

Index

- BI-CG, 333
- BLAS, 38, 50
 - Level-1, 51
 - Level-2, 51
 - Level-3, 52
- GELDA, 250
- GENDA, 250
- GMRES, 289, 331, 332
 - stagnation, 333
- k*-Means Algorithm, 152
- LAPACK, 78, 79
- LSQR , 330
- MR, 333
- PCG, 327
- QMR, 333
- SYMMLQ , 330
- absolute error, 9
- absolute orientation problem, 157
- active constraint, 90, 137
- active set strategies, 338
- Adams family, 239
- Adams–Bashforth, 239
- Adams–Moulton, 239
- aggregation of Markov chains, 218, 219
- algebraic multigrid, 356, 360
- annealing, 197
- arc length, 294
- Arnoldi, 331
- Arnoldi basis, 331
- array steering vectors, 98
- Automatic differentiation, 122
- axpy, 51
- back substitution, 55
- backslash, 55
- backtracking linesearch, 119
- backward error, 17, 23, 306
- backward Euler method, 235
- band matrix, 313
- barrier function, 141
- barrier parameter, 141
- Basic Linear Algebra Subroutines, 37, 50
- basis, 50
- Bauer-Fike Theorem, 69
- beetle, red flour, 306
- bifurcate, 292
- bifurcation diagram, 304
- binary arithmetic, 8
- biological modeling, 301
- bits, 8
- bivariate, 189
- blind deconvolution, 169, 175
- boundary conditions, 269
- boundary value problem, 250, 251
- bracketing, 119
- Broyden’s good method, 124
- Broyden’s method, 289
- cache, 32
 - cache line, 32
 - miss penalty, 34
- Case Studies, x
- catastrophic cancellation, 14, 15
- central limit theorem, 191
- chaos, 304
- characteristic frequencies, 351

- Cholesky decomposition, 56, 316
 closed set, 144
 closed-loop control, 270
 clustering of data, 149
 coarse grid, 354, 358
 column-oriented algorithm, 32
 compiler, 11
 complementarity, 138
 computational science, 7
 computational scientist, 7
 computer arithmetic, 5, 8, 31
 - floating-point precision, 11
 - IEEE floating-point standard, 10
 - numerical disasters, 14
 - printed values, 10
 - speed, 36
 - symbolic computation, 17
 computer hardware, 3, 34
 computer memory, 31
 computer memory management, 32
 computer software, 3, 39
 - correctness, 43
 - debugging, 42
 - design, 41, 43
 - documentation, 39, 43
 - efficiency, 43
 - overhead of function call, 193
 - validation, 42
 computer word, 8
 condition number, 20, 25, 30
 cone, 144
 confidence interval, 28, 30
 confidence level, 28
 conic convex optimization, 144
 conjugate gradients, 289, 327
 conservation law, 245, 257
 constrained optimization problem, 135
 constraint qualification, 138
 continuation method, 142, 146, 291, 296, 305
 control system, 71, 265, 346
 controllable, 267
 convex, 110, 136, 144, 151
 convolution, 83
 Crank–Nicholson method, 237
 Cuthill–McKee, 316
 damped, 266
 damped least squares, 83
 data clustering problem, 149
 - k*-means algorithm, 152, 155
 - pitfalls, 151, 153
 data fitting
 - ecological modeling, 301
 - exponential fitting, 163, 168
 - rate constant, 165, 168
 deblurring images, 81
 defective, 77
 degree of graph node, 314
 delay differential equation (DDE), 260
 dense matrix, 47
 descent direction, 112
 desk checks, 42
 determinant, 50
 deterministic, 187, 192
 differential-algebraic equation, 226, 247, 260
 index, 248
 methods, 249
 software, 250
 standard form, 247
 strangeness, 249
 differential-index, 249
 diffusion term, 262
 dimers, 199
 direct method, 311, 323, 328
 direction
 - of negative curvature, 112, 113
 - of positive curvature, 113
 - of steepest ascent, 113
 - of steepest descent, 113, 127
 direction of arrival, 97
 Eigen-ESPRIT, 100
 ESPRIT, 103
 Music algorithm, 103
 SVD-ESPRIT, 99
 URV-ESPRIT, 103
 discrepancy principle, 171
 discrete Fourier (sine) transform, 345
 discrete ill-posed problem, 81
 discrete Newton, 123
 discretize, 321
 disk, 32

- dot-product, 51
- double-precision, 9
- downhill direction, 112, 113
- dual problem, 145
- dual variable, 28, 137
- dynamical system, 301, 306
 - bifurcation, 304, 306
 - equilibria, 303
 - parameter estimation, 304
 - stability, 303, 306
- ecological modeling, 301
- edge of a graph, 314
- eigendecomposition, 68, 72, 79
 - Krylov subspace method, 333
- eigenfunction, 348
- eigenvalue, 49, 68, 99, 230, 347, 348, 351
 - minimax characterization, 347
 - Bauer-Fike Theorem, 69
 - existence, 69
 - Gershgorin circle theorem, 56
 - Google, 333
 - Krylov subspace method, 334
 - operator, 347, 351
 - computing estimates, 349
 - properties, 350
 - uses, 351
 - perturbation, 69
 - updated matrix, 90
 - use in information retrieval, 333
 - Weilandt-Hoffman Theorem, 69
- eigenvector, 69, 99, 347
 - perturbation, 69
- elastic body, 335
- elastoplastic torsion, 335
- encounter factor, 227
- energy norm, 327, 328
- engineering, 7
- epidemiology, 213, 219, 259
- equilibria populations, 303
- error, 5
 - backward, 17, 23
 - forward, 17, 23
 - measurement, 17
- propagation, 14
- sources, 5
- errors-in-variables, 174
- ESPRIT, 97, 103
- Euler angles, 157
- expected value, 190
- exponential distribution, 188, 191
- exponential windowing, 100
- extinction solution, 303
- family of solutions, 228
- feasible direction, 140, 141
- feasible solution, 135
- fill-in, 313
- fine grid, 354
- finite difference, 251, 269, 273, 321, 349, 353
- finite difference Newton method, 289
- finite element, 251, 275, 321, 336, 349, 351, 353
 - mesh generation, 334, 339
- finite-precision, 5
- first-kind integral equation, 83
- first-order optimality condition, 112, 137, 138
- fixed point, 72
- fixed-point arithmetic, 8
- fixed-point iterations, 289, 290
- flexible-GMRES, 334
- floating-point arithmetic, 8
 - IEEE Standard, 10
 - precision, 11
 - printed values, 10
- flu epidemic of 1918, 219
- forgetting factor, 100
- forward error, 17, 23, 306
- forward substitution, 55
- free energy, 203
- Frobenius norm, 25
- full rank, 50
- functional iteration, 237
- fundamental frequency, 351
- Galerkin method, 275, 326
- gamma distribution, 188
- Gauss elimination, 52

- Gauss–Seidel, 290, 324, 329, 353
 Gear family, 243
 generalized eigenvalue problem, 99, 103
 generating function, 200, 202
 Gershgorin circle theorem, 56
 gimbal lock, 161
 Givens rotation matrix, 58
 global minimizer, 195
 Goldstein–Armijo condition, 119
 Google PageRank, 333
 gradient, 111
 Gram–Schmidt orthogonalization, 60, 331
 graph
 degree, 314
 edge, 314
 node, 314
 grid, 353
 grid points, 273
 Hamiltonian system, 245, 247, 257
 harmonic oscillator, 203
 hat functions, 276
 Helmholtz equation, 359
 Hermitian, 51
 Hessenberg matrix, 51
 Hessian matrix, 111
 high frequency, 356
 high-order term, 55
 higher-order elements, 277
 homotopy function, 291
 Hompack, 296
 Householder transformation, 58, 61, 62, 331
 IEEE standard floating-point arithmetic, 10
 ill-conditioning, 20, 81
 ill-posed problem, 81
 Tikhonov method, 83
 truncated SVD, 84
 image deblurring, 81, 85, 174, 346
 importance sampling, 208, 209
 inexact Newton method, 289
 initial value problem, 226
 inner-product, 51
 integral equation of the first kind, 81, 83
 interior-point methods, 139, 144, 338
 interpolation operator, 355
 interval analysis, 30
 invariant, 267
 invariant subspace, 69, 72
 inverse interpolation, 295, 296
 inverse problems, 81
 iterative method, 311, 322, 323
 Jacobian matrix, 228, 286
 Jordan block, 77
 Jordan canonical form, 77
 kernel function, 83, 169
 Kronecker product, 85, 86
 Krylov subspace, 326
 Krylov subspace method, 326
 Arnoldi, 334
 BI-CG, 334
 eigendecomposition, 333, 334
 flexible-GMRES, 334
 Galerkin, 326
 GMRES, 332, 334
 indefinite matrix, 330
 LSQR, 330, 334
 MR, 334
 normal equations, 330
 PCG, 334
 preconditioned conjugate gradients, 327
 projection, 326
 QMR, 334
 SVD, 333
 SYMMLQ, 330, 334
 variational, 326
 Lagrange multiplier, 24, 30, 136, 138
 Lagrangian function, 136, 138
 Lanczos basis, 333
 Laplacian, 319
 least change, 124
 least squares, 84, 171, 304, 305, 330
 damped, 83
 data fitting, 65
 existence, 66

- ill-conditioned, 74
- iterative method
 - LSQR, 330
 - SYMMLQ, 330
- Levenberg–Marquardt, 118, 289
- Levenberg–Marquardt, 121
- linear, 49, 163
- nonlinear, 159, 160, 165, 287, 305
- perturbation, 66, 168
- rank-deficient, 74
- total least squares, 174
- uniqueness, 66
- updating with new data, 90
- Varpro for separable problems, 168
- left eigenvector, 68
- left singular vector, 73
- legacy code, 39
- Levenberg–Marquardt, 118, 121, 289
- linear conjugate gradients, 128, 329
- linear control theory, 266
- linear least squares, 287
- linear programming, 27, 144, 178, 181
- linear subspace
 - basis, 50
 - orthogonal basis, 50
 - orthonormal basis, 50
- linear system, 49
 - condition number, 20, 25, 26
 - dense, 49
 - existence of solution, 53
 - iterative method
 - Arnoldi, 331
 - BI-CG, 333
 - conjugate gradients, 327
 - flexible-GMRES, 334
 - Gauss–Seidel, 324
 - GMRES, 331, 332
 - indefinite matrix, 330
 - Krylov subspace method, 326
 - MR, 333
 - nonsymmetric matrix, 331
 - normal equations, 330
 - preconditioning, 328
 - QMR, 333
 - restarting, 331
- stationary iterative method, 72, 324
- successive displacements, 324
- symmetric Gauss–Seidel, 329
- perturbation, 53
- singular matrix, 53
- sparse direct, 311
- sparse iterative, 323
- uniqueness of solution, 53
- linearly independent, 347
- Lipschitz continuous, 116, 196, 226, 287
- local minimizer, 110, 195
- low-order term, 55
- LU, 52, 79
- Lyapunov equation, 343
- Lyapunov stability, 266
- machine epsilon, 10
- main memory, 32
- mantissa, 9
- marginal values, 24
- Markov chain, 216, 219
 - aggregation, 219
- Markov property, 216
- mass matrix, 247
- mathematical modeling, 3
 - blind deconvolution of images, 169, 175
 - control of robot, 265
 - direction-of-arrival problem, 97
 - elasticity, 339
 - elastoplastic torsion, 335
 - epidemiology, 259
 - Monte Carlo model, 213
 - ordinary differential equation models, 259
 - partial differential equation models, 261
 - error, 7
 - image deblurring, 81
 - population dynamics, 301
 - reaction rate, 163
 - structure comparison, 157
 - truss configuration, 297
 - vibrational frequencies, 347
- mathematics, 7

- matrix
- MATLAB's gallery, 311, 334
 - condition number, 117
 - Davis collection, 334
 - determinant, 50
 - eigenvalue
 - Bauer-Fike Theorem, 69
 - existence, 69
 - Gershgorin circle theorem, 56
 - perturbation, 69
 - Weilandt-Hoffman Theorem, 69
 - eigenvector
 - linear independence, 69
 - uniqueness, 69
 - generalized eigenvalue problem, 103
 - inverse, 116
 - linear algebra facts, 50
 - low-rank approximation with SVD, 75
 - Matrix Market, 311, 334
 - matrix structure, 51
 - minor, 50
 - norm, 25
 - relation to SVD, 73
 - null space, 50
 - range, 50
 - rank, 50
 - rank (numerical), 81
 - similarity transform, 50
 - singular, 51
 - stiffness matrix, 339
 - testing positive definiteness, 56
 - transpose, 8
 - updating, 95
- matrix decomposition, 49
- Cholesky, 52
 - downdating, 87
 - eigendecomposition, 68, 71, 72, 79, 103
 - implicit updating, 92
 - Jordan canonical form, 77
 - LAPACK, 79
 - LU, 52, 79
 - matrix inverse, 77
- QR, 57, 79
- Givens Rotations, 58
 - Gram-Schmidt, 60
 - Householder, 62
 - uses, 62
- rank-revealing QR (RR-QR), 67, 79
- rank-revealing URV, 103
- Schur decomposition, 344
- singular value decomposition (SVD), 72, 73, 74, 79, 103
- software, 78
- sparse, 311
- summary, 78
- updating, 87
- matrix multiplication
- Strassen algorithm, 37, 346
- matrix norm, 25
- matrix notation, 8
- matrix structure, 342
- Hermitian, 51
 - Hessenberg, 51
 - Kronecker product, 85, 86
 - orthogonal, 51
 - permutation, 51
 - positive definite, 51
 - symmetric, 51
 - tridiagonal, 51
 - unitary, 51
- maximum principle, 252
- mean, 189, 190
- measurement error, 5
- memory management, 32
- merit function, 285
- mesh, 353
- minimizer, 109
- minimum, 109
- minimum degree, 317
- minors, 50
- mistakes, 6
- modeling error, 5
- moments, 189
- monomers, 199
- Monte Carlo, 187
- counting, 195
- estimation, 27, 30

- importance sampling, 208
- integration, 203, 206
- method, 187
- optimization, 195
- random number generation, 219
- sampling, 199
- simulation, 213
 - stratified sampling, 212
- multicore, 31
- multigrid method, 328, 330, 353, 360
 - 1-d problems, 354
 - 2-d problems, 358
 - cost, 357
 - V-cycle, 356
- multiple shooting, 253
- Music algorithm, 103
- NaN, 9
- narrowband, 97
- Nelder–Mead algorithm, 130
- nested dissection, 318
- nested grids, 358
- nested iteration, 355
- Newton direction, 115
- Newton’s method
 - for nonlinear equations, 285, 288
 - for optimization, 114
- Newton–Cotes, 204
- no-change conditions, 124
- node of a graph, 314
- nonlinear conjugate gradients, 127
- nonlinear equations, 285, 351
 - continuation method, 291
 - contraction map, 287
 - existence of solution, 287
 - finite-difference Newton method, 289
 - fixed-point iterations, 290, 296
 - Gauss–Seidel, 290
 - homotopy software, 296
 - inexact Newton method, 289
 - methods for 1-dimensional problems, 286
 - Newton’s method, 288, 296
 - polynomial system, 297
 - quasi-Newton method, 289
- trust region method, 289, 296
- uniqueness of solution, 287
- nonlinear Gauss–Seidel, 290
- nonlinear least squares, 132, 159, 160, 287
- nonsingular, 51
- nonstationary Stokes equation, 249
- nonuniform, 188
- normal distribution, 188, 191
- normal equations, 330
- normalize, 9
- not-a-number, 9
- null space, 50
- numerical analysis, 7
- numerical integration
 - Monte Carlo methods, 204, 206
 - importance sampling, 208
- multidimensional
 - separable function, 206
 - multidimensional integrals by nested quadrature, 205
- numerical rank, 67, 81
- observable, 268
- optimization, 11
 - automatic differentiation, 122
 - computing Hessian matrices, 111
 - constrained, 135
 - active set methods, 90
 - algorithms for bound constraints, 121, 139
 - algorithms for linear equality constraints, 140
 - barrier methods, 141
 - existence of solution, 138
 - interior-point methods, 144
 - linear inequality constraints, 90
 - linear programming, 144, 178, 181
 - optimality conditions: general constraints, 138
 - optimality conditions: linear constraints, 136
 - penalty methods, 141
 - quadratic programming, 339
 - sensitivity of solution, 136

- discrete functions, 198
 feasible point, 135
 global minimizer, 110
 local optimality, 135
 Monte Carlo methods, 195
 Newton direction through matrix
 inverse, 116
 simulated annealing, 196, 197, 202
 traveling salesperson problem, 198
 unconstrained, 109
 algorithms, 113, 133
 conjugate gradient, 127
 descent direction, 119
 existence of solution, 112
 finite difference methods, 130
 finite difference Newton
 methods, 126
 first-derivative methods, 123
 first-order optimality conditions,
 112
 geometric optimality conditions,
 112
 Levenberg–Marquardt method,
 118, 121
 linesearch, 119
 low-storage, 126
 modified Cholesky method, 118,
 133
 modified Newton methods, 117
 Newton’s method, 114, 116
 no derivatives, 129
 optimality conditions, 110
 pattern search methods, 131
 quasi-Newton method, 123, 133
 second-order optimality
 condition, 112
 simplex-based methods, 130
 steepest descent, 127
 summary, 131
 truncated Newton method, 128
 trust region, 121, 133
 uniqueness of solution, 110
 order, 55
 ordinary differential equation, 225
 backward Euler method, 235
 boundary value problem, 225, 250,
 268
 boundedness, 252
 existence, 251
 finite difference methods, 254
 maximum principle, 252
 shooting method, 253
 uniqueness, 251
 choice of method, 257
 control, 271
 conversion of higher-order
 equations to standard form,
 227
 differential-algebraic equation, 247
 dynamical system, 301
 finite difference method, 273, 280
 finite element method, 273, 280
 Gear methods, 243
 Hamiltonian system, 245, 247
 higher order, 227
 initial value problem, 225, 226, 268
 Adams method, 239
 adaptive method, 240, 243
 Euler’s method, 232
 existence of solution, 226
 higher order, 225
 predictor-corrector methods, 237
 Runge-Kutta methods, 243
 software, 228
 stiff solvers, 257, 260
 stiffness, 243
 uniqueness of solution, 226
 Lyapunov stability, 267, 271
 methods, 257
 monotonicity theorem, 252
 multigrid method, 353
 multilevel method, 353
 order of method, 233, 240
 PECE, 240
 solution families, 228
 stability, 228, 232, 303
 stability interval, 235
 stable, 230
 stable method, 235
 standard form, 226
 stepsize control, 240

- stiff, 230
- stochastic, 264
- unstable, 230
- orientation of molecules, 157
- orthogonal basis, 50, 63
- orthogonal matrix, 51
- orthogonal Procrustes problem, 159
- orthonormal basis, 50
- outlier, 151
- overdetermined, 287
- overflow, 9
- PageRank, 333
- parameterized Sard's theorem, 293
- partial differential equation
 - discretization, 262, 321
 - eigenvalue problem, 347
 - elastoplastic torsion, 335
 - Helmholtz equation, 360
 - multigrid method, 353, 360
 - software, 345, 351
 - stiffness matrix, 339
- partial pivoting, 53
- partition function, 203
- pattern search method, 130
- PE(CE)^m, 237
- PECE, 240
- penalty function, 142
- penalty parameter, 142
- permutation matrix, 51, 52, 312
- pitch, 157
- pivot, 53, 316
- pixels, 82
- plastically, 335
- polynomial equation, 285
 - existence of solution, 287
 - uniqueness of solution, 287
- population dynamics, 301
 - equilibria, 303
 - stability, 303
- positive definite, 51, 112, 316
- positive definite Lyapunov function, 267
- positive semidefinite, 112
- positive spanning set, 131
- potential energy, 196
- preconditioned conjugate gradients, 327
- preconditioner, 324, 327, 328
 - incomplete Cholesky, 328
 - multigrid, 328
 - sparse approximate inverse, 328
 - symmetric Gauss–Seidel, 329
- primal-dual central path, 145
- principal value, 347
- probability, 187, 190
- probability density function, 190
- profile, 313
- prolongation, 356
- pseudo-Monte Carlo, 187
- pseudorandom, 187, 192
- QR, 57, 79
- QR iteration, 70
- quadratic convergence, 116
- quadratic model, 114
- quadratic programming, 121, 338
- quasi-Newton method, 123, 289
- quasi-random numbers, 210
- Quaternions, 161
- random number
 - distribution, 188, 190
 - central limit theorem, 191
 - mean, 190
 - normal, 191
 - variance, 190
- generation, 188
 - pseudorandom number, 192, 194, 219
 - quasi-random numbers, 210
- importance sampling, 208, 209
- quasi-random numbers, 212
- stratified sampling, 212
- testing, 193
- range, 50
- rank, 50
- rank-1 matrix, 90
- rank-revealing QR (RR-QR), 67, 79
- rank-revealing URV, 102
- rate, 117
- rate constant, 163, 302
 - data fitting, 165
 - sensitivity, 163

- real symmetric, 314
- rectangle rule, 83
- rectangular windowing, 98
- reduced costs, 24
- registers, 32
- regularization, 82, 86, 171, 181
 - Tikhonov method, 83, 174
 - truncated SVD, 84, 174
- relative error, 9
- residual, 19, 63
- restriction operator, 356
- Reverse Cuthill–McKee, 316
- right eigenvectors, 68
- right singular vectors, 73
- robot arm, 265
 - control, 270
 - controllability, 265
 - stability, 265
- roll, 157
- root mean squared distance, 159
- rotation, 58
- rounding error, 42
- rounding error, 5, 126
- row-oriented algorithm, 32
- RR-QR decomposition, 67
 - sampling, 187
 - scal, 51
- Schur decomposition, 78, 343, 344
- science, 7
- scientific computing, 7
- secant condition, 123, 290
- second-order condition for optimality, 112, 139
- second-order cone programming, 144
- seed for random number generation, 192
- self-adjoint, 348
- semidefinite programming, 144
- sensitivity analysis, 23
 - condition numbers, 24
 - confidence intervals, 28
 - derivatives, 23
 - Monte Carlo experiments, 27
- separator, 318
- shadow price, 137
- shear modulus, 336
- shear stress, 336
- Sherman–Morrison–Woodbury Formula, 89, 91
- shooting method, 251, 253, 268
- significand, 9
- SIM, 72
- similarity transform, 50, 70
- simplex, 130
- simplex algorithm for linear programming, 90, 135
- simplex method, 144
- simulated annealing, 192, 197, 202
 - log cooling schedule, 199
- simulation
 - differential equation, 259
 - Monte Carlo, 213
- single-precision, 9
- singular value decomposition, 73, 79, 99
 - Krylov subspace method, 333
 - low-rank approximation, 75
 - sum of rank-one matrices, 75
- singular values, 73
- small support, 83, 276
- spaghetti code, 41
- sparse, 309, 316
 - sparse matrix, 47, 274
 - decomposition, 312
 - fill-in, 313
 - graph representation, 314
- iterative method
 - Gauss–Seidel method, 334
 - Jacobi method, 334
 - Krylov subspace method, 334
 - SOR method, 334
 - stationary iterative method, 334
- MATLAB functions, 274
- reordering, 314
 - Cuthill–McKee, 316
 - eigenvector partitioning, 319
 - minimum degree, 317
 - nested dissection, 318
 - nonsymmetric matrix, 321, 322
 - software, 320
 - symmetric matrix, 322
- storage, 311

- stability, 95
 - of a control system, 71
 - of an algorithm, 20, 125
 - of an ODE, 230, 266
- stable, 303
- state in Markov chain, 216
- state vector, 71, 266
- stationary iterative method, 72, 324
- statistical sampling, 199
 - correlation of samples, 201
- statistics, 7
- steady state, 218, 266
- steepest descent, 127
- stochastic, 187
- stochastic differential equations, 264
- strangeness, 249
- Strassen algorithm, 37, 346
- stress function, 335
- successive displacements, 324
- SUNDIALS, 250
- superlinear convergence rate, 117
- SVD, 73
- Sylvester equation, 341, 343
 - Schur algorithm, 346
- symbolic computation, 17, 30
- symmetric, 51
- symmetric Gauss–Seidel, 329
- Taylor series, 112
- Tikhonov method, 174
- Tikhonov regularization, 83, 177
- Toeplitz matrix, 175
- torsion, 335
- total least norm problems, 177
- total least squares, 172, 174
 - structure constraints, 175
- transition matrix, 217
- transpose, 8
- transversal to zero, 293
- trapezoidal rule for integration, 240
- traveling salesperson problem (TSP), 198
- tridiagonal matrix, 51, 70, 313
- truncation error, 5, 126
- truss problem, 297
- trust region, 121, 289
- turning points, 292
- two-point boundary value problem, 273
- unconstrained optimization, 109
- undamped, 265
- underflow, 9
- undriven damped pendulum, 266
- uniform distribution, 188, 190
- unit lower-triangular, 52
- unitary matrix, 51
- univariate, 188
- unstable, 20, 267, 303
- update techniques, 97
- updating linear systems
 - matrix, 89
 - right-hand side, 89
- uphill direction, 113
- upper-Hessenberg, 51, 70
- upper-triangular matrix, 52
- URV, 102
- URV-ESPRIT, 103
- variable metric, 123
- variable projection, 166
- variance, 189, 190
- vector norm, 25, 181
- vector notation, 8
- Volterra’s predator/prey model, 226
- well-conditioned, 20
- well-mixed, 259
- windowing of data
 - exponential, 100
 - rectangular, 99
- Wolfe–Powell condition, 119
- work, 274
- work unit, 357
- yaw, 157
- yield stress, 336
- zero, 285
 - simple, 288