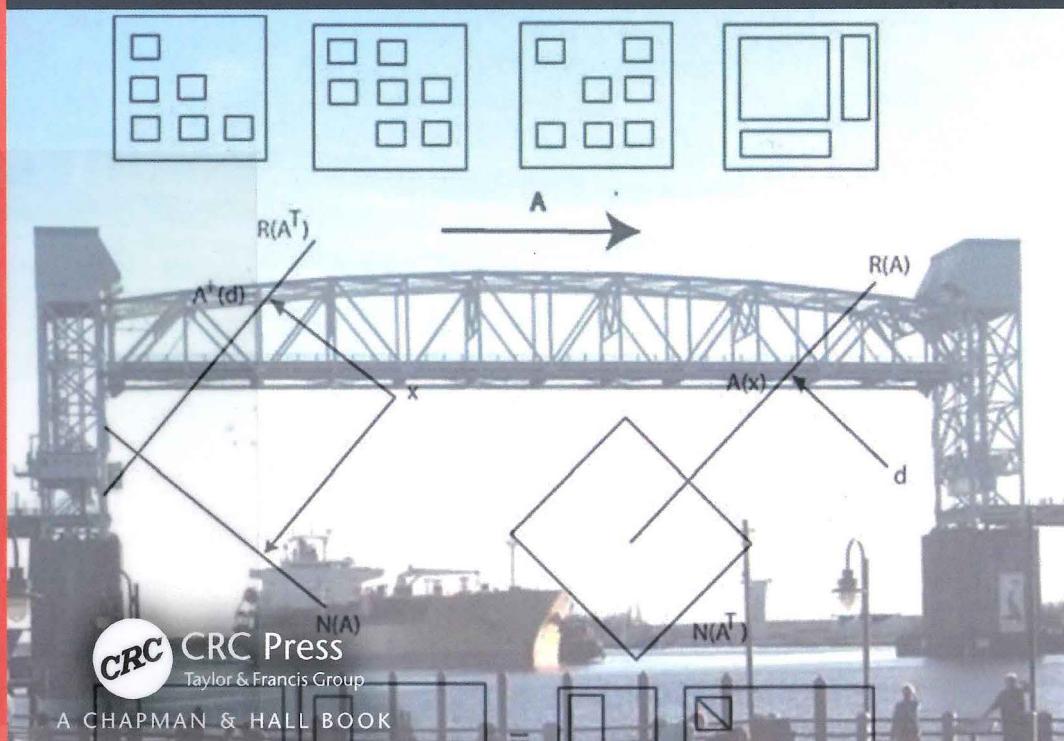


COMPUTATIONAL LINEAR ALGEBRA

with Applications and MATLAB® Computations

Robert E. White



CRC Press
Taylor & Francis Group

A CHAPMAN & HALL BOOK

070100019
สำนักหอสมุด มหาวิทยาลัยเชียงใหม่

012548538
122687464

Computational Linear Algebra

with Applications and MATLAB® Computations



Robert E. White



CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an Informa business
A CHAPMAN & HALL BOOK

Contents

List of Figures	xi
Preface	xiii
Introduction	xv
Author Biography	xvii
1 Solution of $Ax = d$	
1.1 Matrix Models	1
1.1.1 Column vectors and \mathbb{R}^n	1
1.1.2 Matrices	5
1.1.3 Application to visualization of minimum cost	7
1.1.4 Application to two-bar truss	8
1.1.5 Application to two-loop circuit	9
1.1.6 Exercises	11
1.2 Matrix Products	12
1.2.1 Matrix-vector products	13
1.2.2 Matrix-matrix products	16
1.2.3 Application to heat conduction	18
1.2.4 Matrix computations using MATLAB®	21
1.2.5 Exercises	21
1.3 Special Cases of $Ax = d$	22
1.3.1 Five possible classes of “solutions”	22
1.3.2 Triangular matrices	24
1.3.3 Application to heat in wire with current	29
1.3.4 Matrix computations using MATLAB®	29
1.3.5 Exercises	31
1.4 Row Operations and Gauss Elimination	31
1.4.1 Introductory illustration	32
1.4.2 Three types of row operations	33
1.4.3 Gauss elimination for solving $Ax = d$	34
1.4.4 Application to six-bar truss	37
1.4.5 Gauss elimination using MATLAB®	39
1.4.6 Exercises	40
1.5 Inverse Matrices	41
1.5.1 Examples of inverse matrices	41

1.5.2	Gauss–Jordan method to find inverse matrices	44
1.5.3	Properties of inverse matrices	49
1.5.4	Inverse matrices and MATLAB®	53
1.5.5	Exercises	54
1.6	Determinants and Cramer’s Rule	57
1.6.1	Determinants for 2×2 and 3×3 matrices	57
1.6.2	Determinant of an $n \times n$ matrix	59
1.6.3	Cramer’s rule and inverses	62
1.6.4	Determinants using MATLAB®	66
1.6.5	Exercises	67
2	Matrix Factorizations	69
2.1	The Schur Complement	69
2.1.1	Heat diffusion in fin with two directions	73
2.1.2	Exercises	74
2.2	$PA = LU$ and A Nonsingular	75
2.2.1	Exercises	78
2.3	$A = LU, A^{-1} \geq 0$ and M-Matrix	78
2.3.1	Exercises	82
2.4	$A = GG^T$ and A SPD	82
2.4.1	SPD and minimization	85
2.4.2	Exercises	86
3	Least Squares and Normal Equations	89
3.1	Normal Equations	89
3.1.1	Exercises	92
3.2	MATLAB® Code price_expdata.m	93
3.2.1	Exercises	95
3.3	Basis of Subspace	96
3.3.1	Exercises	99
3.4	Projection to Subspace	100
3.4.1	Exercises	102
4	$Ax = d$ with $m < n$	105
4.1	Examples in \mathbb{R}^3	105
4.2	Row Echelon Form	106
4.2.1	Solutions in \mathbb{R}^4	107
4.2.2	General solution of $Ax = d$	110
4.2.3	Exercises	112
4.3	Relationship of $R(A), N(A^T)$ and $R(A^T), N(A)$	113
4.3.1	Construction of bases	116
4.3.2	Exercises	117
4.4	Null Space Method for Equilibrium Equations	118
4.4.1	Block Gauss elimination method	119
4.4.2	Null space method for equilibrium equations	121

4.4.3	Application to three-loop circuit	123
4.4.4	Application to six-bar truss	124
4.4.5	Application to fluid flow	126
4.4.6	Exercises	128
5	Orthogonal Subspaces and Bases	129
5.1	Orthogonal Subspace	129
5.1.1	Exercises	131
5.2	Fundamental Theorem: $\mathbb{R}^n = N(A) \oplus R(A^T)$	131
5.2.1	Exercises	133
5.3	$A = QR$ Factorization	133
5.3.1	MATLAB® code qr_col.m	136
5.3.2	Exercises	138
5.4	Orthonormal Basis	138
5.4.1	Exercises	140
5.5	Four Methods for QR Factors	141
5.5.1	Classical Gram–Schmidt	141
5.5.2	Givens transform	142
5.5.3	Householder transform	143
5.5.4	Exercises	146
6	Eigenvectors and Orthonormal Basis	147
6.1	Eigenvectors of Symmetric Matrix	147
6.1.1	Exercises	150
6.2	Approximation of Eigenvalues	150
6.2.1	Gershgorin circles	151
6.2.2	Power iterations	151
6.2.3	QR iteration	152
6.2.4	Exercises	153
6.3	Spectral Theorem Factors $AQ = QD$	153
6.3.1	Exercises	155
6.4	Applications	155
6.4.1	Nonsingular $Ax = d$	155
6.4.2	Singular value decomposition	156
6.4.3	Exercises	159
7	Singular Value Decomposition	161
7.1	“Small” SVD	161
7.1.1	Exercises	164
7.2	“Full” SVD	164
7.2.1	MATLAB® code svd_ex.m	166
7.2.2	Exercises	169
7.3	“Truncated” SVD	169
7.3.1	Exercises	172

8 Three Applications of SVD	173
8.1 Image Compression	173
8.1.1 MATLAB® code svdimage.m	175
8.2 Search Engines	177
8.2.1 MATLAB® codes sengine.m, senginesparse.m	179
8.3 Noise Filter	184
8.3.1 MATLAB® code Image1dsvd.m	185
9 Pseudoinverse of A	189
9.1 Σ^\dagger and $A^\dagger = V\Sigma^\dagger U^T$	189
9.1.1 Exercises	192
9.2 A^\dagger and Least Squares	193
9.2.1 Exercises	195
9.3 Ill-Conditioned Least Squares	196
9.3.1 Exercises	199
9.4 Application to Hazard Identification	199
9.4.1 MATLAB® code hazidsvd1.m	201
10 General Inner Product Vector Spaces	209
10.1 Vector Spaces	209
10.1.1 Exercises	214
10.2 Inner Products and Orthogonal Vectors	214
10.2.1 General inner products	215
10.2.2 Orthonormal vectors	217
10.2.3 Norms on vector spaces	219
10.2.4 Exercises	221
10.3 Schur Decomposition	221
10.3.1 Norms and spectral radius	224
10.3.2 Normal matrices	225
10.3.3 Cayley–Hamilton theorem	227
10.3.4 Exercises	229
10.4 Self-Adjoint Differential Operators	229
10.4.1 Linear operators	230
10.4.2 Sturm-Liouville problem	233
10.4.3 Exercises	235
10.5 Self-Adjoint Positive Definite BVP	235
10.5.1 Exercises	243
11 Iterative Methods	245
11.1 Inverse Matrix Approximations	245
11.1.1 Exercises	247
11.2 Regular Splittings for M-Matrices	247
11.2.1 Exercises	252
11.3 P-Regular Splittings for SPD Matrices	253
11.3.1 SOR for diffusion in 3D	255

11.3.2 MATLAB® implementation of SOR	256
11.3.3 Exercises	258
11.4 Conjugate Gradient for SPD Matrices	259
11.4.1 MATLAB® implementations of CG	262
11.4.2 Exercises	266
11.5 Generalized Minimum Residual	267
11.5.1 MATLAB® implementations of GMRES	271
11.5.2 Exercises	275
12 Nonlinear Problems and Least Squares	277
12.1 Picard Approximation	277
12.1.1 MATLAB® code piccool.m	281
12.2 Newton Method	283
12.2.1 MATLAB® code newtcool.m	286
12.3 Levenberg-Marquardt Method	288
12.3.1 MATLAB® code levmarqprice.m	291
12.4 SIRD Epidemic Models	293
12.4.1 MATLAB® code sird_parid.m	295
12.5 The Cumulated Infection Version of SIRD	300
12.5.1 US COVID-19: An aggregated model	302
Bibliography	305
Index	307