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理科类系列教材

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Introductory LINEAR ALGEBRA

An Applied First Course 8/E

线性代数及其应用

（第8版）

□ Bernard Kolman
□ David R.Hill
原著
□ 王殿军 改编

高等教育出版社
Higher Education Press

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郑 重 声 明

LIST OF BASIC COMPUTATIONAL PROCEDURES

- ☐ Gauss–Jordan reduction procedure
- ☐ Gaussian elimination procedure
- ☐ Procedure for computing the inverse of a matrix
- ☐ Procedure for obtaining the LU-factorization of a matrix
- ☐ Procedure for determining a clique in a digraph
- ☐ Procedure for determining if a digraph is strongly connected
- ☐ First procedure for computing the steady-state vector of a regular transition matrix
- ☐ Second procedure for computing the steady-state vector of a regular transition matrix
- ☐ Cramer's rule
- ☐ Procedure for computing the standard matrix of a linear transformation $L\colon R^n \to R^m$
- ☐ Procedure to check if given vectors span a vector space
- ☐ Procedure to determine if given vectors are linearly dependent or linearly independent
- ☐ Procedure for finding a subset of S that is a basis for span S, where S is a set of nonzero vectors in a vector space
- ☐ Procedure for finding a subset of S that is a basis for span S, where S is a set of nonzero vectors in R^m
- ☐ Procedure for finding a basis for the solution space of a homogeneous system
- ☐ Procedure for finding a basis for span S, where S is a subset of R^n

- ☐ Procedure for computing the rank of a matrix
- ☐ Procedure for computing the transition matrix from one basis to another basis
- ☐ Gram–Schmidt process
- ☐ Procedure for finding the QR-factorization of an $m \times n$ matrix
- ☐ Procedure for computing the least squares solution to $A\mathbf{x} = \mathbf{b}$
- ☐ Procedure for computing the least squares line for n given data points
- ☐ Procedure for computing the least squares polynomial for n given data points
- ☐ Procedure to check if a received word $\mathbf{x}_t$ is a code word
- ☐ Procedure for generating a Hamming (check) matrix
- ☐ Procedure for diagonalizing a matrix
- ☐ Procedure for diagonalizing a symmetric matrix by an orthogonal matrix
- ☐ Procedure for obtaining the general solution to $\mathbf{x}' = A\mathbf{x}$, where A is diagonalizable
- ☐ Procedure for identifying a nondegenerate conic section whose graph is not in standard form
- ☐ Procedure for computing the matrix of a linear transformation $L\colon R^n \to R^m$
- ☐ Random iteration approach
- ☐ Procedure for solving a linear programming problem geometrically
- ☐ The simplex method

出版者的话

为适应当前我国高校各类创新人才培养的需要，大力推进教育部倡导的双语教学，配合教育部实施的"高等学校教学质量与教学改革工程"和"精品课程"建设的需要，我社开始有计划、大规模地开展了海外优秀理科系列教材的影印及改编工作。海外优秀教材在立体化配套、多种教学资源的整合以及为课程提供整体教学解决方案等方面对我们有不少可资借鉴之处。但一个不容忽视的问题是，外版教材与我国现行的教学内容、教学体系、教学模式和习惯等存在着巨大的差异。譬如，重点课程的原版教材通常很厚，内容很多，容量是国内自编教材的好几倍，国外的情况是，老师未必会都讲，剩下大量的内容留给学生自学；而国内的情况则不尽相同。受国内教学学时所限，完全照搬是不合时宜的。教材的国际化必须与本民族的文化教育传统相融合，在原有的基础上吸收国外优秀教材的长处，这使得我们需要对外文原版教材进行适当的改编。改编不是简单地使内容增删，而是结合国内教学特点，引进国外先进的教学思想，在教学内容和方式上更中国化，使之更符合国内的课程设置及教学环境。

在引进改编海外优秀教材的过程中，我们坚持了两条原则：1. 精选版本，打造精品系列；2. 慎选改编者，保证品质。

首先，我们和 Pearson Education, John Wiley & Sons, McGraw-Hill 以及 Thomson Learning 等国外出版公司进行了广泛接触，经推荐并在国内专家的协助下，提交引进版权总数达 200 余种，学科专业领域涉及数学、物理、化学化工、地理、环境等。收到样书后，我们聘请了国内高校一线教师、专家学者参与这些原版教材的评介工作，从中遴选出了一批优秀教材进行改编，并组织出版。这批教材普遍具有以下特点：(1) 基本上是近几年出版的，在国际上被广泛使用，在同类教材中具有相当的权威性；(2) 高版次，历经多年教学实践检验，内容翔实准确，反映时代要求；(3) 各种教学资源配套整齐，为师生提供了极大的便利；(4) 插图精美、丰富，图文并茂，与正文相辅相成；(5) 语言简练、流畅，可读性强，比较适合非英语国家的学生阅读。

其次，慎选改编者。原版教材确定后，随之碰到的问题是寻找合适的

改编者。要改编一本教材，必须要从头到尾吃透它，有这样的精力自编一本教材都绰绰有余了。我们与国内众多高等院校的众多专家学者进行了广泛的接触和细致的协商，几经酝酿，最终确定下来改编者。大多数改编者都是有国外留学背景的中青年学者，他们既有相当高的学术水平，又热爱教学，活跃在教学第一线。他们能够承担此任，不单是因为他们了解引进版教材的知识结构、表达方式和写作方法，更重要的是他们有精力、有热情，愿意付出，有的甚至付出了比写一本新教材更多的劳动。我们向他们表示最真诚的谢意。

在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作，这套引进改编的教材体现了一定的权威性、系统性、先进性和经济性等特点。

这套教材出版后，我们将结合各高校的双语教学计划，开展大规模的宣传、培训工作，及时地将本套丛书推荐给高校使用。在使用过程中，我们衷心希望广大高校教师和同学提出宝贵的意见和建议。如有好的教材值得引进，也请与高等教育出版社高等理科分社联系。

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高等教育出版社

2005 年 5 月

**To the memory of Lillie
and to Lisa and Stephen**

B. K.

To Suzanne

D. R. H.

PREFACE

Material Covered

This book presents an introduction to linear algebra and to some of its significant applications. It is designed for a course at the freshman or sophomore level. There is more than enough material for a semester or quarter course. By omitting certain sections, it is possible in a one-semester or quarter course to cover the essentials of linear algebra (including eigenvalues and eigenvectors), to show how the computer is used, and to explore some applications of linear algebra. It is no exaggeration to say that with the many applications of linear algebra in other areas of mathematics, physics, biology, chemistry, engineering, statistics, economics, finance, psychology, and sociology, linear algebra is the undergraduate course that will have the most impact on students' lives. The level and pace of the course can be readily changed by varying the amount of time spent on the theoretical material and on the applications. Calculus is not a prerequisite; examples and exercises using very basic calculus are included and these are labeled "Calculus Required."

The emphasis is on the computational and geometrical aspects of the subject, keeping abstraction to a minimum. Thus we sometimes omit proofs of difficult or less-rewarding theorems while amply illustrating them with examples. The proofs that are included are presented at a level appropriate for the student. We have also devoted our attention to the essential areas of linear algebra; the book does not attempt to cover the subject exhaustively.

What Is New in the Eighth Edition

We have been very pleased by the widespread acceptance of the first seven editions of this book. The reform movement in linear algebra has resulted in a number of techniques for improving the teaching of linear algebra. The **Linear Algebra Curriculum Study Group** and others have made a number of important recommendations for doing this. In preparing the present edition, we have considered these recommendations as well as suggestions from faculty and students. Although many changes have been made in this edition, our objective has remained the same as in the earlier editions:

> **to develop a textbook that will help the instructor to teach and the student to learn the basic ideas of linear algebra and to see some of its applications.**

To achieve this objective, the following features have been developed in this edition:

- New sections have been added as follows:
  - Section 1.5, *Matrix Transformations*, introduces at a very early stage some geometric applications.
  - Section 2.1, *An Introduction to Coding*, along with supporting material on bit matrices throughout the first six chapters, provides an introduction to the basic ideas of coding theory.
- More geometric material has been added.
- New exercises at all levels have been added. Some of these are more open-ended, allowing for exploration and discovery, as well as writing.
- More illustrations have been added.
- MATLAB M-files have been upgraded to more modern versions.
- Key terms have been added at the end of each section, reflecting the increased emphasis in mathematics on communication skills.
- True/false questions now ask the student to justify his or her answer, providing an additional opportunity for exploration and writing.
- Another 25 true/false questions have been added to the cumulative review at the end of the first ten chapters.
- A glossary, new to this edition, has been added.

Exercises

The exercises in this book are grouped into three classes. The first class, *Exercises*, contains routine exercises. The second class, *Theoretical Exercises*, includes exercises that fill in gaps in some of the proofs and amplify material in the text. Some of these call for a verbal solution. In this technological age, it is especially important to be able to write with care and precision; therefore, exercises of this type should help to sharpen such skills. These exercises can also be used to raise the level of the course and to challenge the more capable and interested student. The third class consists of exercises developed by David R. Hill and are labeled by the prefix ML (for MATLAB). These exercises are designed to be solved by an appropriate computer software package.

Answers to all odd-numbered numerical and ML exercises appear in the back of the book. At the end of Chapter 10, there is a cumulative review of the introductory linear algebra material presented thus far, consisting of 100 true/false questions (with answers in the back of the book). The **Instructor's Solutions Manual**, containing answers to all even-numbered exercises and solutions to all theoretical exercises, is available (to instructors only) at no cost from the publisher.

Presentation

We have learned from experience that at the sophomore level, abstract ideas must be introduced quite gradually and must be supported by firm foundations. Thus we begin the study of linear algebra with the treatment of matrices as mere arrays of numbers that arise naturally in the solution of systems of linear equations—a problem already familiar to the student. Much attention has been devoted from one edition to the next to refine and improve the pedagogical aspects of the exposition. The abstract ideas are carefully balanced by the considerable emphasis on the geometrical and computational foundations of the subject.

Material Covered

Chapter 1 deals with matrices and their properties. Section 1.5, *Matrix Transformations*, new to this edition, provides an early introduction to this important topic. This chapter is comprised of two parts: The first part deals with matrices and linear systems and the second part with solutions of linear systems. Chapter 2 (optional) discusses applications of linear equations and matrices to the areas of coding theory, computer graphics, electrical circuits, Markov chains, linear economic models. Section 2.1, *An Introduction to Coding*, new to this edition, develops foundations for introducing some basic material in coding theory. To keep this material at a very elementary level, it is necessary to use lengthier technical discussions. Chapter 3 presents the basic properties of determinants rather quickly. Chapter 4 deals with vectors in R^n. In this chapter we also give an introduction to linear transformations. Chapter 5 (optional) provides an opportunity to explore some of the many geometric ideas dealing with vectors in R^2 and R^3; we limit our attention to the areas of cross product in R^3 and lines and planes.

In Chapter 6 we come to a more abstract notion, that of a vector space. The abstraction in this chapter is more easily handled after the material covered on vectors in R^n. Chapter 7 (optional) presents two applications of real vector spaces: *QR*-factorization, least squares. Chapter 8, on eigenvalues and eigenvectors, the pinnacle of the course, is now presented in three sections to improve pedagogy. The diagonalization of symmetric matrices is carefully developed.

Chapter 9 (optional) deals with two applications of eigenvalues and eigenvectors. These include the Fibonacci sequence, quadratic forms. Chapter 10 covers linear transformations and matrices. Chapter 11, provides a brief introduction to MATLAB (which stands for MATRIX LABORATORY), a very useful software package for linear algebra computation, described below.

Appendix A presents two more advanced topics in linear algebra: inner product spaces and composite and invertible linear transformations.

Applications

Most of the applications are entirely independent; they can be covered either after completing the entire introductory linear algebra material in the course or they can be taken up as soon as the material required for a particular application has been developed. Brief Previews of most applications are given at appropriate places in the book to indicate how to provide an immediate application of the material just studied. The chart at the end of this Preface, giving the prerequisites for each of the applications, and the Brief Previews will be helpful in deciding which applications to cover and when to cover them.

Some of the sections in Chapters 2, 5, 7 and 9 can also be used as independent student projects. Classroom experience with the latter approach has met with favorable student reaction. Thus the instructor can be quite selective both in the choice of material and in the method of study of these applications.

End of Chapter Material

Every chapter contains a summary of *Key Ideas for Review*, a set of supplementary exercises, and a chapter test (all answers appear in the back of the book).

MATLAB Software

Although the ML exercises can be solved using a number of software packages, in our judgment MATLAB is the most suitable package for this purpose. MATLAB is a versatile and powerful software package whose cornerstone is its linear algebra capability. MATLAB incorporates professionally developed quality computer routines for linear algebra computation. The code employed by MATLAB is written in the C language and is upgraded as new versions of MATLAB are released. MATLAB is available from The Math Works, Inc., 24 Prime Park Way, Natick, MA 01760, (508) 653-1415; e-mail: `info@mathworks.com` and is not distributed with this book or the instructional routines developed for solving the ML exercises. The Student Edition of MATLAB also includes a version of *Maple*, thereby providing a symbolic computational capability.

Chapter 11 of this edition consists of a brief introduction to MATLAB's capabilities for solving linear algebra problems. Although programs can be written within MATLAB to implement many mathematical algorithms, *it should be noted that the reader of this book is not asked to write programs. The user is merely asked to use* MATLAB *(or any other comparable software package) to solve specific numerical problems.* Approximately 24 instructional M-files have been developed to be used with the ML exercises in this book and are available from the following Prentice Hall Web site: `www.prenhall.com/kolman`. These M-files are designed to transform many of MATLAB's capabilities into courseware. This is done by providing pedagogy that allows the student to interact with MATLAB, thereby letting the student think through all the steps in the solution of a problem and relegating MATLAB to act as a powerful calculator to relieve the drudgery of a tedious computation. Indeed, this is the ideal role for MATLAB (or any other similar package) in a beginning linear algebra course, for in this course, more than in many others, the tedium of lengthy computations makes it almost impossible to solve a modest-size problem. Thus, by introducing pedagogy and reining in the power of MATLAB, these M-files provide a working partnership between the student and the computer. Moreover, the introduction to a powerful tool such as MATLAB early in the student's college career opens the way for other software support in higher-level courses, especially in science and engineering.

Supplements

Student Solutions Manual (0-13-143741-0). Prepared by Dennis Kletzing, Stetson University, and Nina Edelman and Kathy O'Hara, Temple University, contains solutions to all odd-numbered exercises, both numerical and theoretical. It can be purchased from the publisher.

Instructor's Solutions Manual (0-13-143742-9). Contains answers to all even-numbered exercises and solutions to all theoretical exercises—is available (to instructors only) at no cost from the publisher.

Optional combination packages. Provide a computer workbook free of charge when packaged with this book.

- *Linear Algebra Labs with MATLAB*, by David R. Hill and David E. Zitarelli, 3rd edition, ISBN 0-13-124092-7 (supplement and text).
- *Visualizing Linear Algebra with Maple*, by Sandra Z. Keith, ISBN 0-13-124095-1 (supplement and text).
- *ATLAST Computer Exercises for Linear Algebra*, by Steven Leon, Eugene Herman, and Richard Faulkenberry, 2nd edition, ISBN 0-13-124094-3 (supplement and text).
- *Understanding Linear Algebra with MATLAB*, by Erwin and Margaret Kleinfeld, ISBN 0-13-124093-5 (supplement and text).

Prerequisites for Applications

Prerequisites for Applications

Section 2.1	Material on bits in Chapter 1
Section 2.2	Section 1.5
Section 2.3	Section 1.6
Section 2.4	Section 1.6
Section 2.5	Section 1.7
Section 2.6	Section 1.7
Section 5.1	Chapter 3
Section 5.2	Section 5.1
Section 7.1	Section 6.8
Section 7.2	Sections 1.6, 1.7, 4.1, 6.9
Section 9.1	Section 8.2
Section 9.2	Section 8.3

To Users of Previous Editions:

During the 29-year life of the previous seven editions of this book, the book was primarily used to teach a sophomore-level linear algebra course. This course covered the essentials of linear algebra and used any available extra time to study selected applications of the subject. *In this new edition we have not changed the structural foundation for teaching the essential linear algebra material. Thus, this material can be taught in exactly the same manner as before.* The placement of the applications in a more cohesive and pedagogically unified manner together with the newly added applications and other material should make it easier to teach a richer and more varied course.

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In the eighth edition: Jüergen Gerlach, Radford University; Lanita Presson, University of Alabama, Huntsville; Tomaz Pisanski, Colgate University; Mike Daven, Mount Saint Mary College; David Goldberg, Purdue University; Aimee J. Ellington, Virginia Commonwealth University.

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We thank Dennis Kletzing, Stetson University, and Nina Edelman and Kathy O'Hara, Temple University, for preparing the *Student Solutions Manual*.

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TO THE STUDENT

It is very likely that this course is unlike any other mathematics course that you have studied thus far in at least two important ways. First, it may be your initial introduction to abstraction. Second, it is a mathematics course that may well have the greatest impact on your vocation.

Unlike other mathematics courses, this course will not give you a toolkit of isolated computational techniques for solving certain types of problems. Instead, we will develop a core of material called linear algebra by introducing certain definitions and creating procedures for determining properties and proving theorems. Proving a theorem is a skill that takes time to master, so at first we will only expect you to read and understand the proof of a theorem. As you progress in the course, you will be able to tackle some simple proofs. We introduce you to abstraction slowly, keep it to a minimum, and amply illustrate each abstract idea with concrete numerical examples and applications. Although you will be doing a lot of computations, the goal in most problems is not merely to get the "right" answer, but to understand and explain how to get the answer and then interpret the result.

Linear algebra is used in the everyday world to solve problems in other areas of mathematics, physics, biology, chemistry, engineering, statistics, economics, finance, psychology, and sociology. Applications that use linear algebra include the transmission of information, the development of special effects in film and video, recording of sound, Web search engines on the Internet, and economic analyses. Thus, you can see how profoundly linear algebra affects you. A selected number of applications are included in this book, and if there is enough time, some of these may be covered in this course. Additionally, many of the applications can be used as self-study projects.

There are three different types of exercises in this book. First, there are computational exercises. These exercises and the numbers in them have been carefully chosen so that almost all of them can readily be done by hand. When you use linear algebra in real applications, you will find that the problems are much bigger in size and the numbers that occur in them are not always "nice." This is not a problem because you will almost certainly use powerful software to solve them. A taste of this type of software is provided by the third type of exercises. These are exercises designed to be solved by using a computer and MATLAB, a powerful matrix-based application that is widely used in industry. The second type of exercises are theoretical. Some of these may ask you to prove a result or discuss an idea. In today's world, it is not enough to be able to compute an answer; you often have to prepare a report discussing your solution, justifying the steps in your solution, and interpreting your results. These types of exercises will give you experience in writing mathematics. Mathematics uses words, not just symbols.

How to Succeed in Linear Algebra

- Read the book slowly with pencil and paper at hand. You might have to read a particular section more than once. Take the time to verify the steps marked "verify" in the text.
- Make sure to do your homework on a timely basis. If you wait until the problems are explained in class, you will miss learning how to solve a problem by yourself. Even if you can't complete a problem, try it anyway, so that when you see it done in class you will understand it more easily. You might find it helpful to work with other students on the material covered in class and on some homework problems.
- Make sure that you ask for help as soon as something is not clear to you. Each abstract idea in this course is based on previously developed ideas—much like laying a foundation and then building a house. If any of the ideas are fuzzy to you or missing, your knowledge of the course will not be sturdy enough for you to grasp succeeding ideas.
- Make use of the pedagogical tools provided in this book. At the end of each section we have a list of key terms; at the end of each chapter we have a list of key ideas for review, supplementary exercises, and a chapter test. At the end of the first ten chapters (completing the core linear algebra material in the course) we have a comprehensive review consisting of 100 true/false questions that ask you to justify your answer. Finally, there is a glossary for linear algebra at the end of the book. Answers to the odd-numbered exercises appear at the end of the book. The *Student Solutions Manual* provides detailed solutions to all odd-numbered exercises, both numerical and theoretical. It can be purchased from the publisher (ISBN 0-13-143742-9).

We assure you that your efforts to learn linear algebra well will be amply rewarded in other courses and in your professional career.

We wish you much success in your study of linear algebra.