2006年1月第1次印刷
字　　数	620 000	定　　价	39.60元

本书如有缺页、倒页、脱页等质量问题，请到所购图书销售部门联系调换。

物料号　16730-00

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高等教育出版社

2005年5月

改编者的话

科学计算作为当今科学研究的三种基本手段之一，是数学将触角伸向其他学科的桥梁，因此它的发展受到广泛关注。有些发达国家甚至将科学计算作为衡量国家综合实力的一个重要方面，大力推动其发展。也正因为如此，“科学计算”（或通常所称的“数值分析”、“计算方法”）成为国内外理工科大学中开设最普遍的数学课程之一，其对象主要为研究生或高年级本科生。

国内外现有的“数值分析”教材有很多，笔者认为这本《Applied Numerical Analysis》很有特色，也是多年积累而成的优秀之作。该书经过多年的反复锤炼，体系科学严谨，内容选材精良。但缺点是书的篇幅过大，使用上不方便。笔者根据国内教学的需要和“科学计算”学科的发展，本着如下原则进行了改编。

（1）删去了原书的最后一章“有限元方法”。因为国内学校开设的“数值分析”或“计算方法”课程，通常课内为50~70学时（甚至更少），所以很难涉及这部分内容。同时删去这部分，完全不影响原书的理论体系和完整性。

（2）删去了原书的第4章“函数逼近”，原内容包括Chebyshev多项式、有理函数逼近和Fourier级数（其中Fourier级数的部分内容被整合到现在的4.4节中）。这主要还是出于学时限制的考虑。

（3）计算机的发展，特别是数学软件的成熟和普及使用，使得“科学计算”有了更高的平台。因此算法的描述在20年前的“数值分析”教材中是重要的，而今天无疑应当淡化。改编中较大幅度地删节了算法描述部分。

（4）“数值分析”教材的核心是基本概念和算法思想的理解，软件使用的细节不宜过多，因此书中Matlab和Maple程序部分改编中也进行了适当简化。

本书结构合理，可读性强，对以科学计算为工具的科技人员有参考价值，更可以作为研究生和高年级本科生“数值分析”课程的教材或参考书。

Preface

In this seventh edition, we continue on the path established in previous editions. Quoting from the preface of the sixth edition, we "retain the same features that have made the book popular: ease of reading so that the instructor does not have to 'interpret the book' for the student, many illustrative examples that often solve the same problem with different procedures to clarify the comparison of methods, many exercises from which the instructor may choose appropriately for the class, more challenging problems and projects that show practical applications of the material."

We have made substantial improvements on the previous edition. These include:

Theoretical matters that previously were in a separate section near the end of each chapter have been merged with the description of the procedures.

Example computer programs that admittedly were not of professional quality have been deleted, with the idea that this is not normally a programming course anyway. Easy-to-read algorithms have been retained so that students can write programs if they desire.

There is greater emphasis on computer algebra systems; MATLAB is the predominant system, but this is compared with Maple and *Mathematica*. The use of spreadsheets to solve problems is covered as well.

A new chapter on optimization (Chapter 6) has been added that includes multivariable cases as well as single-variable situations. Linear programming has been included, of course, but the treatment is intended to provide a real understanding of the simplex method rather than to merely give a recipe for solving the problem.

Nonlinear programming is treated to contrast this with the simpler linear case.

Boundary value problems for ordinary differential equations have been separated from those for partial differential equations and are included in the chapter on ordinary differential equations. Partial differential equations that satisfy boundary conditions (elliptic equations) are combined with the other types of partial differential equations in a single chapter.

Many exercises have been modified or rewritten to provide an even greater variety. New exercises and projects have been added and some of these are more challenging than in the previous edition.

As in previous editions, this book is unique in its inclusion of a thorough survey of numerical methods for solving partial differential equations and an introduction to the finite element method.

Many suggestions from reviewers have allowed us to clarify and extend the treatment of several topics and we have made editorial changes to make the book easier to read and understand.

We again quote from the preface to the sixth edition:

> *Applied Numerical Analysis* is written as a text for sophomores and juniors in engineering, science, mathematics, and computer science. It should be a valuable source book for practicing engineers. Because of its coverage of many numerical methods, the text can serve as a valuable reference.
>
> Although we assume that the student has a good knowledge of calculus, appropriate topics are reviewed in the context of their use. An appendix gives a summary of the most important items that are needed to develop and analyze numerical procedures. We purposely keep the mathematical notation simple for clarity. Furthermore, the answers to exercises marked with a ▶ are found in the back of the text.

Acknowledgements

Many instructors have given valuable suggestions and constructive criticism. We mention those whose thorough reviews have helped make this edition better:

Todd Arbogast, *University of Texas at Austin*
Neil Berger, *University of Illinois at Chicago*
Barbara Bertram, *Michigan Technological Sciences*
Herman Gollwitzer, *Drexel University*

Chenyi Hu, *University of Houston-Downtown*

Tim Sauer, *George Mason University*

Daoqi Yang, *Wayne State University*

Kathie Yerion, *Gonzaga University*

We also want to express our thanks to those at Addison-Wesley who have worked extensively with us to ensure the publication of another quality edition: Greg Tobin, Bill Hoffman, RoseAnne Johnson, Cindy Cody, Pam Laskey, Heather Peck, and Barbara Atkinson.

Contents

目　　录

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Preliminaries

This book teaches how a computer can be used to solve problems that may not be solvable by the techniques that are taught in most calculus and linear algebra courses. It also shows how those problems that you may have solved before can be solved in a different way. Our emphasis is on problems that exist in the real world, although these examples will be simplified. Many of these simplified examples can be solved analytically, which allows a comparison with the computer-derived solution.

Modern mathematics began when Isaac Newton found mathematical models that matched the empirical laws that Johannes Kepler had reached after about 20 years of observation of the planets. Today, most of applied mathematics is a repetition of what Newton did: to develop mathematical relationships that can be used to simulate some real-world situation and to predict its response to different external factors.

The beauty of mathematics is that it builds on simple cases to arrive at more complex and useful ones. This is true for this book — we start with mathematical applications that are easily understood but that become the basis for other, more important applications of numerical analysis.

Contents of This Chapter

We begin each chapter of this book with a list of the topics that are discussed in that chapter.

0.1 Analysis Versus Numerical Analysis

The word *analysis* in mathematics usually means to solve a problem through equations. Of course, the equations must then be reduced to an answer through the procedures of algebra, calculus, differential equations, partial differential equations, or the like. Numerical analysis is similar in that problems are solved, but now the only procedures that are used are arithmetic: add, subtract, multiply, divide, and compare. Since these operations are exactly those that computers can do, numerical analysis and computers are intimately related.

An analytical answer is not always meaningful by itself. Consider this simple cubic equation:

$$x^3 - x^2 - 3x + 3 = 0.$$

It is not hard to find the factors that show that one of the roots is $\sqrt{3}$. That is fine, unless you want to cut a board to that length. But rulers are not graduated in square-root values. So what can you do? Maybe you have a calculator that lets you find the value, or you might use logarithms, or look it up in a table. Numerical analysis has a rich store of methods to find the answer by purely arithmetical operations.

Here's a challenge. You are on a desert island with nothing to work with but a sharp stick that you can use to draw in the sand. You've forgotten everything about mathematics except the four arithmetic operations and you can also compare values (much like a computer). For some reason, maybe because you have nothing more interesting to do, you want to get a good value for the cube root of 2. How would you go about this? One way would be trial and error: You try a set of values to see which one gives a result of 2 when it is multiplied three times, something like this:

$1.2^3 = 1.728$	too small
$1.4^3 = 2.744$	too large
$1.25^3 = 1.9531$	pretty close
$1.26^3 = 2.0004$	really close!

This could go on for some time, but you begin to see that you could interpolate between the last two trials and get an even better answer.

Now you say to yourself, "How good an answer do I really need? Maybe 1.26 is as close as I need. After all, when multiplied, 1.26^3 gives a result that differs from 2.0000 by a very small number, 0.0004."

In this book, we will describe methods that can solve this little problem efficiently and also methods for much more difficult ones. For example, this integral, which gives the length of one arch of the curve $y = \sin(x)$, has no closed form solution:

$$\int_0^\pi \sqrt{1+\cos^2(x)}dx.$$

Numerical analysis can compute the length of this curve by standardized methods that apply to essentially any integrand; there is never a need to make a special substitution or to do integration by parts. Further, the only mathematical operations required are addition, subtraction, multiplication, and division, plus doing comparisons.

Another difference between a numerical result and the analytical answer is that the former is always an approximation. Analytical methods usually give the result in terms of mathematical functions that can be evaluated for a specific instance. This also has the advantage that the behavior and properties of the function are often apparent; this is not the case for a numerical answer. However, numerical results can be plotted to show some of the behavior of the solution.

While the numerical result is an approximation, this can usually be as accurate as needed. The necessary accuracy is, of course, determined by the application. The $\sqrt[3]{2}$ example suggests that the accuracy desired depends totally on the context of the problem. (There are limitations to the achievable level of accuracy, because of the way that computers do arithmetic; we will explain these limitations later.) To achieve high accuracy, very many separate operations must be carried out, but computers do them so rapidly without ever making mistakes that this is no significant problem. Actually, evaluating an analytical result to get the numerical answer for a specific application is subject to the same errors.

The analysis of computer errors and the other sources of error in numerical methods is a critically important part of the study of numerical analysis. This subject will occur often throughout this book.

Here are those operations that numerical analysis can do and that are covered in this book:

- Find where $f(x) = 0$ for a nonlinear equation or system of equations.
- Solve systems of linear equations, even large systems.