

7th edition

Elementary Linear Algebra

Ron Larson

International Edition IOT FOR SALE IN USA, CANADA, OR AUSTRALIA

INDEX OF APPLICATIONS

BIOLOGY AND LIFE SCIENCES

Age distribution vector, 372, 383, 384, 387 Age progression software, 174 Age transition matrix, 372, 383, 384, 387 Agriculture, 37, 50, 101 Cosmetic surgery results simulation, 174 Duchenne muscular dystrophy, 359 Galloping speeds of animals, 270 Genetics, 359 Health care expenditures, 140 Heart rhythm analysis, 249 Hemophilia A. 359 Hereditary baldness, 359 Nutrition, 11 Population of deer, 37 of laboratory mice, 95 of rabbits, 373 of sharks, 388 of small fish, 388 Population genetics, 359 Population growth, 372, 373, 383, 384, 387, 388, 390 Predator-prey relationship, 388 Red-green color blindness, 359 Reproduction rates of deer, 97 Sex-linked inheritance, 359 Spread of a virus, 95 Vitamin C content, 11 Wound healing simulation, 174 X-linked inheritance, 359

BUSINESS AND ECONOMICS

Borrowing money, 23 Computer operator charges, 139 Demand for a grade of gasoline, 97 for a rechargeable power drill, 97 Demand matrix, external, 91 Economic system, 90, 91 of a small community, 96 Finance, 23 Gasoline sales, 99 Industrial system, 96, 101 Input-output matrix, 90 Leontief input-output model(s), 90, 91, 97 Major League Baseball salaries, 101 Manufacturing labor and material costs, 99 models and prices, 144 production levels, 51, 99

Net profit, Microsoft, 32 Output matrix, 91 Profit, from crops, 50 Purchase of a product, 95 Revenue fast-food stand, 236 General Dynamics Corporation, 260, 270 Google, Inc., 286 telecommunications company, 236 textbook publishers, 137 Sales, 37 concession area, 42 Wal-Mart, 32 Satellite television service, 85, 86, 141 Textbook publishing, 137

ENGINEERING AND TECHNOLOGY

Aircraft design, 79 Circuit design, 316 Computer graphics, 332 Computer monitors, 184 Control system, 308 Controllability matrix, 308 Cryptography, 87-89, 95-97, 100, 101 Data encryption, 87 Decoding a message, 89, 96, 97, 100, 101 Digital signal processing, 166 Electrical network analysis, 30, 31, 34, 37, 144 Electronic equipment, 184 Encoding a message, 88, 95, 97, 100 Encryption key, 87 Engineering and control, 124 Error checking digit, 194 matrix, 194 Feed horn, 217 Global Positioning System, 16 Image morphing and warping, 174 Information retrieval, 58 Internet search engine, 58 Ladder network, 316 Locating lost vessels at sea, 16 Movie special effects, 174 Network analysis, 29-31, 33, 34, 37 Radar, 166 Sampling, 166 Satellite dish, 217 Smart phones, 184 Televisions, 184 Wireless communications, 166

MATHEMATICS AND GEOMETRY

Adjoint of a matrix, 128, 129, 136, 140, 144 Collinear points in the xy-plane, 133, 137 Conic section(s), 220, 223 general equation, 135 rotation of axes, 215-218, 220, 223, 377-379, 384, 387 Contraction in *R*², 331, 335, 336 Coplanar points in space, 134, 137 Cramer's Rule, 124, 130, 131, 136, 137, 140 Cross product of two vectors, 271-274, 282, 283, 286 Differential equation(s) linear, 212, 219, 220, 223 second order, 158 system of first order, 348, 374, 375, 383, 384, 387, 388, 390 Expansion in R², 331, 335, 336, 339 Fibonacci sequence, 388 Fourier approximation(s), 279-281, 283, 286 Geometry of linear transformations in R^2 , 330-332, 335, 336, 339 Hessian matrix, 369 Jacobian, 108, 139 Lagrange multiplier, 34 Laplace transform, 124 Least squares approximation(s), 275-278, 283 linear, 276, 283, 286 quadratic, 277, 283, 286 Linear programming, 47 Magnification in R^2 , 335, 336 Mathematical modeling, 267, 268, 270 Parabola passing through three points, 144 Partial fraction decomposition, 34, 37 Polynomial curve fitting, 25-28, 32, 34, 37 Quadratic form(s), 376–382, 384, 387, 390 Quadric surface, rotation of, 382, 384 Reflection in R², 330, 335, 336, 339, 340 Relative maxima and minima, 369 Rotation in R², 297, 337, 385, 389 in R³, 333, 334, 336, 339 Second Partials Test for relative extrema, 369 Shear in R², 331, 332, 335, 336, 339 Taylor polynomial of degree 1, 276 Three-point form of the equation of a plane, 135, 137, 140 Translation in R^2 , 302, 337 Triple scalar product, 282 Two-point form of the equation of a line, 133, 137, 140, 144 Unit circle, 247 Wronskian, 213, 219, 220, 223

PHYSICAL SCIENCES

Acoustical noise levels, 28 Airplane speed, 11 Area of a parallelogram using cross product, 273, 274, 282, 286 of a triangle using cross product, 283 using determinants, 132, 137, 140, 144 Astronomy, 27, 268 Balancing a chemical equation, 4 Beam deflection, 64, 72 Chemical mixture, 37 reaction, 4 Computational fluid dynamics, 79 Crystallography, 207 Degree of freedom, 158 Diffusion, 348 Dynamical systems, 388 Earthquake monitoring, 16 Electric and magnetic flux, 234 Flexibility matrix, 64, 72 Force matrix, 72 to pull an object up a ramp, 151 Geophysics, 166 Grayscale, 184 Hooke's Law, 64 Kepler's First Law of Planetary Motion, 135 Kirchhoff's Laws, 30, 316 Lattice of a crystal, 207 Mass-spring system, 158, 161 Mean distance from the sun, 27, 268

Natural frequency, 158 Newton's Second Law of Motion, 158 Ohm's Law, 316 Pendulum, 219 Planetary orbits, 135 periods, 27, 268 Primary additive colors, 184 RGB color model, 184 Stiffness matrix, 64, 72 Temperature, 34 Torque, 271 Traffic flow, 28, 33 Undamped system, 158 Unit cell, 207 end-centered monoclinic, 207 Vertical motion, 37 Volume of a parallelepiped, 282, 283, 286 of a solid, 108 of a tetrahedron, 134, 137 Water flow, 33 Weather, 325 Work, 242

SOCIAL SCIENCES AND DEMOGRAPHICS

Cellular phone subscribers, 101 Consumer preference model, 85, 86, 95, 141 Doctoral degrees awarded, 270 Energy consumption, 285 Final grades, 100 Motor vehicle registration, 97 Politics, voting apportionment, 51 Population of consumers, 95 regions of the United States, 51 of smokers and nonsmokers, 95 United States, 32 world, 267 Population migration, 100 Smokers and nonsmokers, 95 Sports, Super Bowl I, 36 Television watching, 95 Test scores, 102

STATISTICS AND PROBABILITY

Canonical regression analysis, 298 Least squares regression analysis, 92–94, 97, 101, 259, 265–270 cubic polynomial, 270 line, 93, 97, 101, 265, 268, 270, 290 quadratic polynomial, 267, 270 Markov chain, 325 Multiple regression analysis, 298 Multivariate statistics, 298 State matrix, 85, 100, 141, 325 Steady state probability vector, 386 Stochastic matrices, 84–86, 95, 97, 100, 325

MISCELLANEOUS

Architecture, 382 Catedral Metropolitana Nossa Senhora Aparecida, 382 Determining directions, 16 Dominoes, A2 Flight crew scheduling, 47 Sudoku, 114 Tips, 23 U.S. Postal Service, 194 ZIP + 4 barcode, 194

Elementary Linear Algebra

This page intentionally left blank

Elementary Linear Algebra Seventh Edition

Ron Larson

The Pennsylvania State University The Behrend College



Australia • Brazil • Japan • Korea • Mexico • Singapore • Spain • United Kingdom • United States



Elementary Linear Algebra Seventh Edition Ron Larson

Vice President, Editorial Director: P.J. Boardman Publisher: Richard Stratton Senior Sponsoring Editor: Molly Taylor Senior Development Editor: Laura Wheel Assistant Editor: Shaylin Walsh Hogan Editorial Assistant: Alexander Gontar Associate Media Editor: Andrew Coppola Senior Marketing Manager: Jennifer Pursley Jones Marketing Coordinator: Michael Ledesma Marketing Communications Manager: Mary Anne Payumo Content Project Manager: Jill Quinn Manufacturing Planner: Doug Bertke Rights Acquisition Specialist: Shalice Shah-Caldwell Text Designer: Larson Texts, Inc. Cover Designer: Larson Texts, Inc. Cover Image: © Arnaldo Pomodoro Compositor: Larson Texts, Inc.

© 2013, 2009, 2004, Brooks/Cole, Cengage Learning

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transmitted, stored, or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, Web distribution, information networks, or information storage and retrieval systems, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the publisher.

For product information and technology assistance, contact us at Cengage Learning Customer & Sales Support, 1-800-354-9706.

For permission to use material from this text or product, submit all requests online at **www.cengage.com/permissions**. Further permissions questions can be emailed to **permissionrequest@cengage.com.**

Library of Congress Control Number: 2011935270

Student Edition: ISBN-13: 978-1-133-11087-3 ISBN-10: 1-133-11087-8

Brooks/Cole

20 Channel Center Street Boston, MA 02210 USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil, and Japan. Locate your local office at: **international.cengage.com/region**

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

For your course and learning solutions, visit **www.cengage.com**. Purchase any of our products at your local college store or at our preferred online store *www.cengagebrain.com*.

Instructors: Please visit *login.cengage.com* and log in to access instructor-specific resources.

Contents

1	Γ	Systems of Linear Equations		
		1.1	Introduction to Systems of Linear Equations	2
		1.2	Gaussian Elimination and Gauss-Jordan Elimination	13
		1.3	Applications of Systems of Linear Equations	25
			Review Exercises	35
			Project 1 Graphing Linear Equations	38
			Project 2 Underdetermined and Overdetermined Systems	38
2	Γ	Mat	rices	39
		2.1	Operations with Matrices	40
		2.2	Properties of Matrix Operations	52
		2.3	The Inverse of a Matrix	62
		2.4	Elementary Matrices	74
		2.5	Applications of Matrix Operations	84
			Review Exercises	98
			Project 1 Exploring Matrix Multiplication	102
			Project 2 Nilpotent Matrices	102
3	Γ	Dete	erminants	103
		3.1	The Determinant of a Matrix	104
		3.2	Determinants and Elementary Operations	112
		3.3	Properties of Determinants	120
		3.4	Applications of Determinants	128
			Review Exercises	138
			Project 1 Stochastic Matrices	141
			Project 2 The Cayley-Hamilton Theorem	141
			Cumulative Test for Chapters 1–3	143
4	Γ	Vect	or Spaces	145

	4.1	Vectors in <i>Rⁿ</i>	146			
	4.2	Vector Spaces	155			
	4.3	Subspaces of Vector Spaces	162			
	4.4	169				
	4.5 Basis and Dimension4.6 Rank of a Matrix and Systems of Linear Equations					
	4.7	Coordinates and Change of Basis				
	4.8	Applications of Vector Spaces	212			
		Review Exercises				
		Project 1 Solutions of Linear Systems	224			
		Project 2 Direct Sum	224			

5		Inne	r Product Spaces	225
		5.1	Length and Dot Product in <i>R</i> ⁿ	226
		5.2	Inner Product Spaces	237
		5.3	Orthonormal Bases: Gram-Schmidt Process	248
		5.4	Mathematical Models and Least Squares Analysis	259
		5.5	Applications of Inner Product Spaces	271
			Review Exercises	284
			Project 1 The QR-Factorization	287
			Project 2 Orthogonal Matrices and Change of Basis	288
			Cumulative lest for Chapters 4 and 5	289
6	Π	Line	ar Transformations	291
		6.1	Introduction to Linear Transformations	292
		6.2	The Kernel and Range of a Linear Transformation	303
		6.3	Matrices for Linear Transformations	314
		6.4	Transition Matrices and Similarity	324
		6.5	Applications of Linear Transformations	330
			Review Exercises	337
			Project 1 Reflections in R ² (I)	340
			Project 2 Reflections in R ² (II)	340
7	Γ	Eige	nvalues and Eigenvectors	341
		7.1	Eigenvalues and Eigenvectors	342
		7.2	Diagonalization	353
		7.3	Symmetric Matrices and Orthogonal Diagonalization	362
		7.4	Applications of Eigenvalues and Eigenvectors	372
			Review Exercises	385
			Project 1 Population Growth and Dynamical Systems (I)	388
			Project 2 The Fibonacci Sequence	388
			Cumulative Test for Chapters 6 and 7	389
8	Γ	Com	plex Vector Spaces (online)*	
		8.1	Complex Numbers	
		8.2	Conjugates and Division of Complex Numbers	

- 8.3 Polar Form and DeMoivre's Theorem
- 8.4 Complex Vector Spaces and Inner Products
- 8.5 Unitary and Hermitian Matrices Review Exercises Project Population Growth and Dynamical Systems (II)

A1

9 📕 Linear Programming (online)*

- 9.1 Systems of Linear Inequalities
- 9.2 Linear Programming Involving Two Variables
- 9.3 The Simplex Method: Maximization
- 9.4 The Simplex Method: Minimization
- 9.5 The Simplex Method: Mixed Constraints Review Exercises Project Cholesterol Levels

10 Numerical Methods (online)*

- **10.1** Gaussian Elimination with Partial Pivoting
- **10.2** Iterative Methods for Solving Linear Systems
- **10.3** Power Method for Approximating Eigenvalues
- **10.4** Applications of Numerical Methods Review Exercises Project Population Growth

Appendix

Mathematical Induction and Other Forms of Proofs

Online Technology Guide (online)*			
Answer Key	A7		
Index	A39		
*Available online at <i>www.cengagebrain.com.</i>			