

INDEX

A

Acquaintance matrix, 92
Adjugate matrix, 170
Algebraic multiplicity, 191
Almost periodic, 216
Alternating direction, 303
Alternative, 330
Angle, 105
Arc, 334
Area, 173, 176
Associative law, 13, 16
Attainable, 51
Average error, 111, 119
Axes of ellipse, 254, 263, 270

B

Back-substitution, 3, 24
Band matrix, 40
Bandwidth, 41, 302
BASIC, 373
Basic solution, 314
Basic variables, 57
Basis, 67, 356
Block multiplication, 174
Boolean algebra, 156
Boundary value, 38, 277
Bridge, 183, 345
Buniakowsky, 108

C

C'' , 219
California, 6, 199, 288
Capacity, 335, 337
Cauchy, 108
Cayley – Hamilton, 235
Change of basis, 356, 358
Change of variables, 231
Characteristic equation, 182
Characteristic polynomial, 182, 186, 188
Checkerboard matrix, 92, 189
Chess, 345, 347
Cholesky, 36, 253, 287, 368
Coefficient matrix, 9
Cofactors, 165, 166
Column space, 51, 66, 73
Combination
 of columns, 10, 15, 51
 of rows, 16
Commuting matrices, 18, 193
 counterexample, 17
 symmetric, 110
Complementary slackness, 326
Complete pivoting, 44
Completing square, 246, 251
Complex numbers, 217
Complex vectors, 219, 231
Compound interest, 195
Condition number, 280, 282, 285

Cone, 331
Congruence transformation, 259
Conjugate, 217
Conjugate gradients, 303
Conjugate transpose, 220
Constraint, 268, 306
Consumption matrix, 203
Convergence factor, 289, 298
Coordinate vectors, 64
Corner, 312, 314
Correlation, 148, 226
Cosine, 106
Cost function, 306
Covariance, 148
Cramer's rule, 171
Cross-product matrix, 109
Crout, 25
Cut, 335
Cycling, 316

D

Dantzig, 311, 345
Decay, 202, 209
Defective matrix, 185, 191, 211
Degeneracy, 316
Dependence, 63
Determinant, 153, 186
 formulas for, 161, 164, 166
 properties of, 156
Diagonal matrix, 25
Diagonalization, 190, 207, 366
Diagonally dominant, 304
Diet problem, 308, 323
Difference equation, 39, 195
Differential equation, 37, 180, 205, 350
Diffusion, 208, 209, 214
Dimension, 69
 of fundamental spaces, 75
Direct sum, 96
Distance, 107
Distinct eigenvalues, 191
Distributive law, 16
Dual problem, 309, 323, 345
Duality theorem, 324, 333, 345
Dynamic programming, 338

E

Earth, 184, 193
Echelon form, 56, 62
Edge, 312
Eigenspace, 183

Eigenvalues, 153, 181, 185
 distinct, 191
 of product, 188, 193
 repeated, 191, 225
Eigenvectors, 181
 generalized, 207, 360
EISPACK, 367
Elementary matrices, 12, 30, 34
Elimination
 Gauss–Jordan, 31, 62
 Gaussian, 1, 22, 29, 60
Ellipsoid, 254, 263, 270
Epidemic, 201
Equations, normal, 114
Equilibrium, 326, 340
Error, 111, 119, 281, 297
Even permutation, 175, 178
Exchange, 1, 27, 44, 156
Existence, 78
Expansion in cofactors, 165
Exponential, 181, 205, 210, 340, 365

F

Factor analysis, 225
Factorization
 LDL^T , 36, 251
 LDU , 25
 LU , 22, 57
 $\bar{L}\bar{U}$, 97, 98, 144
 QR , 131, 293
 $Q_1\Sigma Q_2^T$, 142, 293
Feasible set, 306, 311
Fibonacci, 196, 198
Filippov, 239, 361
Finite differences, 38, 161, 167, 302
Finite elements, 273
Fitting of data, 118, 124
Five-point scheme, 302
Fix, 276
Floating point, 42
Forsythe, 42
Fortran, 12, 370
Forward substitution, 25
Four fundamental spaces, 71, 88, 221
Fourier series, 134
Fredholm, 89, 330
Free variables, 57, 72, 314
Frequency, 214
Friction, 216
Front wall, 84
Function space, 49, 133
Fundamental subspaces, 71, 88, 221
Fundamental theorem, 75, 87

G

Gale, 332, 345
 Galois, 186
 Game theory, 339
 Gauss, 3, 42
 Gauss–Jordan, 31, 62, 317
 Gauss–Seidel, 299, 301, 304
 Gaussian elimination, 1, 22, 29, 60, 175
 General solution, 57, 60
 Generalized eigenvalue problem, 256, 261, 277
 Generalized eigenvectors, 207, 360
 Generalized inverse, 138
 Geodesy, 104
 Geometric multiplicity, 191
 Gerschgorin, 304
 Givens, 261
 Golub, 303
 Gram–Schmidt, 129, 135, 259, 293

H

Halfspace, 305
 Heat equation, 210
 Hermitian, 221, 227, 235
 Hessian matrix, 248
 Higher order equations, 208
 Hilbert matrix, 44, 135
 Hilbert space, 133, 351
 Hockney, 303
 Homogeneous, 58
 Householder, 128, 291

I

Idempotent matrix, 116, 366
 Identity matrix, 17
 Ill-conditioned, 42, 281
 Imaginary number, 193
 Incidence matrix, 90, 335
 Inconsistent, 55
 Indefinite, 247
 Independence, 62, 70
 Infinite dimensions, 49, 354
 Influence coefficient, 155
 Inhomogeneous term, 7
 Initial-value problem, 183
 Inner product, 10, 82, 133, 210
 complex, 220
 of functions, 134
 weighted, 148
 Input–output, 204
 Integer programming, 336

Interest, 195
 Interpolation, 80
 Intersection, 92
 Inverse, 20, 30, 76
 formula for, 170
 generalized, 138
 of products, 31
 of transpose, 35
 Inverse power method, 289
 Invertible, 30, 80
 I.Q., 225
 Irreversibility, 210
 Isomorphism, 95
 Iterative method, 279, 297
 Iterative refinement, 304

J

Jacobi, 291, 298, 301, 304
 Jacobian, 154
 Jordan form, 207, 238, 359

K

Kernel, 72
 Kirchhoff, 89
 Kuhn–Tucker, 326, 345

L

Lagrange multiplier, 326
 Law of inertia, 256, 259
 LDL^T factorization, 36, 251
 LDU factorization, 25
 Least squares, 103, 111
 weighted, 148
 Least squares fit, 118, 124
 Left-inverse, 30, 77
 Left nullspace, 75
 Left nullvector, 75
 Left shift, 352
 Legendre, 135, 137
 Length, 81, 133, 148, 217, 219
 weighted, 148
 Leontief, 204
 Linear dependence, 63
 Linear equation, 6
 Linear independence, 62, 70
 Linear programming, 305
 Linear transformation, 79, 348, 352
 LINPACK, 367
 Lower triangular, 20
 LU factorization, 22, 57
 $\bar{L}\bar{U}$ factorization, 97, 98, 144

Luenberger, 322
Lyapunov, 213

M

Markov process, 199, 210
Marriage problem, 338
Matrix, 9
 adjugate, 170
 band, 40
 checkerboard, 92, 189
 coefficient, 9
 consumption, 203
 correlation, 148, 226
 cross-product, 109
 defective, 185, 191, 211
 diagonal, 190
 diagonalizable, 191, 366
 elementary, 12, 30, 34
 exponential of, 206, 365
 Hermitian, 221, 227, 335
 Hessenberg, 95, 233, 291, 295
 Hilbert, 44, 135
 idempotent, 116, 366
 identity, 17
 ill-conditioned, 42, 281
 incidence, 90, 335
 invertible, 30
 Jordan, 207, 238
 multiplication of, 13, 16
 negative definite, 246
 nonnegative, 199, 203
 nonsingular, 29, 80
 normal, 228, 237
 orthogonal, 126, 160
 payoff, 339
 permutation, 27, 29
 positive definite, 36, 250
 projection, 116, 236, 358
 reflection, 117, 291, 349
 representing, 352, 357
 rotation, 126, 229
 semidefinite, 246, 257
 similar, 232
 singular, 27
 skew-Hermitian, 228, 230
 skew-symmetric, 12, 212, 343
 square root of, 195, 254
 symmetric, 35, 222
 transition, 200
 transpose, 34
 triangular, 19, 187, 234
 tridiagonal, 39, 296
 unitary, 223, 229

Maximin, 269
Maximal flow, 334
Mean, 121, 125
Methane, 110
Middle-aged, 121
Minimax, 272
Minimax theorem, 344
Minimum, 244
Minimum principle, 264
Minimum problem, 311, 313, 329
Minor, 166
Mixed strategy, 339, 345
Modulus, 218
Moler, 42, 369
Moore, 138
Muir, 153
Multiplication
 matrix-vector, 10
 matrix, 13, 16
Multiplicity, 191
Multipliers, 21, 45
Multivariate analysis, 225

N

Negative definite, 246
Network, 334
Neutrally stable, 202, 211
Newton's law, 214, 261
Noble, 42
Node, 334
Nonlinear, 121
Nonnegative matrix, 199, 203
Nonnegative solution, 331
Nonsingular, 29, 80
Nontrivial, 63
Norm, 202, 284, 286
Normal equation, 114
Normal matrix, 228, 237
Normal modes, 215
Nullity, 72, 97
Nullspace, 52, 58, 72, 75

O

Odd permutation, 175, 178
Ohm, 90
One-to-one, 79
Onto, 79
Operation count, 5, 33, 41, 295
Optimal vector, 307, 326
Optimality condition, 317, 318
Orthogonal basis, 121, 125
Orthogonal complement, 86

Orthogonal eigenvectors, 222, 228
 Orthogonal matrix, 126, 160, 223
 Orthogonal subspaces, 84
 Orthogonal vectors, 82
 Orthogonalization, 128, 135
 Orthonormal, 122
 Orthonormal eigenvectors, 223, 237
 Oscillation, 214, 261
 Overdetermined system, 104
 Overrelaxation, 299

P

Pan, 5
 Pancake, 103
 Parallelogram, 8
 Parallelepiped, 154, 171
 Partial pivoting, 44
 Particular solution, 60
 Partitioning, 174
 Payoff, 339
 Peanut butter, 308, 330
 Penrose, 138, 145
 Permutation, 163, 175
 Permutation factor, 29
 Permutation matrix, 27, 47
 determinant of, 159, 164
 Perpendicular, 82, 113
 Phase I, 312, 320
 Phase II, 313
 Piecewise polynomials, 275
 Pivots, 3, 56
 formula for, 174
 product of, 161
 in simplex method, 317
 Plane rotation, 291, 296
 Poker, 346
 Polar coordinates, 154, 218
 Polynomial, 350
 Positive definite, 245
 Positive definite matrix, 36, 250
 Power method, 288
 Primal problem, 323
 Principal components, 225
 Principal submatrix, 252
 Prisoner's dilemma, 346
 Product
 of determinants, 158
 inner, 10, 82, 220
 of matrices, 14, 16, 96, 174, 355
 of pivots, 161
 of transposes, 35
 Projection, 107, 112
 on orthogonal axes, 123

Projection matrix, 116, 236, 358
 Pseudoinverse, 89, 138, 145
 formulas for, 142, 144
 Psychologists, 225
 Pythagoras, 81

Q

QR factorization, 131, 293
 QR algorithm, 294
 $Q_1 \Sigma Q_2^T$ factorization, 142, 293
 Quadratic form, 244, 248
 Quantum mechanics, 233

R

\mathbf{R}^n , 48
 Range, 72
 Rank, 60, 62, 74, 97
 of product, 97
 of submatrix, 98
 Rank one, 76, 98
 Rayleigh quotient, 266, 290
 Rayleigh – Ritz, 274
 Real versus complex, 231
 Reflection, 117, 291, 349
 Regression, 103, 118, 124, 148, 225
 Repeated eigenvalues, 191, 225
 Representing matrix, 352, 357
 Revised simplex method, 321
 Right-inverse, 30, 77
 Rotation, 126, 229
 of earth, 184, 193
 plane, 291, 296
 Roundoff, 42, 281, 285
 Routh, 213
 Row exchange, 27, 44, 156
 Row rank = column rank, 74
 Row-reduced echelon form, 62
 Row space, 66, 71

S

Saddle point, 247, 340, 344
 Scalar, 7
 Scalar multiplication, 54
 Schur, 234
 Schwartz inequality, 107, 110, 134
Scientific American, 196, 334
 Semidefinite, 246, 257
 Separating hyperplane, 331
 Shadow prices, 329
 Shearing, 350
 Shift, 295, 296

Similar matrices, 232
 Similarity transformation, 232, 234, 240, 357, 363
 Simplex method, 311, 321
 Simultaneous diagonalization, 263
 Singular matrix, 27
 Singular value, 142, 286, 293
 Skew-Hermitian, 228, 230
 Skew-symmetric, 12, 160, 343
 Slack variable, 307, 313
 Solvable, 51
 Space, 48
 Span, 51, 66, 70
 Spectral radius, 297, 300
 Spectral theorem, 224, 236
 Splitting, 297
 Springs, 215
 Square root, 195, 254
 Stable, 181, 202, 211, 213, 235
 Standard basis, 122
 Statistics, 104, 150
 Steady state, 6, 200, 210
 Stewart, 296, 367
 Stopping test, 317, 318
 Straight line fit, 118, 124, 136
 Stretching, 349
 String of vectors, 360
 Submatrix, 98
 Subspace, 49, 53
 fundamental, 71, 88, 221
 Successive overrelaxation, 299
 Sum of spaces, 93
 Sum of squares, 249, 251, 255, 257
 Summation notation, 11, 18
 Sunflower, 196
 Superdecay, 209
 Sylvester, 259
 Symmetric elimination, 257
 Symmetric matrix, 35, 222

T

Tableau, 316, 320
 Tetrahedron, 110
 Thorp, 346
 Trace, 186, 189, 233
 Transition matrix, 200
 Transportation problem, 310, 338
 Transpose, 34, 108
 determinant, 158
 of product, 35, 221
 of inverse, 35
 Traveling salesman, 338

Triangle inequality, 110
 Triangular matrix, 39, 187, 234
 Tridiagonal, 39, 296
 Trivial solution, 58

U

Unbounded, 307, 315
 Uncertainty principle, 233
 Underdetermined, 55
 Union, 93
 Uniqueness, 78
 Unit circle, 218
 Unit vectors, 83
 Unitary matrix, 223, 229
 Unstable, 202, 211
 Upper triangular, 19

V

Value, 307, 340
 Vandermonde, 80, 161
 Variance, 121
 Vector, 7
 Vector space, 48, 54, 350
 Volume, 154, 171
 von Neumann, 42, 203, 233, 344

W

Wave equation, 216
 Weak duality, 324, 335
 Weight, 112, 146
 Weighted least squares, 148
 Well-conditioned, 42
 Wilkinson, 42, 280, 285, 296
 Wronskian, 208

X

X-ray machine, 152

Y

Young, 301

Z

Zero determinant, 157, 158
 Zero length, 148
 Zero pivot, 4, 27, 56
 Zero vector, 54

A 0
 B 1
 C 2
 D 3
 E 4
 F 5
 G 6
 H 7
 I 8
 J 9