
Contents

Preface to the Third Edition	xi
Software	xiii
Selected References	xv

1 Matrix Multiplication Problems 1

1.1	Basic Algorithms and Notation	2
1.2	Exploiting Structure	16
1.3	Block Matrices and Algorithms	24
1.4	Vectorization and Re-Use Issues	34

2 Matrix Analysis 48

2.1	Basic Ideas from Linear Algebra	48
2.2	Vector Norms	52
2.3	Matrix Norms	54
2.4	Finite Precision Matrix Computations	59
2.5	Orthogonality and the SVD	69
2.6	Projections and the CS Decomposition	75
2.7	The Sensitivity of Square Linear Systems	80

3 General Linear Systems 87

3.1	Triangular Systems	88
3.2	The LU Factorization	94
3.3	Roundoff Analysis of Gaussian Elimination	104
3.4	Pivoting	109
3.5	Improving and Estimating Accuracy	123

4	Special Linear Systems	133
4.1	The LDM^T and LDL^T Factorizations	135
4.2	Positive Definite Systems	140
4.3	Banded Systems	152
4.4	Symmetric Indefinite Systems	161
4.5	Block Systems	174
4.6	Vandermonde Systems and the FFT	183
4.7	Toeplitz and Related Systems	193
5	Orthogonalization and Least Squares	206
5.1	Householder and Givens Matrices	208
5.2	The QR Factorization	223
5.3	The Full Rank LS Problem	236
5.4	Other Orthogonal Factorizations	248
5.5	The Rank Deficient LS Problem	256
5.6	Weighting and Iterative Improvement	264
5.7	Square and Underdetermined Systems	270
6	Parallel Matrix Computations	275
6.1	Basic Concepts	276
6.2	Matrix Multiplication	292
6.3	Factorizations	300
7	The Unsymmetric Eigenvalue Problem	308
7.1	Properties and Decompositions	310
7.2	Perturbation Theory	320
7.3	Power Iterations	330
7.4	The Hessenberg and Real Schur Forms	341
7.5	The Practical QR Algorithm	352
7.6	Invariant Subspace Computations	362
7.7	The QZ Method for $Ax = \lambda Bx$	375
8	The Symmetric Eigenvalue Problem	391
8.1	Properties and Decompositions	393
8.2	Power Iterations	405

8.3	The Symmetric QR Algorithm	414
8.4	Jacobi Methods	426
8.5	Tridiagonal Methods	439
8.6	Computing the SVD	448
8.7	Some Generalized Eigenvalue Problems	461

9 Lanczos Methods 470

9.1	Derivation and Convergence Properties	471
9.2	Practical Lanczos Procedures	479
9.3	Applications to $Ax = b$ and Least Squares	490
9.4	Arnoldi and Unsymmetric Lanczos	499

10 Iterative Methods for Linear Systems 508

10.1	The Standard Iterations	509
10.2	The Conjugate Gradient Method	520
10.3	Preconditioned Conjugate Gradients	532
10.4	Other Krylov Subspace Methods	544

11 Functions of Matrices 555

11.1	Eigenvalue Methods	556
11.2	Approximation Methods	562
11.3	The Matrix Exponential	572

12 Special Topics 579

12.1	Constrained Least Squares	580
12.2	Subset Selection Using the SVD	590
12.3	Total Least Squares	595
12.4	Computing Subspaces with the SVD	601
12.5	Updating Matrix Factorizations	606
12.6	Modified/Structured Eigenproblems	621

Bibliography 637

Index 687