

# General Index to Volumes 1 and 2

In this index, page numbers 1 through 934 refer to Volume 1, *Numerical Recipes in Fortran 77*, while page numbers 935 through 1446 refer to Volume 2, *Numerical Recipes in Fortran 90*. Front matter in Volume 1 is indicated by page numbers in the range 1/i through 1/xxxi, while front matter in Volume 2 is indicated 2/i through 2/xx.

- A**bstract data types 2/xiii, 1030
- Accelerated convergence of series 160ff., 1070
- Accuracy 19f.
  - achievable in minimization 392, 397, 404
  - achievable in root finding 346f.
  - contrasted with fidelity 832, 840
  - CPU different from memory 181
  - vs. stability 704, 729, 830, 844
- Accuracy parameters 1362f.
- Acknowledgments 1/xvi, 2/x
- Ada 2/x
- Adams-Bashford-Moulton method 741
- Adams' stopping criterion 366
- Adaptive integration 123, 135, 703, 708ff., 720, 726, 731f., 737, 742ff., 788, 1298ff., 1303, 1308f.
  - Monte Carlo 306ff., 1161ff.
- Addition, multiple precision 907, 1353
- Addition theorem, elliptic integrals 255
- ADI (alternating direction implicit) method 847, 861f., 906
- Adjoint operator 867
- Adobe Illustrator 1/xvi, 2/xx
- Advective equation 826
- AGM (arithmetic geometric mean) 906
- Airy function 204, 234, 243f.
  - routine for 244f., 1121
- Aitken's delta squared process 160
- Aitken's interpolation algorithm 102
- Algol 2/x, 2/xiv
- Algorithms, non-numerical 881ff., 1343ff.
- Aliasing 495, 569
  - see also* Fourier transform
- all() intrinsic function 945, 948
- All-poles model 566
  - see also* Maximum entropy method (MEM)
- All-zeros model 566
  - see also* Periodogram
- Allocatable array 938, 941, 952ff., 1197, 1212, 1266, 1293, 1306, 1336
- allocate statement 938f., 941, 953f., 1197, 1266, 1293, 1306, 1336
- allocated() intrinsic function 938, 952ff., 1197, 1266, 1293
- Allocation status 938, 952ff., 961, 1197, 1266, 1293
- Alpha AXP 2/xix
- Alternating-direction implicit method (ADI) 847, 861f., 906
- Alternating series 160f., 1070
- Alternative extended Simpson's rule 128
- American National Standards Institute (ANSI) 2/x, 2/xiii
- Amoeba 403
  - see also* Simplex, method of Nelder and Mead
- Amplification factor 828, 830, 832, 840, 845f.
- Amplitude error 831
- Analog-to-digital converter 812, 886
- Analyticity 195
- Analyze/factorize/operate package 64, 824
- Anderson-Darling statistic 621
- Andrew's sine 697
- Annealing, method of simulated 387f., 436ff., 1219ff.
  - assessment 447
  - for continuous variables 437, 443ff., 1222
  - schedule 438
  - thermodynamic analogy 437
  - traveling salesman problem 438ff., 1219ff.
- ANSI (American National Standards Institute) 2/x, 2/xiii
- Antonov-Saleev variant of Sobol' sequence 300, 1160
- any() intrinsic function 945, 948
- APL (computer language) 2/xi
- Apple 1/xxiii
  - Macintosh 2/xix, 4, 886
- Approximate inverse of matrix 49
- Approximation of functions 99, 1043
  - by Chebyshev polynomials 185f., 513, 1076ff.
  - Padé approximant 194ff., 1080f.
  - by rational functions 197ff., 1081f.
  - by wavelets 594f., 782
  - see also* Fitting
- Argument
  - keyword 2/xiv, 947f., 1341
  - optional 2/xiv, 947f., 1092, 1228, 1230, 1256, 1272, 1275, 1340
- Argument checking 994f., 1086, 1090, 1092, 1370f.

- Arithmetic  
 arbitrary precision 881, 906ff., 1352ff.  
 floating point 881, 1343  
 IEEE standard 276, 882, 1343  
 rounding 882, 1343  
 Arithmetic coding 881, 902ff., 1349ff.  
 Arithmetic-geometric mean (AGM) method 906  
 Arithmetic-if statement 2/xi  
 Arithmetic progression 971f., 996, 1072, 1127, 1365, 1371f.  
 Array 953ff.  
 allocatable 938, 941, 952ff., 1197, 1212, 1266, 1293, 1306, 1336  
 allocated with pointer 941  
 allocation 953  
 array manipulation functions 950  
 array sections 939, 941, 943ff.  
 of arrays 2/xii, 956, 1336  
 associated pointer 953f.  
 assumed-shape 942  
 automatic 938, 954, 1197, 1212, 1336  
 centered subarray of 113  
 conformable to a scalar 942f., 965, 1094  
 constructor 2/xii, 968, 971, 1022, 1052, 1055, 1127  
 copying 991, 1034, 1327f., 1365f.  
 cumulative product 997f., 1072, 1086, 1375  
 cumulative sum 997, 1280f., 1365, 1375  
 deallocation 938, 953f., 1197, 1266, 1293  
 disassociated pointer 953  
 extents 938, 949  
 in Fortran 90 941  
 increasing storage for 955, 1070, 1302  
 index loss 967f.  
 index table 1173ff.  
 indices 942  
 inquiry functions 948ff.  
 intrinsic procedures 2/xiii, 948ff.  
 of length 0 944  
 of length 1 949  
 location of first "true" 993, 1041, 1369  
 location of maximum value 993, 1015, 1017, 1365, 1369  
 location of minimum value 993, 1369f.  
 manipulation functions 950, 1247  
 masked swapping of elements in two arrays 1368  
 operations on 942, 949, 964ff., 969, 1026, 1040, 1050, 1200, 1326  
 outer product 949, 1076  
 parallel features 941ff., 964ff., 985  
 passing variable number of arguments to function 1022  
 of pointers forbidden 956, 1337  
 rank 938, 949  
 reallocation 955, 992, 1070f., 1365, 1368f.  
 reduction functions 948ff.  
 shape 938, 944, 949  
 size 938  
 skew sections 945, 985  
 stride 944  
 subscript bounds 942  
 subscript triplet 944  
 swapping elements of two arrays 991, 1015, 1365ff.  
 target 938  
 three-dimensional, in Fortran 90 1248  
 transformational functions 948ff.  
 unary and binary functions 949  
 undefined status 952ff., 961, 1266, 1293  
 zero-length 944  
 Array section 2/xiii, 943ff., 960  
 matches by shape 944  
 pointer alias 939, 944f., 1286, 1333  
 skew 2/xii, 945, 960, 985, 1284  
 vs. `eoshift` 1078  
`array_copy()` utility function 988, 991, 1034, 1153, 1278, 1328  
`arith()` utility function 972, 974, 988, 996, 1072, 1086, 1127  
 replaces do-list 968  
 Artificial viscosity 831, 837  
 Ascending transformation, elliptic integrals 256  
 ASCII character set 6, 888, 896, 902  
 Assembly language 269  
`assert()` utility function 988, 994, 1086, 1090, 1249  
`assert_eq()` utility function 988, 995, 1022  
`associated()` intrinsic function 952f.  
 Associated Legendre polynomials 246ff., 764, 1122f., 1319  
 recurrence relation for 247  
 relation to Legendre polynomials 246  
 Association, measures of 604, 622ff., 1275  
 Assumed-shape array 942  
 Asymptotic series 161  
 exponential integral 218  
 Attenuation factors 583, 1261  
 Autocorrelation 492  
 in linear prediction 558  
 use of FFT 538f., 1254  
 Wiener-Khinchin theorem 492, 566f.  
 AUTODIN-II polynomial 890  
 Automatic array 938, 954, 1197, 1212, 1336  
 specifying size of 938, 954  
 Automatic deallocation 2/xv, 961  
 Autonomous differential equations 729f.  
 Autoregressive model (AR) *see* Maximum entropy method (MEM)  
 Average deviation of distribution 605, 1269  
 Averaging kernel, in Backus-Gilbert method 807  
**B**acksubstitution 33ff., 39, 42, 92, 1017  
 in band diagonal matrix 46, 1021  
 in Cholesky decomposition 90, 1039  
 complex equations 41  
 direct for computing  $\mathbf{A}^{-1} \cdot \mathbf{B}$  40  
 with QR decomposition 93, 1040  
 relaxation solution of boundary value problems 755, 1316  
 in singular value decomposition 56, 1022f.  
 Backtracking 419  
 in quasi-Newton methods 376f., 1195  
 Backus-Gilbert method 806ff.  
 Backus, John 2/x  
 Backward deflation 363

- Bader-Deuffhard method 730, 735, 1310f.  
 Bairstow's method 364, 370, 1193  
 Balancing 476f., 1230f.  
 Band diagonal matrix 42ff., 1019  
     backsubstitution 46, 1021  
     LU decomposition 45, 1020  
     multiply by vector 44, 1019  
     storage 44, 1019  
 Band-pass filter 551, 554f.  
     wavelets 584, 592f.  
 Bandwidth limited function 495  
 Bank accounts, checksum for 894  
 Bar codes, checksum for 894  
 Bartlett window 547, 1254ff.  
 Base case, of recursive procedure 958  
 Base of representation 19, 882, 1343  
 BASIC, Numerical Recipes in 1, 2/x, 2/xviii  
 Basis functions in general linear least squares 665  
 Bayes' Theorem 810  
 Bayesian  
     approach to inverse problems 799, 810f., 816f.  
     contrasted with frequentist 810  
     vs. historic maximum entropy method 816f.  
     views on straight line fitting 664  
 Bays' shuffle 270  
 Bernoulli number 132  
 Bessel functions 223ff., 234ff., 936, 1101ff.  
     asymptotic form 223f., 229f.  
     complex 204  
     continued fraction 234, 239  
     double precision 223  
     fractional order 223, 234ff., 1115ff.  
     Miller's algorithm 175, 228, 1106  
     modified 229ff.  
     modified, fractional order 239ff.  
     modified, normalization formula 232, 240  
     modified, routines for 230ff., 1109ff.  
     normalization formula 175  
     parallel computation of 1107ff.  
     recurrence relation 172, 224, 232, 234  
     reflection formulas 236  
     reflection formulas, modified functions 241  
     routines for 225ff., 236ff., 1101ff.  
     routines for modified functions 241ff., 1118  
     series for  $K_\nu$  241  
     series for  $Y_\nu$  235  
     spherical 234, 245, 1121f.  
     turning point 234  
     Wronskian 234, 239  
 Best-fit parameters 650, 656, 660, 698, 1285ff.  
     *see also* Fitting  
 Beta function 206ff., 1089  
     incomplete *see* Incomplete beta function  
 BFGS algorithm *see* Broyden-Fletcher-Goldfarb-Shanno algorithm  
 Bias, of exponent 19  
 Bias, removal in linear prediction 563  
 Biconjugacy 77  
 Biconjugate gradient method  
     elliptic partial differential equations 824  
     preconditioning 78f., 824, 1037  
     for sparse system 77, 599, 1034ff.  
 Bicubic interpolation 118f., 1049f.  
 Bicubic spline 120f., 1050f.  
 Big-endian 293  
 Bilinear interpolation 117  
 Binary constant, initialization 959  
 Binomial coefficients 206ff., 1087f.  
     recurrences for 209  
 Binomial probability function 208  
     cumulative 222f.  
     deviates from 281, 285f., 1155  
 Binormal distribution 631, 690  
 Biorthogonality 77  
 Bisection 111, 359, 1045f.  
     compared to minimum bracketing 390ff.  
     minimum finding with derivatives 399  
     root finding 343, 346f., 352f., 390, 469, 1184f.  
 BISYNCH 890  
 Bit 18  
     manipulation functions *see* Bitwise logical functions  
     reversal in fast Fourier transform (FFT) 499f., 525  
 bit\_size() intrinsic function 951  
 Bitwise logical functions 2/xiii, 17, 287, 890f., 951  
 Block-by-block method 788  
 Block of statements 7  
 Bode's rule 126  
 Boltzmann probability distribution 437  
 Boltzmann's constant 437  
 Bootstrap method 686f.  
 Bordering method for Toeplitz matrix 85f.  
 Borwein and Borwein method for  $\pi$  906, 1357  
 Boundary 155f., 425f., 745  
 Boundary conditions  
     for differential equations 701f.  
     initial value problems 702  
     in multigrid method 868f.  
     partial differential equations 508, 819ff., 848ff.  
     for spheroidal harmonics 764  
     two-point boundary value problems 702, 745ff., 1314ff.  
 Boundary value problems *see* Differential equations; Elliptic partial differential equations; Two-point boundary value problems  
 Box-Muller algorithm for normal deviate 279f., 1152  
 Bracketing  
     of function minimum 343, 390ff., 402, 1201f.  
     of roots 341, 343ff., 353f., 362, 364, 369, 390, 1183f.  
 Branch cut, for hypergeometric function 203  
 Branching 9  
 Break iteration 14  
 Brenner, N.M. 500, 517

- Brent's method  
 minimization 389, 395ff., 660f., 1204ff., 1286  
 minimization, using derivative 389, 399, 1205  
 root finding 341, 349, 660f., 1188f., 1286
- Broadcast (parallel capability) 965ff.
- Broyden-Fletcher-Goldfarb-Shanno algorithm 390, 418ff., 1215
- Broyden's method 373, 382f., 386, 1199f.  
 singular Jacobian 386
- btest() intrinsic function 951
- Bubble sort 321, 1168
- Bugs 4  
 in compilers 1/xvii  
 how to report 1/iv, 2/iv
- Bulirsch-Stoer  
 algorithm for rational function interpolation 105f., 1043  
 method (differential equations) 202, 263, 702f., 706, 716, 718ff., 726, 740, 1138, 1303ff.  
 method (differential equations), stepsize control 719, 726  
 for second order equations 726, 1307
- Burg's LP algorithm 561, 1256
- Byte 18
- C** (programming language) 13, 2/viii  
 and case construct 1010  
 Numerical Recipes in 1, 2/x, 2/xvii
- C++ 1/xiv, 2/viii, 2/xvi, 7f.  
 class templates 1083, 1106
- Calendar algorithms 1f., 13ff., 1010ff.
- Calibration 653
- Capital letters in programs 3, 937
- Cards, sorting a hand of 321
- Carlson's elliptic integrals 255f., 1128ff.
- case construct 2/xiv, 1010  
 trapping errors 1036
- Cash-Karp parameters 710, 1299f.
- Cauchy probability distribution *see* Lorentzian probability distribution
- Cauchy problem for partial differential equations 818f.
- Cayley's representation of  $\exp(-iHt)$  844
- CCITT (Comité Consultatif International Télégraphique et Téléphonique) 889f., 901
- CCITT polynomial 889f.
- ceiling() intrinsic function 947
- Center of mass 295ff.
- Central limit theorem 652f.
- Central tendency, measures of 604ff., 1269
- Change of variable  
 in integration 137ff., 788, 1056ff.  
 in Monte Carlo integration 298  
 in probability distribution 279
- Character functions 952
- Character variables, in Fortran 90 1183
- Characteristic polynomial  
 digital filter 554  
 eigensystems 449, 469  
 linear prediction 559  
 matrix with a specified 368, 1193  
 of recurrence relation 175
- Characteristics of partial differential equations 818
- Chebyshev acceleration in successive over-relaxation (SOR) 859f., 1332
- Chebyshev approximation 84, 124, 183, 184ff., 1076ff.  
 Clenshaw-Curtis quadrature 190  
 Clenshaw's recurrence formula 187, 1076  
 coefficients for 185f., 1076  
 contrasted with Padé approximation 195  
 derivative of approximated function 183, 189, 1077f.  
 economization of series 192f., 195, 1080  
 for error function 214, 1095  
 even function 188  
 and fast cosine transform 513  
 gamma functions 236, 1118  
 integral of approximated function 189, 1078  
 odd function 188  
 polynomial fits derived from 191, 1078  
 rational function 197ff., 1081f.  
 Remes exchange algorithm for filter 553
- Chebyshev polynomials 184ff., 1076ff.  
 continuous orthonormality 184  
 discrete orthonormality 185  
 explicit formulas for 184  
 formula for  $x^k$  in terms of 193, 1080
- Check digit 894, 1345f.
- Checksum 881, 888  
 cyclic redundancy (CRC) 888ff., 1344f.
- Cherry, sundae without a 809
- Chi-by-eye 651
- Chi-square fitting *see* Fitting; Least squares fitting
- Chi-square probability function 209ff., 215, 615, 654, 798, 1272  
 as boundary of confidence region 688f.  
 related to incomplete gamma function 215
- Chi-square test 614f.  
 for binned data 614f., 1272  
 chi-by-eye 651  
 and confidence limit estimation 688f.  
 for contingency table 623ff., 1275  
 degrees of freedom 615f.  
 for inverse problems 797  
 least squares fitting 653ff., 1285  
 nonlinear models 675ff., 1292  
 rule of thumb 655  
 for straight line fitting 655ff., 1285  
 for straight line fitting, errors in both coordinates 660, 1286ff.  
 for two binned data sets 616, 1272  
 unequal size samples 617
- Chip rate 290
- Chirp signal 556
- Cholesky decomposition 89f., 423, 455, 1038  
 backsubstitution 90, 1039  
 operation count 90  
 pivoting 90  
 solution of normal equations 668
- Circulant 585
- Class, data type 7
- Clenshaw-Curtis quadrature 124, 190, 512f.

- Clenshaw's recurrence formula 176f., 191, 1078  
 for Chebyshev polynomials 187, 1076  
 stability 176f.
- Clocking errors 891
- CM computers (Thinking Machines Inc.) 964
- CM Fortran 2/xv
- cn function 261, 1137f.
- Coarse-grid correction 864f.
- Coarse-to-fine operator 864, 1337
- Coding  
 arithmetic 902ff., 1349ff.  
 checksums 888, 1344  
 decoding a Huffman-encoded message 900, 1349  
 Huffman 896f., 1346ff.  
 run-length 901  
 variable length code 896, 1346ff.  
 Ziv-Lempel 896  
*see also* Arithmetic coding; Huffman coding
- Coefficients  
 binomial 208, 1087f.  
 for Gaussian quadrature 140ff., 1059ff.  
 for Gaussian quadrature, nonclassical weight function 151ff., 788f., 1064  
 for quadrature formulas 125ff., 789, 1328
- Cohen, Malcolm 2/xiv
- Column degeneracy 22
- Column operations on matrix 29, 31f.
- Column totals 624
- Combinatorial minimization *see* Annealing
- Comité Consultatif International Télégraphique et Téléphonique (CCITT) 889f., 901
- Common block  
 obsolescent 2/xif.  
 superseded by internal subprogram 957, 1067  
 superseded by module 940, 953, 1298, 1320, 1322, 1324, 1330
- Communication costs, in parallel processing 969, 981, 1250
- Communication theory, use in adaptive integration 721
- Communications protocol 888
- Comparison function for rejection method 281
- Compilers 964, 1364  
 CM Fortran 968  
 DEC (Digital Equipment Corp.) 2/viii  
 IBM (International Business Machines) 2/viii  
 Microsoft Fortran PowerStation 2/viii  
 NAG (Numerical Algorithms Group) 2/viii, 2/xiv  
 for parallel supercomputers 2/viii
- Complementary error function 1094f.  
*see* Error function
- Complete elliptic integral *see* Elliptic integrals
- Complex arithmetic 171f.  
 avoidance of in path integration 203  
 cubic equations 179f.  
 for linear equations 41  
 quadratic equations 178
- Complex error function 252
- Complex plane  
 fractal structure for Newton's rule 360f.  
 path integration for function evaluation 201ff., 263, 1138  
 poles in 105, 160, 202f., 206, 554, 566, 718f.
- Complex systems of linear equations 41f.
- Compression of data 596f.
- Concordant pair for Kendall's tau 637, 1281
- Condition number 53, 78
- Confidence level 687, 691ff.
- Confidence limits  
 bootstrap method 687f.  
 and chi-square 688f.  
 confidence region, confidence interval 687  
 on estimated model parameters 684ff.  
 by Monte Carlo simulation 684ff.  
 from singular value decomposition (SVD) 693f.
- Confluent hypergeometric function 204, 239
- Conformable arrays 942f., 1094
- Conjugate directions 408f., 414ff., 1210
- Conjugate gradient method  
 biconjugate 77, 1034  
 compared to variable metric method 418  
 elliptic partial differential equations 824  
 for minimization 390, 413ff., 804, 815, 1210, 1214  
 minimum residual method 78  
 preconditioner 78f., 1037  
 for sparse system 77f., 599, 1034  
 and wavelets 599
- Conservative differential equations 726, 1307
- Constrained linear inversion method 799f.
- Constrained linear optimization *see* Linear programming
- Constrained optimization 387
- Constraints, deterministic 804ff.
- Constraints, linear 423
- CONTAINS statement 954, 957, 1067, 1134, 1202
- Contingency coefficient C 625, 1275
- Contingency table 622ff., 638, 1275f.  
 statistics based on chi-square 623ff., 1275  
 statistics based on entropy 626ff., 1275f.
- Continued fraction 163ff.  
 Bessel functions 234  
 convergence criterion 165  
 equivalence transformation 166  
 evaluation 163ff.  
 evaluation along with normalization condition 240  
 even and odd parts 166, 211, 216  
 even part 249, 251  
 exponential integral 216  
 Fresnel integral 248f.  
 incomplete beta function 219f., 1099f.  
 incomplete gamma function 211, 1092f.  
 Lentz's method 165, 212  
 modified Lentz's method 165  
 Pincherle's theorem 175  
 ratio of Bessel functions 239  
 rational function approximation 164, 211, 219f.  
 recurrence for evaluating 164f.

- and recurrence relation 175
- sine and cosine integrals 250f.
- Steed's method 164f.
- tangent function 164
- typography for 163
- Continuous variable (statistics) 623
- Control structures 7ff., 2/xiv
  - bad 15
  - named 959, 1219, 1305
- Convergence
  - accelerated, for series 160ff., 1070
  - of algorithm for pi 906
  - criteria for 347, 392, 404, 483, 488, 679, 759
  - eigenvalues accelerated by shifting 470f.
  - golden ratio 349, 399
  - of golden section search 392f.
  - of Levenberg-Marquardt method 679
  - linear 346, 393
  - of QL method 470f.
  - quadratic 49, 351, 356, 409f., 419, 906
  - rate 346f., 353, 356
  - recurrence relation 175
  - of Ridders' method 351
  - series vs. continued fraction 163f.
  - and spectral radius 856ff., 862
- Conversion intrinsic functions 946f.
- Convex sets, use in inverse problems 804
- Convolution
  - denoted by asterisk 492
  - finite impulse response (FIR) 531
  - of functions 492, 503f.
  - of large data sets 536f.
  - for multiple precision arithmetic 909, 1354
  - multiplication as 909, 1354
  - necessity for optimal filtering 535
  - overlap-add method 537
  - overlap-save method 536f.
  - and polynomial interpolation 113
  - relation to wavelet transform 585
  - theorem 492, 531ff., 546
  - theorem, discrete 531ff.
  - treatment of end effects 533
  - use of FFT 523, 531ff., 1253
  - wraparound problem 533
- Cooley-Tukey FFT algorithm 503, 1250
  - parallel version 1239f.
- Co-processor, floating point 886
- Copyright rules 1/xx, 2/xix
- Cornwell-Evans algorithm 816
- Corporate promotion ladder 328
- Corrected two-pass algorithm 607, 1269
- Correction, in multigrid method 863
- Correlation coefficient (linear) 630ff., 1276
- Correlation function 492
  - autocorrelation 492, 539, 558
  - and Fourier transforms 492
  - theorem 492, 538
  - treatment of end effects 538f.
  - using FFT 538f., 1254
  - Wiener-Khinchin theorem 492, 566f.
- Correlation, statistical 603f., 622
  - Kendall's tau 634, 637ff., 1279
  - linear correlation coefficient 630ff., 658, 1276
  - linear related to least square fitting 630, 658
  - nonparametric or rank statistical 633ff., 1277
  - among parameters in a fit 657, 667, 670
  - in random number generators 268
  - Spearman rank-order coefficient 634f., 1277
  - sum squared difference of ranks 634, 1277
- Cosine function, recurrence 172
- Cosine integral 248, 250ff., 1125f.
  - continued fraction 250
  - routine for 251f., 1125
  - series 250
- Cosine transform *see* Fast Fourier transform (FFT); Fourier transform
- Coulomb wave function 204, 234
- count() intrinsic function 948
- Courant condition 829, 832ff., 836
  - multidimensional 846
- Courant-Friedrichs-Lewy stability criterion *see* Courant condition
- Covariance
  - a priori 700
  - in general linear least squares 667, 671, 1288ff.
  - matrix, by Cholesky decomposition 91, 667
  - matrix, of errors 796, 808
  - matrix, is inverse of Hessian matrix 679
  - matrix, when it is meaningful 690ff.
  - in nonlinear models 679, 681, 1292
  - relation to chi-square 690ff.
  - from singular value decomposition (SVD) 693f.
  - in straight line fitting 657
- cpu\_time() intrinsic function (Fortran 95) 961
- CR method *see* Cyclic reduction (CR)
- Cramer's V 625, 1275
- Crank-Nicolson method 840, 844, 846
- Cray computers 964
- CRC (cyclic redundancy check) 888ff., 1344f.
- CRC-12 890
- CRC-16 polynomial 890
- CRC-CCITT 890
- Creativity, essay on 9
- Critical (Nyquist) sampling 494, 543
- Cross (denotes matrix outer product) 66
- Crosstabulation analysis 623
  - see also* Contingency table
- Crout's algorithm 36ff., 45, 1017
- cshift() intrinsic function 950
  - communication bottleneck 969
- Cubic equations 178ff., 360
- Cubic spline interpolation 107ff., 1044f.
  - see also* Spline
- cumprod() utility function 974, 988, 997, 1072, 1086
- cumsum() utility function 974, 989, 997, 1280, 1305
- Cumulant, of a polynomial 977, 999, 1071f., 1192

- Cumulative binomial distribution 222f.  
 Cumulative Poisson function 214  
     related to incomplete gamma function 214  
 Curvature matrix *see* Hessian matrix  
 cycle statement 959, 1219  
 Cycle, in multigrid method 865  
 Cyclic Jacobi method 459, 1225  
 Cyclic reduction (CR) 848f., 852ff.  
     linear recurrences 974  
     tridiagonal systems 976, 1018  
 Cyclic redundancy check (CRC) 888ff., 1344f.  
 Cyclic tridiagonal systems 67, 1030
- D.C.** (direct current) 492  
 Danielson-Lanczos lemma 498f., 525, 1235ff.  
 DAP Fortran 2/xi  
 Data  
     assigning keys to 889  
     continuous vs. binned 614  
     entropy 626ff., 896, 1275  
     essay on 603  
     fitting 650ff., 1285ff.  
     fraudulent 655  
     glitches in 653  
     iid (independent and identically distributed) 686  
     modeling 650ff., 1285ff.  
     serial port 892  
     smoothing 604, 644ff., 1283f.  
     statistical tests 603ff., 1269ff.  
     unevenly or irregularly sampled 569, 574, 648f., 1258ff.  
     use of CRCs in manipulating 889  
     windowing 545ff., 1254  
     *see also* Statistical tests  
 Data compression 596f., 881  
     arithmetic coding 902ff., 1349ff.  
     cosine transform 513  
     Huffman coding 896f., 902, 1346ff.  
     linear predictive coding (LPC) 563ff.  
     lossless 896  
 Data Encryption Standard (DES) 290ff., 1144, 1147f., 1156ff.  
 Data hiding 956ff., 1209, 1293, 1296  
 Data parallelism 941, 964ff., 985  
 DATA statement 959  
     for binary, octal, hexadecimal constants 959  
     repeat count feature 959  
     superseded by initialization expression 943, 959, 1127  
 Data type 18, 936  
     accuracy parameters 1362f.  
     character 1183  
     derived 2/xiii, 937, 1030, 1336, 1346  
     derived, for array of arrays 956, 1336  
     derived, initialization 2/xv  
     derived, for Numerical Recipes 1361  
     derived, storage allocation 955  
     DP (double precision) 1361f.  
     DPC (double precision complex) 1361  
     I1B (1 byte integer) 1361  
     I2B (2 byte integer) 1361  
     I4B (4 byte integer) 1361  
     intrinsic 937  
     LGT (default logical type) 1361  
     nrtype.f90 1361f.  
     passing complex as real 1140  
     SP (single precision) 1361f.  
     SPC (single precision complex) 1361  
     user-defined 1346  
 DAUB4 584ff., 588, 590f., 594, 1264f.  
 DAUB6 586  
 DAUB12 598  
 DAUB20 590f., 1265  
 Daubechies wavelet coefficients 584ff., 588, 590f., 594, 598, 1264ff.  
 Davidon-Fletcher-Powell algorithm 390, 418ff., 1215  
 Dawson's integral 252ff., 600, 1127f.  
     approximation for 252f.  
     routine for 253f., 1127  
 dble() intrinsic function (deprecated) 947  
 deallocate statement 938f., 953f., 1197, 1266, 1293  
 Deallocation, of allocatable array 938, 953f., 1197, 1266, 1293  
 Debugging 8  
 DEC (Digital Equipment Corp.) 1/xxiii, 2/xix, 886  
     Alpha AXP 2/viii  
     Fortran 90 compiler 2/viii  
     quadruple precision option 1362  
     VAX 4  
 Decomposition *see* Cholesky decomposition; LU decomposition; QR decomposition; Singular value decomposition (SVD)  
 Deconvolution 535, 540, 1253  
     *see also* Convolution; Fast Fourier transform (FFT); Fourier transform  
 Defect, in multigrid method 863  
 Deferred approach to the limit *see* Richardson's deferred approach to the limit  
 Deflation  
     of matrix 471  
     of polynomials 362ff., 370f., 977  
 Degeneracy of linear algebraic equations 22, 53, 57, 670  
 Degenerate kernel 785  
 Degenerate minimization principle 795  
 Degrees of freedom 615f., 654, 691  
 Dekker, T.J. 353  
 Demonstration programs 3, 936  
 Deprecated features  
     common block 2/xif., 940, 953, 957, 1067, 1298, 1320, 1322, 1324, 1330  
     dble() intrinsic function 947  
     EQUIVALENCE statement 2/xif., 1161, 1286  
     statement function 1057, 1256  
 Derivatives  
     computation via Chebyshev approximation 183, 189, 1077f.  
     computation via Savitzky-Golay filters 183, 645  
     matrix of first partial *see* Jacobian determinant  
     matrix of second partial *see* Hessian matrix

- numerical computation 180ff., 379, 645, 732, 750, 771, 1075, 1197, 1309  
of polynomial 167, 978, 1071f.  
use in optimization 388f., 399, 1205ff.
- Derived data type *see* Data type, derived
- DES *see* Data Encryption Standard
- Descending transformation, elliptic integrals 256
- Descent direction 376, 382, 419
- Descriptive statistics 603ff., 1269ff.  
*see also* Statistical tests
- Design matrix 645, 665, 795, 801, 1082
- Determinant 25, 41
- Deviate, random *see* Random deviate
- DFP algorithm *see* Davidon-Fletcher-Powell algorithm
- diagadd() utility function 985, 989, 1004
- diagmult() utility function 985, 989, 1004, 1294
- Diagonal dominance 43, 679, 780, 856
- Difference equations, finite *see* Finite difference equations (FDEs)
- Difference operator 161
- Differential equations 701ff., 1297ff.  
accuracy vs. stability 704, 729  
Adams-Bashforth-Moulton schemes 741  
adaptive stepsize control 703, 708ff., 719, 726, 731, 737, 742f., 1298ff., 1303ff., 1308f., 1311ff.  
algebraically difficult sets 763  
backward Euler's method 729  
Bader-Deuffhard method for stiff 730, 735, 1310f.  
boundary conditions 701f., 745ff., 749, 751f., 771, 1314ff.  
Bulirsch-Stoer method 202, 263, 702, 706, 716, 718ff., 740, 1138, 1303  
Bulirsch-Stoer method for conservative equations 726, 1307  
comparison of methods 702f., 739f., 743  
conservative 726, 1307  
danger of too small stepsize 714  
eigenvalue problem 748, 764ff., 770ff., 1319ff.  
embedded Runge-Kutta method 709f., 731, 1298, 1308  
equivalence of multistep and multivalued methods 743  
Euler's method 702, 704, 728f.  
forward Euler's method 728  
free boundary problem 748, 776  
high-order implicit methods 730ff., 1308ff.  
implicit differencing 729, 740, 1308  
initial value problems 702  
internal boundary conditions 775ff.  
internal singular points 775ff.  
interpolation on right-hand sides 111  
Kaps-Rentrop method for stiff 730, 1308  
local extrapolation 709  
modified midpoint method 716f., 719, 1302f.  
multistep methods 740ff.  
multivalued methods 740  
order of method 704f., 719
- path integration for function evaluation 201ff., 263, 1138
- predictor-corrector methods 702, 730, 740ff.
- reduction to first-order sets 701, 745
- relaxation method 746f., 753ff., 1316ff.
- relaxation method, example of 764ff., 1319ff.
- r.h.s. independent of  $x$  729f.
- Rosenbrock methods for stiff 730, 1308f.
- Runge-Kutta method 702, 704ff., 708ff., 731, 740, 1297f., 1308
- Runge-Kutta method, high-order 705, 1297
- Runge-Kutta-Fehlberg method 709ff., 1298
- scaling stepsize to required accuracy 709
- second order 726, 1307
- semi-implicit differencing 730
- semi-implicit Euler method 730, 735f.
- semi-implicit extrapolation method 730, 735f., 1311ff.
- semi-implicit midpoint rule 735f., 1310f.
- shooting method 746, 749ff., 1314ff.
- shooting method, example 770ff., 1321ff.
- similarity to Volterra integral equations 786
- singular points 718f., 751, 775ff., 1315f., 1323ff.
- step doubling 708f.
- stepsize control 703, 708ff., 719, 726, 731, 737, 742f., 1298, 1303ff., 1308f.  
stiff 703, 727ff., 1308ff.
- stiff methods compared 739
- Stoermer's rule 726, 1307
- see also* Partial differential equations; Two-point boundary value problems
- Diffusion equation 818, 838ff., 855
- Crank-Nicolson method 840, 844, 846
- Forward Time Centered Space (FTCS) 839ff., 855
- implicit differencing 840
- multidimensional 846
- Digamma function 216
- Digital filtering *see* Filter
- Dihedral group  $D_5$  894
- dim optional argument 948
- Dimensional expansion 965ff.
- Dimensions (units) 678
- Diminishing increment sort 322, 1168
- Dirac delta function 284, 780
- Direct method *see* Periodogram
- Direct methods for linear algebraic equations 26, 1014
- Direct product *see* Outer product of matrices
- Direction of largest decrease 410f.
- Direction numbers, Sobol's sequence 300
- Direction-set methods for minimization 389, 406f., 1210ff.
- Dirichlet boundary conditions 820, 840, 850, 856, 858
- Disclaimer of warranty 1/xx, 2/xvii
- Discordant pair for Kendall's tau 637, 1281
- Discrete convolution theorem 531ff.



- Discrete Fourier transform (DFT) 495ff., 1235ff.  
as approximate continuous transform 497  
*see also* Fast Fourier transform (FFT)
- Discrete optimization 436ff., 1219ff.
- Discriminant 178, 457
- Diskettes  
are ANSI standard 3  
how to order 1/xxi, 2/xvii
- Dispersion 831
- DISPO *see* Savitzky-Golay filters
- Dissipation, numerical 830
- Divergent series 161
- Divide and conquer algorithm 1226, 1229
- Division  
complex 171  
multiple precision 910f., 1356  
of polynomials 169, 362, 370, 1072
- dn function 261, 1137f.
- Do-list, implied 968, 971, 1127
- Do-loop 2/xiv
- Do-until iteration 14
- Do-while iteration 13
- Dogleg step methods 386
- Domain of integration 155f.
- Dominant solution of recurrence relation 174
- Dot (denotes matrix multiplication) 23
- dot\_product() intrinsic function 945, 949, 969, 1216
- Double exponential error distribution 696
- Double precision  
converting to 1362  
as refuge of scoundrels 882  
use in iterative improvement 47, 1022
- Double root 341
- Downhill simplex method *see* Simplex, method of Nelder and Mead
- DP, defined 937
- Driver programs 3
- Dual viewpoint, in multigrid method 875
- Duplication theorem, elliptic integrals 256
- DWT (discrete wavelet transform) *see* Wavelet transform
- Dynamical allocation of storage 2/xiii, 869, 938, 941f., 953ff., 1327, 1336  
garbage collection 956  
increasing 955, 1070, 1302
- E**ardley, D.M. 338
- EBCDIC 890
- Economization of power series 192f., 195, 1080
- Eigensystems 449ff., 1225ff.  
balancing matrix 476f., 1230f.  
bounds on eigenvalues 50  
calculation of few eigenvalues 454, 488  
canned routines 454f.  
characteristic polynomial 449, 469  
completeness 450  
defective 450, 476, 489  
deflation 471  
degenerate eigenvalues 449ff.  
elimination method 453, 478, 1231  
factorization method 453  
fast Givens reduction 463  
generalized eigenproblem 455  
Givens reduction 462f.  
Hermitian matrix 475  
Hessenberg matrix 453, 470, 476ff., 488, 1232  
Householder transformation 453, 462ff., 469, 473, 475, 478, 1227f., 1231  
ill-conditioned eigenvalues 477  
implicit shifts 472ff., 1228f.  
and integral equations 779, 785  
invariance under similarity transform 452  
inverse iteration 455, 469, 476, 487ff., 1230  
Jacobi transformation 453, 456ff., 462, 475, 489, 1225f.  
left eigenvalues 451  
list of tasks 454f.  
multiple eigenvalues 489  
nonlinear 455  
nonsymmetric matrix 476ff., 1230ff.  
operation count of balancing 476  
operation count of Givens reduction 463  
operation count of Householder reduction 467  
operation count of inverse iteration 488  
operation count of Jacobi method 460  
operation count of QL method 470, 473  
operation count of QR method for Hessenberg matrices 484  
operation count of reduction to Hessenberg form 479  
orthogonality 450  
parallel algorithms 1226, 1229  
polynomial roots and 368, 1193  
QL method 469ff., 475, 488f.  
QL method with implicit shifts 472ff., 1228f.  
QR method 52, 453, 456, 469ff., 1228  
QR method for Hessenberg matrices 480ff., 1232ff.  
real, symmetric matrix 150, 467, 785, 1225, 1228  
reduction to Hessenberg form 478f., 1231  
right eigenvalues 451  
shifting eigenvalues 449, 470f., 480  
special matrices 454  
termination criterion 484, 488  
tridiagonal matrix 453, 469ff., 488, 1228
- Eigenvalue and eigenvector, defined 449
- Eigenvalue problem for differential equations 748, 764ff., 770ff., 1319ff.
- Eigenvalues and polynomial root finding 368, 1193
- EISPACK 454, 475
- Electromagnetic potential 519
- ELEMENTAL attribute (Fortran 95) 961, 1084
- Elemental functions 2/xiii, 2/xv, 940, 942, 946f., 961, 986, 1015, 1083, 1097f.
- Elimination *see* Gaussian elimination
- Ellipse in confidence limit estimation 688
- Elliptic integrals 254ff., 906  
addition theorem 255

- Carlson's forms and algorithms 255f., 1128ff.
- Cauchy principal value 256f.  
duplication theorem 256
- Legendre 254ff., 260f., 1135ff.  
routines for 257ff., 1128ff.  
symmetric form 255  
Weierstrass 255
- Elliptic partial differential equations 818, 1332ff.  
alternating-direction implicit method (ADI) 861f., 906  
analyze/factorize/operate package 824  
biconjugate gradient method 824  
boundary conditions 820  
comparison of rapid methods 854  
conjugate gradient method 824  
cyclic reduction 848f., 852ff.  
Fourier analysis and cyclic reduction (FACR) 848ff., 854  
Gauss-Seidel method 855, 864ff., 876, 1338, 1341  
incomplete Cholesky conjugate gradient method (ICCG) 824  
Jacobi's method 855f., 864  
matrix methods 824  
multigrid method 824, 862ff., 1009, 1334ff.  
rapid (Fourier) method 824, 848ff.  
relaxation method 823, 854ff., 1332  
strongly implicit procedure 824  
successive over-relaxation (SOR) 857ff., 862, 866, 1332
- elsewhere construct 943
- Emacs, GNU 1/xvi
- Embedded Runge-Kutta method 709f., 731, 1298, 1308
- Encapsulation, in programs 7
- Encryption 290, 1156
- endo statement 12, 17
- Entropy 896  
of data 626ff., 811, 1275
- EOM (end of message) 902
- eoshift() intrinsic function 950  
communication bottleneck 969  
vector shift argument 1019f.  
vs. array section 1078
- epsilon() intrinsic function 951, 1189
- Equality constraints 423
- Equations  
cubic 178ff., 360  
normal (fitting) 645, 666ff., 800, 1288  
quadratic 20, 178  
*see also* Differential equations; Partial differential equations; Root finding
- Equivalence classes 337f., 1180
- EQUIVALENCE statement 2/xif., 1161, 1286
- Equivalence transformation 166
- Error  
checksums for preventing 891  
clocking 891  
double exponential distribution 696  
local truncation 875  
Lorentzian distribution 696f.  
in multigrid method 863  
nonnormal 653, 690, 694ff.  
relative truncation 875  
roundoff 180f., 881, 1362  
series, advantage of an even 132f., 717, 1362  
systematic vs. statistical 653, 1362  
truncation 20f., 180, 399, 709, 881, 1362  
varieties found by check digits 895  
varieties of, in PDEs 831ff.  
*see also* Roundoff error
- Error function 213f., 601, 1094f.  
approximation via sampling theorem 601  
Chebyshev approximation 214, 1095  
complex 252  
for Fisher's z-transformation 632, 1276  
relation to Dawson's integral 252, 1127  
relation to Fresnel integrals 248  
relation to incomplete gamma function 213  
routine for 214, 1094  
for significance of correlation 631, 1276  
for sum squared difference of ranks 635, 1277
- Error handling in programs 2/xii, 2/xvi, 3, 994f., 1036, 1370f.
- Estimation of parameters *see* Fitting; Maximum likelihood estimate
- Estimation of power spectrum 542ff., 565ff., 1254ff., 1258
- Euler equation (fluid flow) 831
- Euler-Maclaurin summation formula 132, 135
- Euler's constant 216ff., 250
- Euler's method for differential equations 702, 704, 728f.
- Euler's transformation 160f., 1070  
generalized form 162f.
- Evaluation of functions *see* Function
- Even and odd parts, of continued fraction 166, 211, 216
- Even parity 888
- Exception handling in programs *see* Error handling in programs
- exit statement 959, 1219
- Explicit differencing 827
- Exponent in floating point format 19, 882, 1343
- exponent intrinsic function 1107
- Exponential deviate 278, 1151f.
- Exponential integral 215ff., 1096f.  
asymptotic expansion 218  
continued fraction 216  
recurrence relation 172  
related to incomplete gamma function 215  
relation to cosine integral 250  
routine for  $Ei(x)$  218, 1097  
routine for  $E_n(x)$  217, 1096  
series 216
- Exponential probability distribution 570
- Extended midpoint rule 124f., 129f., 135, 1054f.
- Extended Simpson's rule 128, 788, 790
- Extended Simpson's three-eighths rule 789
- Extended trapezoidal rule 125, 127, 130ff., 135, 786, 1052ff., 1326  
roundoff error 132
- Extrapolation (so-called) 574, 1261

- Extrapolation 99ff.  
in Bulirsch-Stoer method 718ff., 726, 1305ff.  
differential equations 702  
by linear prediction 557ff., 1256f.  
local 709  
maximum entropy method as type of 567  
polynomial 724, 726, 740, 1305f.  
rational function 718ff., 726, 1306f.  
relation to interpolation 101  
for Romberg integration 134  
*see also* Interpolation
- Extremization *see* Minimization
- F**-distribution probability function 222
- F-test for differences of variances 611, 613, 1271
- FACR *see* Fourier analysis and cyclic reduction (FACR)
- Facsimile standard 901
- Factorial  
double (denoted “!!”) 247  
evaluation of 159, 1072, 1086  
relation to gamma function 206  
routine for 207f., 1086ff.
- False position 347ff., 1185f.
- Family tree 338
- FAS (full approximation storage algorithm) 874, 1339ff.
- Fast Fourier transform (FFT) 498ff., 881, 981, 1235f.  
alternative algorithms 503f.  
as approximation to continuous transform 497  
Bartlett window 547, 1254  
bit reversal 499f., 525  
and Clenshaw-Curtis quadrature 190  
column-parallel algorithm 981, 1237ff.  
communication bottleneck 969, 981, 1250  
convolution 503f., 523, 531ff., 909, 1253, 1354  
convolution of large data sets 536f.  
Cooley-Tukey algorithm 503, 1250  
Cooley-Tukey algorithm, parallel 1239f.  
correlation 538f., 1254  
cosine transform 190, 511ff., 851, 1245f.  
cosine transform, second form 513, 852, 1246  
Danielson-Lanczos lemma 498f., 525  
data sets not a power of 2 503  
data smoothing 645  
data windowing 545ff., 1254  
decimation-in-frequency algorithm 503  
decimation-in-time algorithm 503  
discrete autocorrelation 539, 1254  
discrete convolution theorem 531ff.  
discrete correlation theorem 538  
at double frequency 575  
effect of caching 982  
endpoint corrections 578f., 1261ff.  
external storage 525  
figures of merit for data windows 548  
filtering 551ff.  
FIR filter 553  
four-step framework 983, 1239  
Fourier integrals 577ff., 1261  
Fourier integrals, infinite range 583  
Hamming window 547  
Hann window 547  
history 498  
IIR filter 553ff.  
image processing 803, 805  
integrals using 124  
inverse of cosine transform 512ff.  
inverse of sine transform 511  
large data sets 525  
leakage 544  
memory-local algorithm 528  
multidimensional 515ff., 1236f., 1241, 1246, 1251  
for multiple precision arithmetic 906  
for multiple precision multiplication 909, 1354  
number-theoretic transforms 503f.  
operation count 498  
optimal (Wiener) filtering 539ff., 558  
order of storage in 501  
parallel algorithms 981ff., 1235ff.  
partial differential equations 824, 848ff.  
Parzen window 547  
periodicity of 497  
periodogram 543ff., 566  
power spectrum estimation 542ff., 1254ff.  
for quadrature 124  
of real data in 2D and 3D 519ff., 1248f.  
of real functions 504ff., 519ff., 1242f., 1248f.  
related algorithms 503f.  
row-parallel algorithm 981, 1235f.  
Sande-Tukey algorithm 503  
sine transform 508ff., 850, 1245  
Singleton’s algorithm 525  
six-step framework 983, 1240  
square window 546, 1254  
timing 982  
treatment of end effects in convolution 533  
treatment of end effects in correlation 538f.  
Tukey’s trick for frequency doubling 575  
use in smoothing data 645  
used for Lomb periodogram 574, 1259  
variance of power spectrum estimate 544f., 549  
virtual memory machine 528  
Welch window 547, 1254  
Winograd algorithms 503  
*see also* Discrete Fourier transform (DFT);  
Fourier transform; Spectral density
- Faure sequence 300
- Fax (facsimile) Group 3 standard 901
- Feasible vector 424
- FFT *see* Fast Fourier transform (FFT)
- Field, in data record 329
- Figure-of-merit function 650
- Filon’s method 583
- Filter 551ff.  
acausal 552  
bilinear transformation method 554  
causal 552, 644

- characteristic polynomial 554
- data smoothing 644f., 1283f.
- digital 551ff.
- DISPO 644
- by fast Fourier transform (FFT) 523, 551ff.
- finite impulse response (FIR) 531, 552
- homogeneous modes of 554
- infinite impulse response (IIR) 552ff., 566
- Kalman 700
- linear 552ff.
- low-pass for smoothing 644ff., 1283f.
- nonrecursive 552
- optimal (Wiener) 535, 539ff., 558, 644
- quadrature mirror 585, 593
- realizable 552, 554f.
- recursive 552ff., 566
- Remes exchange algorithm 553
- Savitzky-Golay 183, 644ff., 1283f.
- stability of 554f.
- in the time domain 551ff.
- Fine-to-coarse operator 864, 1337
- Finite difference equations (FDEs) 753, 763, 774
  - alternating-direction implicit method (ADI) 847, 861f.
  - art not science 829
  - Cayley's form for unitary operator 844
  - Courant condition 829, 832ff., 836
  - Courant condition (multidimensional) 846
  - Crank-Nicolson method 840, 844, 846
  - eigenmodes of 827f.
  - explicit vs. implicit schemes 827
  - forward Euler 826f.
  - Forward Time Centered Space (FTCS) 827ff., 839ff., 843, 855
  - implicit scheme 840
  - Lax method 828ff., 836
  - Lax method (multidimensional) 845f.
  - mesh drifting instability 834f.
  - numerical derivatives 181
  - partial differential equations 821ff.
  - in relaxation methods 753ff.
  - staggered leapfrog method 833f.
  - two-step Lax-Wendroff method 835ff.
  - upwind differencing 832f., 837
  - see also* Partial differential equations
- Finite element methods, partial differential equations 824
- Finite impulse response (FIR) 531
- Finkelstein, S. 1/xvi, 2/ix
- FIR (finite impulse response) filter 552
- Fisher's z-transformation 631f., 1276
- Fitting 650ff., 1285ff.
  - basis functions 665
  - by Chebyshev approximation 185f., 1076
  - chi-square 653ff., 1285ff.
  - confidence levels related to chi-square values 691ff.
  - confidence levels from singular value decomposition (SVD) 693f.
  - confidence limits on fitted parameters 684ff.
  - covariance matrix not always meaningful 651, 690
  - degeneracy of parameters 674
  - an exponential 674
  - freezing parameters in 668, 700
  - Gaussians, a sum of 682, 1294
  - general linear least squares 665ff., 1288, 1290f.
  - Kalman filter 700
  - K-S test, caution regarding 621f.
  - least squares 651ff., 1285
  - Legendre polynomials 674, 1291f.
  - Levenberg-Marquardt method 678ff., 816, 1292f.
  - linear regression 655ff., 1285ff.
  - maximum likelihood estimation 652f., 694ff.
  - Monte Carlo simulation 622, 654, 684ff.
  - multidimensional 675
  - nonlinear models 675ff., 1292f.
  - nonlinear models, advanced methods 683
  - nonlinear problems that are linear 674
  - nonnormal errors 656, 690, 694ff.
  - polynomial 83, 114, 191, 645, 665, 674, 1078, 1291
  - by rational Chebyshev approximation 197ff., 1081f.
  - robust methods 694ff., 1294
  - of sharp spectral features 566
  - standard (probable) errors on fitted parameters 657f., 661, 667, 671, 684ff., 1285f., 1288, 1290
  - straight line 655ff., 667f., 698, 1285ff., 1294ff.
  - straight line, errors in both coordinates 660ff., 1286ff.
  - see also* Error; Least squares fitting; Maximum likelihood estimate; Robust estimation
- Five-point difference star 867
- Fixed point format 18
- Fletcher-Powell algorithm *see* Davidon-Fletcher-Powell algorithm
- Fletcher-Reeves algorithm 390, 414ff., 1214
- Floating point co-processor 886
- Floating point format 18ff., 882, 1343
  - care in numerical derivatives 181
  - IEEE 276, 882, 1343
- floor() intrinsic function 948
- Flux-conservative initial value problems 825ff.
- FMG (full multigrid method) 863, 868, 1334ff.
- FOR iteration 9f., 12
- forall statement 2/xii, 2/xv, 960, 964, 986
  - access to associated index 968
  - skew array sections 985, 1007
- Formats of numbers 18ff., 882, 1343
- Fortran 9
  - arithmetic-if statement 2/xi
  - COMMON block 2/xif., 953, 957
  - deprecated features 2/xif., 947, 1057, 1161, 1256, 1286
  - dynamical allocation of storage 869, 1336
  - EQUIVALENCE statement 2/xif., 1161, 1286
  - evolution of 2/xivff.
  - exception handling 2/xii, 2/xvi
  - filenames 935
  - Fortran 2000 (planned) 2/xvi

- Fortran 95 2/xv, 945, 947, 1084, 1100, 1364
- HPF (High-Performance Fortran) 2/xvf.
- Numerical Recipes in 2/x, 2/xvii, 1
- obsolescent features 2/xif.
- side effects 960
- see also* Fortran 90
- Fortran D 2/xv
- Fortran 77 1/xix
  - bit manipulation functions 17
  - hexadecimal constants 17
- Fortran 8x 2/xi, 2/xiii
- Fortran 90 3
  - abstract data types 2/xiii, 1030
  - all() intrinsic function 945, 948
  - allocatable array 938, 941, 953ff., 1197, 1212, 1266, 1293, 1306, 1336
  - allocate statement 938f., 941, 953f., 1197, 1266, 1293, 1306, 1336
  - allocated() intrinsic function 938, 952ff., 1197, 1266, 1293
  - any() intrinsic function 945, 948
  - array allocation and deallocation 953
  - array of arrays 2/xii, 956, 1336
  - array constructor 2/xii, 968, 971, 1022, 1052, 1055, 1127
  - array constructor with implied do-list 968, 971
  - array extents 938, 949
  - array features 941ff., 953ff.
  - array intrinsic procedures 2/xiii, 948ff.
  - array of length 0 944
  - array of length 1 949
  - array manipulation functions 950
  - array parallel operations 964f.
  - array rank 938, 949
  - array reallocation 955
  - array section 2/xiif., 2/xiii, 939, 941ff., 960, 1078, 1284, 1286, 1333
  - array shape 938, 949
  - array size 938, 942
  - array transpose 981f.
  - array unary and binary functions 949
  - associated() intrinsic function 952f.
  - associated pointer 953f.
  - assumed-shape array 942
  - automatic array 938, 954, 1197, 1212, 1336
  - backwards-compatibility 935, 946
  - bit manipulation functions 2/xiii, 951
  - bit\_size() intrinsic function 951
  - broadcasts 965f.
  - btest() intrinsic function 951
  - case construct 1010, 1036
  - case insensitive 937
  - ceiling() intrinsic function 947
  - character functions 952
  - character variables 1183
  - cmplx function 1125
  - communication bottlenecks 969, 981, 1250
  - compatibility with Fortran 77 935, 946
  - compilers 2/viii, 2/xiv, 1364
  - compiling 936
  - conformable arrays 942f., 1094
  - CONTAINS statement 954, 957, 985, 1067, 1134, 1202
  - control structure 2/xiv, 959, 1219, 1305
  - conversion elemental functions 946
  - count() intrinsic function 948
  - cshift() intrinsic function 950, 969
  - cycle statement 959, 1219
  - data hiding 956ff., 1209
  - data parallelism 964
  - DATA statement 959
  - data types 937, 1336, 1346, 1361
  - deallocate statement 938f., 953f., 1197, 1266, 1293
  - deallocating array 938, 953f., 1197, 1266, 1293
  - defined types 956
  - deprecated features 947, 1057, 1161, 1256, 1286
  - derived types 937, 955
  - dimensional expansion 965ff.
  - do-loop 2/xiv
  - dot\_product() intrinsic function 945, 949, 969, 1216
  - dynamical allocation of storage 2/xiii, 938, 941f., 953ff., 1327, 1336
  - elemental functions 940, 942, 946f., 951, 1015, 1083, 1364
  - elsewhere construct 943
  - eoshift() intrinsic function 950, 969, 1019f., 1078
  - epsilon() intrinsic function 951, 1189
  - evolution 2/xivff., 959, 987f.
  - example 936
  - exit statement 959, 1219
  - exponent() intrinsic function 1107
  - floor() intrinsic function 948
  - Fortran tip icon 1009
  - garbage collection 956
  - gather-scatter operations 2/xiif., 969, 981, 984, 1002, 1032, 1034, 1250
  - generic interface 2/xiii, 1083
  - generic procedures 939, 1015, 1083, 1094, 1096, 1364
  - global variables 955, 957, 1210
  - history 2/xff.
  - huge() intrinsic function 951
  - iand() intrinsic function 951
  - ibclr() intrinsic function 951
  - ibits() intrinsic function 951
  - ibset() intrinsic function 951
  - ieor() intrinsic function 951
  - IMPLICIT NONE statement 2/xiv, 936
  - implied do-list 968, 971, 1127
  - index loss 967f.
  - initialization expression 943, 959, 1012, 1127
  - inquiry functions 948
  - integer model 1144, 1149, 1156
  - INTENT attribute 1072, 1092
  - interface 939, 942, 1067, 1084, 1384
  - internal subprogram 2/xii, 2/xiv, 957, 1057, 1067, 1202f., 1256, 1302
  - interprocessor communication 969, 981, 1250
  - intrinsic data types 937

- intrinsic procedures 939, 945ff., 987, 1016
- ior() intrinsic function 951
- ishft() intrinsic function 951
- ishftc() intrinsic function 951
- ISO (International Standards Organization) 2/xf., 2/xiiif.
- keyword argument 2/xiv, 947f., 1341
- kind() intrinsic function 951
- KIND parameter 937, 946, 1125, 1144, 1192, 1254, 1261, 1284, 1361
- language features 935ff.
- lbound() intrinsic function 949
- lexical comparison 952
- linear algebra 969f., 1000ff., 1018f., 1026, 1040, 1200, 1326
- linear recurrence 971, 988
- linking 936
- literal constant 937, 1361
- logo for tips 2/viii, 1009
- mask 948, 967f., 1006f., 1038, 1102, 1200, 1226, 1305, 1333f., 1368, 1378, 1382
- matmul() intrinsic function 945, 949, 969, 1026, 1040, 1050, 1076, 1200, 1216, 1290, 1326
- maxexponent() intrinsic function 1107
- maxloc() intrinsic function 949, 961, 992f., 1015
- maxval() intrinsic function 945, 948, 961, 1016, 1273
- memory leaks 953, 956, 1327
- memory management 938, 953ff.
- merge() intrinsic function 945, 950, 1010, 1094f., 1099f.
- Metcalf and Reid (M&R) 935
- minloc() intrinsic function 949, 961, 992f.
- minval() intrinsic function 948, 961
- missing language features 983ff., 987ff.
- modularization 956f.
- MODULE facility 2/xiii, 936f., 939f., 953f., 957, 1067, 1298, 1320, 1322, 1324, 1330, 1346
- MODULE subprograms 940
- modulo() intrinsic function 946, 1156
- named constant 940, 1012, 1361
- named control structure 959, 1219, 1305
- nearest() intrinsic function 952, 1146
- nested where construct forbidden 943
- not() intrinsic function 951
- nullify statement 953f., 1070, 1302
- numerical representation functions 951
- ONLY option 941, 957, 1067
- operator overloading 2/xiiif.
- operator, user-defined 2/xii
- optional argument 2/xiv, 947f., 1092, 1228, 1230, 1256, 1272, 1275, 1340
- outer product 969f.
- overloading 940, 1083, 1102
- pack() intrinsic function 945, 950, 964, 969, 991, 1170, 1176, 1178
- pack, for selective evaluation 1087
- parallel extensions 2/xv, 959ff., 964, 981, 984, 987, 1002, 1032
- parallel programming 963ff.
- PARAMETER attribute 1012
- pointer 2/xiiif., 938f., 941, 944f., 952ff., 1067, 1070, 1197, 1210, 1212, 1266, 1302, 1327, 1336
- pointer to function (missing) 1067
- portability 963
- present() intrinsic function 952
- PRIVATE attribute 957, 1067
- product() intrinsic function 948
- programming conventions 937
- PUBLIC attribute 957, 1067
- quick start 936
- radix() intrinsic function 1231
- random\_number() intrinsic function 1141, 1143
- random\_seed() intrinsic function 1141
- real() intrinsic function 947, 1125
- RECURSIVE keyword 958, 1065, 1067
- recursive procedure 2/xiv, 958, 1065, 1067, 1166
- reduction functions 948
- reshape() intrinsic function 950, 969, 1247
- RESULT keyword 958, 1073
- SAVE attribute 953f., 958f., 1052, 1070, 1266, 1293
- scale() intrinsic function 1107
- scatter-with-combine (missing function) 984
- scope 956ff.
- scoping units 939
- select case statement 2/xiv, 1010, 1036
- shape() intrinsic function 938, 949
- size() intrinsic function 938, 942, 945, 948
- skew sections 985
- sparse matrix representation 1030
- specification statement 2/xiv
- spread() intrinsic function 945, 950, 966ff., 969, 1000, 1094, 1290f.
- statement functions deprecated 1057
- stride (of an array) 944
- structure constructor 2/xii
- subscript triplet 944
- sum() intrinsic function 945, 948, 966
- tiny() intrinsic function 952
- transformational functions 948
- transpose() intrinsic function 950, 960, 969, 981, 1247
- tricks 1009, 1072, 1146, 1274, 1278, 1280
- truncation elemental functions 946
- type checking 1140
- ubound() intrinsic function 949
- undefined pointer 953
- unpack() intrinsic function 950, 964, 969
- USE statement 936, 939f., 954, 957, 1067, 1384
- utility functions 987ff.
- vector subscripts 2/xiiif., 969, 981, 984, 1002, 1032, 1034, 1250
- visibility 956ff., 1209, 1293, 1296
- WG5 technical committee 2/xi, 2/xiii, 2/xvf.
- where construct 943, 985, 1060, 1291
- X3J3 Committee 2/viii, 2/xf., 2/xv, 947, 959, 964, 968, 990
- zero-length array 944

- see also* Intrinsic procedures  
*see also* Fortran
- Fortran 95 947, 959ff.  
 allocatable variables 961  
 blocks 960  
`cpu_time()` intrinsic function 961  
 elemental functions 2/xiii, 2/xv, 940, 961, 986, 1015, 1083f., 1097f.  
 forall statement 2/xii, 2/xv, 960, 964, 968, 986, 1007  
 initialization of derived data type 2/xv  
 initialization of pointer 2/xv, 961  
 minor changes from Fortran 90 961  
 modified intrinsic functions 961  
 nested where construct 2/xv, 960, 1100  
 pointer association status 961  
 pointers 961  
 PURE attribute 2/xv, 960f., 964, 986  
 SAVE attribute 961  
 side effects 960  
 and skew array section 945, 985  
*see also* Fortran
- Fortran 2000 2/xvi
- Forward deflation 363
- Forward difference operator 161
- Forward Euler differencing 826f.
- Forward Time Centered Space *see* FTCS
- Four-step framework, for FFT 983, 1239
- Fourier analysis and cyclic reduction (FACR) 848f., 854
- Fourier integrals  
 attenuation factors 583, 1261  
 endpoint corrections 578f., 1261  
 tail integration by parts 583  
 use of fast Fourier transform (FFT) 577ff., 1261ff.
- Fourier transform 99, 490ff., 1235ff.  
 aliasing 495, 569  
 approximation of Dawson's integral 253  
 autocorrelation 492  
 basis functions compared 508f.  
 contrasted with wavelet transform 584, 594  
 convolution 492, 503f., 531ff., 909, 1253, 1354  
 correlation 492, 538f., 1254  
 cosine transform 190, 511ff., 851, 1245f.  
 cosine transform, second form 513, 852, 1246  
 critical sampling 494, 543, 545  
 definition 490  
 discrete Fourier transform (DFT) 184, 495ff.  
 Gaussian function 600  
 image processing 803, 805  
 infinite range 583  
 inverse of discrete Fourier transform 497  
 method for partial differential equations 848ff.  
 missing data 569  
 missing data, fast algorithm 574f., 1259  
 Nyquist frequency 494ff., 520, 543, 545, 569, 571  
 optimal (Wiener) filtering 539ff., 558  
 Parseval's theorem 492, 498, 544  
 power spectral density (PSD) 492f.  
 power spectrum estimation by FFT 542ff., 1254ff.  
 power spectrum estimation by maximum entropy method 565ff., 1258  
 properties of 491f.  
 sampling theorem 495, 543, 545, 600  
 scalings of 491  
 significance of a peak in 570  
 sine transform 508ff., 850, 1245  
 symmetries of 491  
 uneven sampling, fast algorithm 574f., 1259  
 unevenly sampled data 569ff., 574, 1258  
 and wavelets 592f.  
 Wiener-Khinchin theorem 492, 558, 566f.  
*see also* Fast Fourier transform (FFT); Spectral density
- Fractal region 360f.
- Fractional step methods 847f.
- Fredholm alternative 780
- Fredholm equations 779f.  
 eigenvalue problems 780, 785  
 error estimate in solution 784  
 first kind 779  
 Fredholm alternative 780  
 homogeneous, second kind 785, 1325  
 homogeneous vs. inhomogeneous 779f.  
 ill-conditioned 780  
 infinite range 789  
 inverse problems 780, 795ff.  
 kernel 779f.  
 nonlinear 781  
 Nystrom method 782ff., 789, 1325  
 product Nystrom method 789, 1328ff.  
 second kind 779f., 782ff., 1325, 1331  
 with singularities 788, 1328ff.  
 with singularities, worked example 792, 1328ff.  
 subtraction of singularity 789  
 symmetric kernel 785  
*see also* Inverse problems
- Frequency domain 490
- Frequency spectrum *see* Fast Fourier transform (FFT)
- Frequentist, contrasted with Bayesian 810
- Fresnel integrals 248ff.  
 asymptotic form 249  
 continued fraction 248f.  
 routine for 249f., 1123  
 series 248
- Friday the Thirteenth 14f., 1011f.
- FTCS (forward time centered space) 827ff., 839ff., 843  
 stability of 827ff., 839ff., 855
- Full approximation storage (FAS) algorithm 874, 1339ff.
- Full moon 14f., 936, 1011f.
- Full multigrid method (FMG) 863, 868, 1334ff.
- Full Newton methods, nonlinear least squares 683
- Full pivoting 29, 1014
- Full weighting 867
- Function  
 Airy 204, 243f., 1121

- approximation 99ff., 184ff., 1043, 1076ff.  
 associated Legendre polynomial 246ff.,  
 764, 1122f., 1319  
 autocorrelation of 492  
 bandwidth limited 495  
 Bessel 172, 204, 223ff., 234, 1101ff.,  
 1115ff.  
 beta 209, 1089  
 binomial coefficients 208f., 1087f.  
 branch cuts of 202f.  
 chi-square probability 215, 798  
 complex 202  
 confluent hypergeometric 204, 239  
 convolution of 492  
 correlation of 492  
 cosine integral 250f., 1123f.  
 Coulomb wave 204, 234  
 cumulative binomial probability 222f.  
 cumulative Poisson 209ff.  
 Dawson's integral 252ff., 600, 1127f.  
 digamma 216  
 elliptic integrals 254ff., 906, 1128ff.  
 error 213f., 248, 252, 601, 631, 635,  
 1094f., 1127, 1276f.  
 evaluation 159ff., 1070ff.  
 evaluation by path integration 201ff., 263,  
 1138  
 exponential integral 172, 215ff., 250,  
 1096f.  
 F-distribution probability 222  
 Fresnel integral 248ff., 1123  
 gamma 206, 1085  
 hypergeometric 202f., 263ff., 1138ff.  
 incomplete beta 219ff., 610, 1098ff., 1269  
 incomplete gamma 209ff., 615, 654, 657f.,  
 1089ff., 1272, 1285  
 inverse hyperbolic 178, 255  
 inverse trigonometric 255  
 Jacobian elliptic 261, 1137f.  
 Kolmogorov-Smirnov probability 618f.,  
 640, 1274, 1281  
 Legendre polynomial 172, 246, 674, 1122,  
 1291  
 logarithm 255  
 modified Bessel 229ff., 1109ff.  
 modified Bessel, fractional order 239ff.,  
 1118ff.  
 overloading 1083  
 parallel evaluation 986, 1009, 1084, 1087,  
 1090, 1102, 1128, 1134  
 path integration to evaluate 201ff.  
 pathological 99f., 343  
 Poisson cumulant 214  
 representations of 490  
 routine for plotting a 342, 1182  
 sine and cosine integrals 248, 250ff.,  
 1125f.  
 sn, dn, cn 261, 1137f.  
 spherical harmonics 246ff., 1122  
 spheroidal harmonic 764ff., 770ff., 1319ff.,  
 1323ff.  
 Student's probability 221f.  
 variable number of arguments 1022  
 Weber 204
- Functional iteration, for implicit equations  
 740f.  
 FWHM (full width at half maximum) 548f.
- G**amma deviate 282f., 1153f.  
 Gamma function 206ff., 1085  
     incomplete *see* Incomplete gamma func-  
     tion  
 Garbage collection 956  
 Gather-scatter operations 2/xiif., 984, 1002,  
 1032, 1034  
     communication bottleneck 969, 981, 1250  
     many-to-one 984, 1002, 1032, 1034  
 Gauss-Chebyshev integration 141, 144, 512f.  
 Gauss-Hermite integration 144, 789  
     abscissas and weights 147, 1062  
     normalization 147  
 Gauss-Jacobi integration 144  
     abscissas and weights 148, 1063  
 Gauss-Jordan elimination 27ff., 33, 64, 1014f.  
     operation count 34, 39  
     solution of normal equations 667, 1288  
     storage requirements 30  
 Gauss-Kronrod quadrature 154  
 Gauss-Laguerre integration 144, 789, 1060  
 Gauss-Legendre integration 145f., 1059  
     *see also* Gaussian integration  
 Gauss-Lobatto quadrature 154, 190, 512  
 Gauss-Radau quadrature 154  
 Gauss-Seidel method (relaxation) 855, 857,  
 864ff., 1338  
     nonlinear 876, 1341  
 Gauss transformation 256  
 Gaussian (normal) distribution 267, 652, 798  
     central limit theorem 652f.  
     deviates from 279f., 571, 1152  
     kurtosis of 606  
     multivariate 690  
     semi-invariants of 608  
     tails compared to Poisson 653  
     two-dimensional (binormal) 631  
     variance of skewness of 606  
 Gaussian elimination 33f., 51, 55, 1014f.  
     fill-in 45, 64  
     integral equations 786, 1326  
     operation count 34  
     outer product variant 1017  
     in reduction to Hessenberg form 478,  
     1231  
     relaxation solution of boundary value prob-  
     lems 753ff., 777, 1316  
 Gaussian function  
     Hardy's theorem on Fourier transforms  
     600  
     *see also* Gaussian (normal) distribution  
 Gaussian integration 127, 140ff., 789, 1059ff.  
     calculation of abscissas and weights 142ff.,  
     1009, 1059ff.  
     error estimate in solution 784  
     extensions of 153f.  
     Golub-Welsch algorithm for weights and  
     abscissas 150, 1064  
     for integral equations 781, 783, 1325  
     from known recurrence relation 150, 1064



- nonclassical weight function 151ff., 788f., 1064f., 1328f.  
 and orthogonal polynomials 142, 1009, 1061  
 parallel calculation of formulas 1009, 1061  
 preassigned nodes 153f.  
 weight function  $\log x$  153  
 weight functions 140ff., 788f., 1059ff., 1328f.
- Gear's method (stiff ODEs) 730  
 Geiger counter 266  
 Generalized eigenvalue problems 455  
 Generalized minimum residual method (GMRES) 78  
 Generic interface *see* Interface, generic  
 Generic procedures 939, 1083, 1094, 1096, 1364  
   elemental 940, 942, 946f., 1015, 1083  
 Geometric progression 972, 996f., 1365, 1372ff.  
`geop()` utility function 972, 974, 989, 996, 1127  
 Geophysics, use of Backus-Gilbert method 809  
 Gerchberg-Saxton algorithm 805  
`get_diag()` utility function 985, 989, 1005, 1226  
 Gilbert and Sullivan 714  
 Givens reduction 462f., 473  
   fast 463  
   operation count 463  
 Glassman, A.J. 180  
 Global optimization 387f., 436f., 650, 1219ff.  
   continuous variables 443f., 1222  
 Global variables 940, 953f., 1210  
   allocatable array method 954, 1197, 1212, 1266, 1287, 1298  
   communicated via internal subprogram 954, 957f., 1067, 1226  
   danger of 957, 1209, 1293, 1296  
   pointer method 954, 1197, 1212, 1266, 1287, 1302  
 Globally convergent  
   minimization 418ff., 1215  
   root finding 373, 376ff., 382, 749f., 752, 1196, 1314f.  
 GMRES (generalized minimum residual method) 78  
 GNU Emacs 1/xvi  
 Godunov's method 837  
 Golden mean (golden ratio) 21, 349, 392f., 399  
 Golden section search 341, 389ff., 395, 1202ff.  
 Golub-Welsch algorithm, for Gaussian quadrature 150, 1064  
 Goodness-of-fit 650, 654, 657f., 662, 690, 1285  
 GOTO statements, danger of 9, 959  
 Gram-Schmidt  
   biorthogonalization 415f.  
   orthogonalization 94, 450f., 1039  
   SVD as alternative to 58  
 Graphics, function plotting 342, 1182f.  
 Gravitational potential 519  
 Gray code 300, 881, 886ff., 1344  
 Greenbaum, A. 79  
 Gregorian calendar 13, 16, 1011, 1013  
 Grid square 116f.  
 Group, dihedral 894, 1345  
 Guard digits 882, 1343
- H**alf weighting 867, 1337  
 Halton's quasi-random sequence 300  
 Hamming window 547  
 Hamming's motto 341  
 Hann window 547  
 Harmonic analysis *see* Fourier transform  
 Hashing 293, 1144, 1148, 1156  
   for random number seeds 1147f.  
 HDLC checksum 890  
 Heap (data structure) 327f., 336, 897, 1179  
 Heapsort 320, 327f., 336, 1171f., 1179  
 Helmholtz equation 852  
 Hermite polynomials 144, 147  
   approximation of roots 1062  
 Hermitian matrix 450ff., 475  
 Hertz (unit of frequency) 490  
 Hessenberg matrix 94, 453, 470, 476ff., 488, 1231  
   *see also* Matrix  
 Hessian matrix 382, 408, 415f., 419f., 676ff., 803, 815  
   is inverse of covariance matrix 667, 679  
   second derivatives in 676  
 Hexadecimal constants 17f., 276, 293  
   initialization 959  
 Hierarchically band diagonal matrix 598  
 Hierarchy of program structure 6ff.  
 High-order not same as high-accuracy 100f., 124, 389, 399, 705, 709, 741  
 High-pass filter 551  
 High-Performance Fortran (HPF) 2/xvf., 964, 981, 984  
   scatter-with-add 1032  
 Hilbert matrix 83  
 Home page, Numerical Recipes 1/xx, 2/xvii  
 Homogeneous linear equations 53  
 Hook step methods 386  
 Hotelling's method for matrix inverse 49, 598  
 Householder transformation 52, 453, 462ff., 469, 473, 475, 478, 481ff., 1227f.  
   operation count 467  
   in QR decomposition 92, 1039  
 HPF *see* High-Performance Fortran  
 Huffman coding 564, 881, 896f., 902, 1346ff.  
`huge()` intrinsic function 951  
 Hyperbolic functions, explicit formulas for  
   inverse 178  
 Hyperbolic partial differential equations 818  
   advective equation 826  
   flux-conservative initial value problems 825ff.  
 Hypergeometric function 202f., 263ff.  
   routine for 264f., 1138  
 Hypothesis, null 603
- I**2B, defined 937

- I4B, defined 937
- iand() intrinsic function 951
- ibclr() intrinsic function 951
- ibits() intrinsic function 951
- IBM 1/xxiii, 2/xix
  - bad random number generator 268
  - Fortran 90 compiler 2/viii
  - PC 4, 276, 293, 886
  - PC-RT 4
  - radix base for floating point arithmetic 476
  - RS6000 2/viii, 4
- IBM checksum 894
- ibset() intrinsic function 951
- ICCG (incomplete Cholesky conjugate gradient method) 824
- ICF (intrinsic correlation function) model 817
- Identity (unit) matrix 25
- IEEE floating point format 276, 882f., 1343
- ieor() intrinsic function 951
- if statement, arithmetic 2/xi
- if structure 12f.
- ifirstloc() utility function 989, 993, 1041, 1346
- IIR (infinite impulse response) filter 552ff., 566
- Ill-conditioned integral equations 780
- Image processing 519, 803
  - cosine transform 513
  - fast Fourier transform (FFT) 519, 523, 803
  - as an inverse problem 803
  - maximum entropy method (MEM) 809ff.
  - from modulus of Fourier transform 805
  - wavelet transform 596f., 1267f.
- imaxloc() utility function 989, 993, 1017
- iminloc() utility function 989, 993, 1046, 1076
- Implicit
  - function theorem 340
  - pivoting 30, 1014
  - shifts in QL method 472ff.
- Implicit differencing 827
  - for diffusion equation 840
  - for stiff equations 729, 740, 1308
- IMPLICIT NONE statement 2/xiv, 936
- Implied do-list 968, 971, 1127
- Importance sampling, in Monte Carlo 306f.
- Improper integrals 135ff., 1055
- Impulse response function 531, 540, 552
- IMSL 1/xxiii, 2/xx, 26, 64, 205, 364, 369, 454
- In-place selection 335, 1178f.
- Included file, superseded by module 940
- Incomplete beta function 219ff., 1098ff.
  - for F-test 613, 1271
  - routine for 220f., 1097
  - for Student's t 610, 613, 1269
- Incomplete Cholesky conjugate gradient method (ICCG) 824
- Incomplete gamma function 209ff., 1089ff.
  - for chi-square 615, 654, 657f., 1272, 1285
  - deviates from 282f., 1153
  - in mode estimation 610
  - routine for 211f., 1089
- Increment of linear congruential generator 268
- Indentation of blocks 9
- Index 934ff., 1446ff.
  - this entry 1464
- Index loss 967f., 1038
- Index table 320, 329f., 1173ff., 1176
- Inequality constraints 423
- Inheritance 8
- Initial value problems 702, 818f.
  - see also* Differential equations; Partial differential equations
- Initialization of derived data type 2/xv
- Initialization expression 943, 959, 1012, 1127
- Injection operator 864, 1337
- Instability *see* Stability
- Integer model, in Fortran 90 1144, 1149, 1156
- Integer programming 436
- Integral equations 779ff.
  - adaptive stepsize control 788
  - block-by-block method 788
  - correspondence with linear algebraic equations 779ff.
  - degenerate kernel 785
  - eigenvalue problems 780, 785
  - error estimate in solution 784
  - Fredholm 779f., 782ff., 1325, 1331
  - Fredholm alternative 780
  - homogeneous, second kind 785, 1325
  - ill-conditioned 780
  - infinite range 789
  - inverse problems 780, 795ff.
  - kernel 779
  - nonlinear 781, 787
  - Nystrom method 782ff., 789, 1325
  - product Nystrom method 789, 1328ff.
  - with singularities 788ff., 1328ff.
  - with singularities, worked example 792, 1328ff.
  - subtraction of singularity 789
  - symmetric kernel 785
  - unstable quadrature 787f.
  - Volterra 780f., 786f., 1326f.
  - wavelets 782
  - see also* Inverse problems
- Integral operator, wavelet approximation of 597, 782
- Integration of functions 123ff., 1052ff.
  - cosine integrals 250, 1125
  - Fourier integrals 577ff., 1261
  - Fourier integrals, infinite range 583
  - Fresnel integrals 248, 1123
  - Gauss-Hermite 147f., 1062
  - Gauss-Jacobi 148, 1063
  - Gauss-Laguerre 146, 1060
  - Gauss-Legendre 145, 1059
  - integrals that are elliptic integrals 254
  - path integration 201ff.
  - sine integrals 250, 1125
  - see also* Quadrature
- Integro-differential equations 782
- INTENT attribute 1072, 1092
- Interface (Fortran 90) 939, 942, 1067

- for communication between program parts  
957, 1209, 1293, 1296
- explicit 939, 942, 1067, 1384
- generic 2/xiii, 940, 1015, 1083, 1094,  
1096
- implicit 939
- for Numerical Recipes 1384ff.
- Interface block 939, 1084, 1384
- Interface, in programs 2, 8
- Intermediate value theorem 343
- Internal subprogram (Fortran 90) 2/xiv, 954,  
957, 1067, 1202f., 1226
  - nesting of 2/xii
  - resembles C macro 1302
  - supersedes statement function 1057, 1256
- International Standards Organization (ISO)  
2/xf., 2/xiii
- Internet, availability of code over 1/xx, 2/xvii
- Interpolation 99ff.
  - Aitken's algorithm 102
  - avoid 2-stage method 100
  - avoid in Fourier analysis 569
  - bicubic 118f., 1049f.
  - bilinear 117
  - caution on high-order 100
  - coefficients of polynomial 100, 113ff.,  
191, 575, 1047f., 1078
  - for computing Fourier integrals 578
  - error estimates for 100
  - of functions with poles 104ff., 1043f.
  - inverse quadratic 353, 395ff., 1204
  - multidimensional 101f., 116ff., 1049ff.
  - in multigrid method 866, 1337
  - Neville's algorithm 102f., 182, 1043
  - Nystrom 783, 1326
  - offset arrays 104, 113
  - operation count for 100
  - operator 864, 1337
  - order of 100
  - and ordinary differential equations 101
  - oscillations of polynomial 100, 116, 389,  
399
  - parabolic, for minimum finding 395, 1204
  - polynomial 99, 102ff., 182, 1043
  - rational Chebyshev approximation 197ff.,  
1081
  - rational function 99, 104ff., 194ff., 225,  
718ff., 726, 1043f., 1080, 1306
  - reverse (extrapolation) 574, 1261
  - spline 100, 107ff., 120f., 1044f., 1050f.
  - trigonometric 99
  - see also* Fitting
- Interprocessor communication 969, 981
- Interval variable (statistics) 623
- Intrinsic correlation function (ICF) model 817
- Intrinsic data types 937
- Intrinsic procedures
  - array inquiry 938, 942, 948ff.
  - array manipulation 950
  - array reduction 948
  - array unary and binary functions 949
  - backwards-compatibility 946
  - bit manipulation 2/xiii, 951
  - character 952
  - cmplx 1254
  - conversion elemental 946
  - elemental 940, 942, 946f., 951, 1083,  
1364
  - generic 939, 1083f., 1364
  - lexical comparison 952
  - numeric inquiry 2/xiv, 1107, 1231, 1343
  - numerical 946, 951f.
  - numerical representation 951
  - pack used for sorting 1171
  - random-number 1143
  - real 1254
  - top 10 945
  - truncation 946f.
  - see also* Fortran 90
- Inverse hyperbolic function 178, 255
- Inverse iteration *see* Eigensystems
- Inverse problems 779, 795ff.
  - Backus-Gilbert method 806ff.
  - Bayesian approach 799, 810f., 816f.
  - central idea 799
  - constrained linear inversion method 799ff.
  - data inversion 807
  - deterministic constraints 804ff.
  - in geophysics 809
  - Gerchberg-Saxton algorithm 805
  - incomplete Fourier coefficients 813
  - and integral equations 780
  - linear regularization 799ff.
  - maximum entropy method (MEM) 810,  
815f.
  - MEM demystified 814
  - Phillips-Twomey method 799ff.
  - principal solution 797
  - regularization 796ff.
  - regularizing operator 798
  - stabilizing functional 798
  - Tikhonov-Miller regularization 799ff.
  - trade-off curve 795
  - trade-off curve, Backus-Gilbert method  
809
  - two-dimensional regularization 803
  - use of conjugate gradient minimization  
804, 815
  - use of convex sets 804
  - use of Fourier transform 803, 805
  - Van Cittert's method 804
- Inverse quadratic interpolation 353, 395ff.,  
1204
- Inverse response kernel, in Backus-Gilbert  
method 807
- Inverse trigonometric function 255
- ior() intrinsic function 951
- ISBN (International Standard Book Number)  
checksum 894
- ishft() intrinsic function 951
- ishftc() intrinsic function 951
- ISO (International Standards Organization)  
2/xf., 2/xiii
- Iterated integrals 155
- Iteration 9f.
  - functional 740f.
  - to improve solution of linear algebraic  
equations 47ff., 195, 1022
  - for linear algebraic equations 26

- required for two-point boundary value problems 745
  - in root finding 340f.
- Iteration matrix 856
- ITPACK 71
- Iverson, John 2/xi
  
- J**
  - Jacobi matrix, for Gaussian quadrature 150, 1064
  - Jacobi polynomials, approximation of roots 1064
  - Jacobi transformation (or rotation) 94, 453, 456ff., 462, 475, 489, 1041, 1225
  - Jacobian determinant 279, 774
  - Jacobian elliptic functions 261, 1137f.
  - Jacobian matrix 374, 376, 379, 382, 731, 1197f., 1309
    - singular in Newton's rule 386
  - Jacobi's method (relaxation) 855ff., 864
  - Jenkins-Traub method 369
  - Julian Day 1, 13, 16, 936, 1010ff.
  - Jump transposition errors 895
  
- K-S** test *see* Kolmogorov-Smirnov test
- Kalman filter 700
- Kanji 2/xii
- Kaps-Rentrop method 730, 1308
- Kendall's tau 634, 637ff., 1279
- Kennedy, Ken 2/xv
- Kepler's equation 1061
- Kermit checksum 889
- Kernel 779
  - averaging, in Backus-Gilbert method 807
  - degenerate 785
  - finite rank 785
  - inverse response 807
  - separable 785
  - singular 788f., 1328
  - symmetric 785
- Keys used in sorting 329, 889
- Keyword argument 2/xiv, 947f., 1341
- kind() intrinsic function 951
- KIND parameter 946, 1261, 1284
  - and cmplx() intrinsic function 1125, 1192, 1254
  - default 937
  - for Numerical Recipes 1361
  - for random numbers 1144
  - and real() intrinsic function 1125
- Kolmogorov-Smirnov test 614, 617ff., 694, 1273f.
  - two-dimensional 640, 1281ff.
  - variants 620ff., 640, 1281
- Kuiper's statistic 621
- Kurtosis 606, 608, 1269
  
- L**-estimate 694
- Labels, statement 9
- Lag 492, 538, 553
- Lagged Fibonacci generator 1142, 1148ff.
- Lagrange multiplier 795
- Lagrange's formula for polynomial interpolation 84, 102f., 575, 578
- Laguerre polynomials, approximation of roots 1061
- Laguerre's method 341, 365f., 1191f.
- Lanczos lemma 498f.
- Lanczos method for gamma function 206, 1085
- Landen transformation 256
- LAPACK 26, 1230
- Laplace's equation 246, 818
  - see also* Poisson equation
- Las Vegas 625
- Latin square or hypercube 305f.
- Laurent series 566
- Lax method 828ff., 836, 845f.
  - multidimensional 845f.
- Lax-Wendroff method 835ff.
- lbound() intrinsic function 949
- Leakage in power spectrum estimation 544, 548
- Leakage width 548f.
- Leapfrog method 833f.
- Least squares filters *see* Savitzky-Golay filters
- Least squares fitting 645, 651ff., 655ff., 660ff., 665ff., 1285f., 1288f.
  - contrasted to general minimization problems 684ff.
  - degeneracies in 671f., 674
  - Fourier components 570
    - as M-estimate for normal errors 696
    - as maximum likelihood estimator 652
    - as method for smoothing data 645, 1283
  - Fourier components 1258
  - freezing parameters in 668, 700
  - general linear case 665ff., 1288, 1290f.
  - Levenberg-Marquardt method 678ff., 816, 1292f.
  - Lomb periodogram 570, 1258
  - multidimensional 675
  - nonlinear 386, 675ff., 816, 1292
  - nonlinear, advanced methods 683
  - normal equations 645, 666f., 800, 1288
  - normal equations often singular 670, 674
  - optimal (Wiener) filtering 540f.
  - QR method in 94, 668
  - for rational Chebyshev approximation 199f., 1081f.
  - relation to linear correlation 630, 658
  - Savitzky-Golay filter as 645, 1283
  - singular value decomposition (SVD) 25f., 51ff., 199f., 670ff., 1081, 1290
  - skewed by outliers 653
  - for spectral analysis 570, 1258
  - standard (probable) errors on fitted parameters 667, 671
  - weighted 652
  - see also* Fitting
- L'Ecuyer's long period random generator 271, 273
- Least squares fitting
  - standard (probable) errors on fitted parameters 1288, 1290
  - weighted 1285
- Left eigenvalues or eigenvectors 451
- Legal matters 1/xx, 2/xvii
- Legendre elliptic integral *see* Elliptic integrals

- Legendre polynomials 246, 1122  
 fitting data to 674, 1291f.  
 recurrence relation 172  
 shifted monic 151  
*see also* Associated Legendre polynomials;  
 Spherical harmonics
- Lehmer-Schur algorithm 369
- Lemarie's wavelet 593
- Lentz's method for continued fraction 165,  
 212
- Lepage, P. 309
- Leptokurtic distribution 606
- Levenberg-Marquardt algorithm 386, 678ff.,  
 816, 1292  
 advanced implementation 683
- Levinson's method 86, 1038
- Lewis, H.W. 275
- Lexical comparison functions 952
- LGT, defined 937
- License information 1/xx, 2/xviiif.
- Limbo 356
- Limit cycle, in Laguerre's method 365
- Line minimization *see* Minimization, along a  
 ray
- Line search *see* Minimization, along a ray
- Linear algebra, intrinsic functions for paral-  
 lelization 969f., 1026, 1040, 1200,  
 1326
- Linear algebraic equations 22ff., 1014  
 band diagonal 43ff., 1019  
 biconjugate gradient method 77, 1034ff.  
 Cholesky decomposition 89f., 423, 455,  
 668, 1038f.  
 complex 41  
 computing  $\mathbf{A}^{-1} \cdot \mathbf{B}$  40  
 conjugate gradient method 77ff., 599,  
 1034  
 cyclic tridiagonal 67, 1030  
 direct methods 26, 64, 1014, 1030  
 Fortran 90 vs. library routines 1016  
 Gauss-Jordan elimination 27ff., 1014  
 Gaussian elimination 33f., 1014f.  
 Hilbert matrix 83  
 Hotelling's method 49, 598  
 and integral equations 779ff., 783, 1325  
 iterative improvement 47ff., 195, 1022  
 iterative methods 26, 77ff., 1034  
 large sets of 23  
 least squares solution 53ff., 57f., 199f.,  
 671, 1081, 1290  
 LU decomposition 34ff., 195, 386, 732,  
 783, 786, 801, 1016, 1022, 1325f.  
 nonsingular 23  
 overdetermined 25f., 199, 670, 797  
 partitioned 70  
 QR decomposition 91f., 382, 386, 668,  
 1039f., 1199  
 row vs. column elimination 31f.  
 Schultz's method 49, 598  
 Sherman-Morrison formula 65ff., 83  
 singular 22, 53, 58, 199, 670  
 singular value decomposition (SVD) 51ff.,  
 199f., 670ff., 797, 1022, 1081, 1290  
 sparse 23, 43, 63ff., 732, 804, 1020f.,  
 1030  
 summary of tasks 25f.  
 Toeplitz 82, 85ff., 195, 1038  
 tridiagonal 26, 42f., 64, 109, 150, 453f.,  
 462ff., 469ff., 488, 839f., 853, 861f.,  
 1018f., 1227ff.  
 Vandermonde 82ff., 114, 1037, 1047  
 wavelet solution 597ff., 782  
 Woodbury formula 68ff., 83  
*see also* Eigensystems
- Linear congruential random number generator  
 267ff., 1142  
 choice of constants for 274ff.
- Linear constraints 423
- Linear convergence 346, 393
- Linear correlation (statistics) 630ff., 1276
- Linear dependency  
 constructing orthonormal basis 58, 94  
 of directions in  $N$ -dimensional space 409  
 in linear algebraic equations 22f.
- Linear equations *see* Differential equations; In-  
 tegral equations; Linear algebraic equa-  
 tions
- Linear inversion method, constrained 799ff.
- Linear prediction 557ff.  
 characteristic polynomial 559  
 coefficients 557ff., 1256  
 compared to maximum entropy method  
 558  
 compared with regularization 801  
 contrasted to polynomial extrapolation  
 560  
 related to optimal filtering 558  
 removal of bias in 563  
 stability 559f., 1257
- Linear predictive coding (LPC) 563ff.
- Linear programming 387, 423ff., 1216ff.  
 artificial variables 429  
 auxiliary objective function 430  
 basic variables 426  
 composite simplex algorithm 435  
 constraints 423  
 convergence criteria 432  
 degenerate feasible vector 429  
 dual problem 435  
 equality constraints 423  
 feasible basis vector 426  
 feasible vector 424  
 fundamental theorem 426  
 inequality constraints 423  
 left-hand variables 426  
 nonbasic variables 426  
 normal form 426  
 objective function 424  
 optimal feasible vector 424  
 pivot element 428f.  
 primal-dual algorithm 435  
 primal problem 435  
 reduction to normal form 429ff.  
 restricted normal form 426ff.  
 revised simplex method 435  
 right-hand variables 426  
 simplex method 402, 423ff., 431ff., 1216ff.  
 slack variables 429  
 tableau 427  
 vertex of simplex 426

- Linear recurrence *see* Recurrence relation  
 Linear regression 655ff., 660ff., 1285ff.  
     *see also* Fitting  
 Linear regularization 799ff.  
 LINPACK 26  
 Literal constant 937, 1361  
 Little-endian 293  
 Local extrapolation 709  
 Local extremum 387f., 437  
 Localization of roots *see* Bracketing  
 Logarithmic function 255  
 Lomb periodogram method of spectral analysis  
     569f., 1258f.  
     fast algorithm 574f., 1259  
 Loops 9f.  
 Lorentzian probability distribution 282, 696f.  
 Low-pass filter 551, 644f., 1283f.  
 Lower subscript 944  
 lower\_triangle() utility function 989, 1007,  
     1200  
 LP coefficients *see* Linear prediction  
 LPC (linear predictive coding) 563ff.  
 LU decomposition 34ff., 47f., 51, 55, 64, 97,  
     374, 667, 732, 1016, 1022  
     for  $A^{-1} \cdot B$  40  
     backsubstitution 39, 1017  
     band diagonal matrix 43ff., 1020  
     complex equations 41f.  
     Crout's algorithm 36ff., 45, 1017  
     for integral equations 783, 786, 1325f.  
     for inverse iteration of eigenvectors 488  
     for inverse problems 801  
     for matrix determinant 41  
     for matrix inverse 40, 1016  
     for nonlinear sets of equations 374, 386,  
         1196  
     operation count 36, 39  
     outer product Gaussian elimination 1017  
     for Padé approximant 195, 1080  
     pivoting 37f., 1017  
     repeated backsubstitution 40, 46  
     solution of linear algebraic equations 40,  
         1017  
     solution of normal equations 667  
     for Toeplitz matrix 87  
 Lucifer 290
- M**&R (Metcalf and Reid) 935  
 M-estimates 694ff.  
     how to compute 697f.  
     local 695ff.  
     *see also* Maximum likelihood estimate  
 Machine accuracy 19f., 881f., 1189, 1343  
 Macintosh, *see* Apple Macintosh  
 Maehly's procedure 364, 371  
 Magic  
     in MEM image restoration 814  
     in Padé approximation 195  
 Mantissa in floating point format 19, 882,  
     909, 1343  
 Marginals 624  
 Marquardt method (least squares fitting) 678ff.,  
     816, 1292f.  
 Marsaglia shift register 1142, 1148ff.  
 Marsaglia, G. 1142, 1149
- mask 1006f., 1102, 1200, 1226, 1305, 1333f.,  
     1368, 1378, 1382  
     optional argument 948  
     optional argument, facilitates parallelism  
         967f., 1038  
 Mass, center of 295ff.  
 MasterCard checksum 894  
 Mathematical Center (Amsterdam) 353  
 Mathematical intrinsic functions 946, 951f.  
 matmul() intrinsic function 945, 949, 969,  
     1026, 1040, 1050, 1076, 1200, 1216,  
     1290, 1326  
 Matrix 23ff.  
     add vector to diagonal 1004, 1234, 1366,  
         1381  
     approximation of 58f., 598f.  
     band diagonal 42ff., 64, 1019  
     band triangular 64  
     banded 26, 454  
     bidiagonal 52  
     block diagonal 64, 754  
     block triangular 64  
     block tridiagonal 64  
     bordered 64  
     characteristic polynomial 449, 469  
     Cholesky decomposition 89f., 423, 455,  
         668, 1038f.  
     column augmented 28, 1014  
     complex 41  
     condition number 53, 78  
     create unit matrix 1006, 1382  
     curvature 677  
     cyclic banded 64  
     cyclic tridiagonal 67, 1030  
     defective 450, 476, 489  
     of derivatives *see* Hessian matrix; Jacobian  
         determinant  
     design (fitting) 645, 665, 801, 1082  
     determinant of 25, 41  
     diagonal of sparse matrix 1033ff.  
     diagonalization 452ff., 1225ff.  
     elementary row and column operations  
         28f.  
     finite differencing of partial differential  
         equations 821ff.  
     get diagonal 985, 1005, 1226f., 1366,  
         1381f.  
     Hermitian 450, 454, 475  
     Hermitian conjugate 450  
     Hessenberg 94, 453, 470, 476ff., 488,  
         1231ff.  
     Hessian *see* Hessian matrix  
     hierarchically band diagonal 598  
     Hilbert 83  
     identity 25  
     ill-conditioned 53, 56, 114  
     indexed storage of 71f., 1030  
     and integral equations 779, 783, 1325  
     inverse 25, 27, 34, 40, 65ff., 70, 95ff.,  
         1014, 1016f.  
     inverse, approximate 49  
     inverse by Hotelling's method 49, 598  
     inverse by Schultz's method 49, 598  
     inverse multiplied by a matrix 40  
     iteration for inverse 49, 598

- Jacobi transformation 453, 456ff., 462, 1225f.
- Jacobian 731, 1309
- logical dimension 24
- lower triangular 34f., 89, 781, 1016
- lower triangular mask 1007, 1200, 1382
- multiplication denoted by dot 23
- multiplication, intrinsic function 949, 969, 1026, 1040, 1050, 1200, 1326
- norm 50
- normal 450ff.
- nullity 53
- nullspace 25, 53f., 449, 795
- orthogonal 91, 450, 463ff., 587
- orthogonal transformation 452, 463ff., 469, 1227
- orthonormal basis 58, 94
- outer product denoted by cross 66, 420
- partitioning for determinant 70
- partitioning for inverse 70
- pattern multiply of sparse 74
- physical dimension 24
- positive definite 26, 89f., 668, 1038
- QR decomposition 91f., 382, 386, 668, 1039, 1199
- range 53
- rank 53
- residual 49
- row and column indices 23
- row vs. column operations 31f.
- self-adjoint 450
- set diagonal elements 1005, 1200, 1366, 1382
- similarity transform 452ff., 456, 476, 478, 482
- singular 53f., 58, 449
- singular value decomposition 26, 51ff., 797
- sparse 23, 63ff., 71, 598, 732, 754, 804, 1030ff.
- special forms 26
- splitting in relaxation method 856f.
- spread 808
- square root of 423, 455
- symmetric 26, 89, 450, 454, 462ff., 668, 785, 1038, 1225, 1227
- threshold multiply of sparse 74, 1031
- Toeplitz 82, 85ff., 195, 1038
- transpose() intrinsic function 950
- transpose of sparse 73f., 1033
- triangular 453
- tridiagonal 26, 42f., 64, 109, 150, 453f., 462ff., 469ff., 488, 839f., 853, 861f., 1018f., 1227ff.
- tridiagonal with fringes 822
- unitary 450
- updating 94, 382, 386, 1041, 1199
- upper triangular 34f., 91, 1016
- upper triangular mask 1006, 1226, 1305, 1382
- Vandermonde 82ff., 114, 1037, 1047  
*see also* Eigensystems
- Matrix equations *see* Linear algebraic equations
- Matterhorn 606
- maxexponent() intrinsic function 1107
- Maximization *see* Minimization
- Maximum entropy method (MEM) 565ff., 1258
- algorithms for image restoration 815f.
- Bayesian 816f.
- Cornwell-Evans algorithm 816
- demystified 814
- historic vs. Bayesian 816f.
- image restoration 809ff.
- intrinsic correlation function (ICF) model 817
- for inverse problems 809ff.
- operation count 567
- see also* Linear prediction
- Maximum likelihood estimate (M-estimates) 690, 694ff.
- and Bayes' Theorem 811
- chi-square test 690
- defined 652
- how to compute 697f.
- mean absolute deviation 696, 698, 1294
- relation to least squares 652
- maxloc() intrinsic function 949, 992f., 1015
- modified in Fortran 95 961
- maxval() intrinsic function 945, 948, 961, 1016, 1273
- Maxwell's equations 825f.
- Mean(s)
- of distribution 604f., 608f., 1269
- statistical differences between two 609ff., 1269f.
- Mean absolute deviation of distribution 605, 696, 1294
- related to median 698
- Measurement errors 650
- Median 320
- calculating 333
- of distribution 605, 608f.
- as L-estimate 694
- role in robust straight line fitting 698
- by selection 698, 1294
- Median-of-three, in Quicksort 324
- MEM *see* Maximum entropy method (MEM)
- Memory leak 953, 956, 1071, 1327
- Memory management 938, 941f., 953ff., 1327, 1336
- merge construct 945, 950, 1099f.
- for conditional scalar expression 1010, 1094f.
- contrasted with where 1023
- parallelization 1011
- Merge-with-dummy-values idiom 1090
- Merit function 650
- in general linear least squares 665
- for inverse problems 797
- nonlinear models 675
- for straight line fitting 656, 698
- for straight line fitting, errors in both coordinates 660, 1286
- Mesh-drift instability 834f.
- Mesokurtic distribution 606
- Metcalf, Michael 2/viii  
*see also* M&R
- Method of regularization 799ff.

- Metropolis algorithm 437f., 1219
- Microsoft 1/xxii, 2/xix
- Microsoft Fortran PowerStation 2/viii
- Midpoint method *see* Modified midpoint method;  
Semi-implicit midpoint rule
- Mikado, or Town of Titipu 714
- Miller's algorithm 175, 228, 1106
- MIMD machines (Multiple Instruction Multiple  
Data) 964, 985, 1071, 1084
- Minimal solution of recurrence relation 174
- Minimax polynomial 186, 198, 1076
- Minimax rational function 198
- Minimization 387ff.  
along a ray 77, 376f., 389, 406ff., 412f.,  
415f., 418, 1195f., 1211, 1213  
annealing, method of simulated 387f.,  
436ff., 1219ff.  
bracketing of minimum 390ff., 402, 1201f.  
Brent's method 389, 395ff., 399, 660f.,  
1204ff., 1286  
Broyden-Fletcher-Goldfarb-Shanno algo-  
rithm 390, 418ff., 1215  
chi-square 653ff., 675ff., 1285, 1292  
choice of methods 388f.  
combinatorial 436f., 1219  
conjugate gradient method 390, 413ff.,  
804, 815, 1210, 1214  
convergence rate 393, 409  
Davidon-Fletcher-Powell algorithm 390,  
418ff., 1215  
degenerate 795  
direction-set methods 389, 406ff., 1210ff.  
downhill simplex method 389, 402ff., 444,  
697f., 1208, 1222ff.  
finding best-fit parameters 650  
Fletcher-Reeves algorithm 390, 414ff.,  
1214  
functional 795  
global 387f., 443f., 650, 1219, 1222  
globally convergent multidimensional 418,  
1215  
golden section search 390ff., 395, 1202ff.  
multidimensional 388f., 402ff., 1208ff.,  
1214  
in nonlinear model fitting 675f., 1292  
Polak-Ribiere algorithm 389, 414ff., 1214  
Powell's method 389, 402, 406ff., 1210ff.  
quasi-Newton methods 376, 390, 418ff.,  
1215  
and root finding 375  
scaling of variables 420  
by searching smaller subspaces 815  
steepest descent method 414, 804  
termination criterion 392, 404  
use in finding double roots 341  
use for sparse linear systems 77ff.  
using derivatives 389f., 399ff., 1205ff.  
variable metric methods 390, 418ff., 1215  
*see also* Linear programming
- Minimum residual method, for sparse system  
78
- minloc() intrinsic function 949, 992f.  
modified in Fortran 95 961
- MINPACK 683
- minval() intrinsic function 948, 961
- MIPS 886
- Missing data problem 569
- Mississippi River 438f., 447
- MMP (massively multiprocessor) machines  
965ff., 974, 981, 984, 1016ff., 1021,  
1045, 1226ff., 1250
- Mode of distribution 605, 609
- Modeling of data *see* Fitting
- Model-trust region 386, 683
- Modes, homogeneous, of recursive filters 554
- Modified Bessel functions *see* Bessel func-  
tions
- Modified Lentz's method, for continued frac-  
tions 165
- Modified midpoint method 716ff., 720, 1302f.
- Modified moments 152
- Modula-2 7
- Modular arithmetic, without overflow 269,  
271, 275
- Modular programming 2/xiii, 7f., 956ff.,  
1209, 1293, 1296, 1346
- MODULE facility 2/xiii, 936f., 939f., 957,  
1067, 1298, 1320, 1322, 1324, 1330,  
1346  
initializing random number generator 1144ff.  
in nr.f90 936, 941f., 1362, 1384ff.  
in nrtype.f90 936f., 1361f.  
in nrutil.f90 936, 1070, 1362, 1364ff.  
sparse matrix 1031  
undefined variables on exit 953, 1266
- Module subprogram 940
- modulo() intrinsic function 946, 1156
- Modulus of linear congruential generator 268
- Moments  
of distribution 604ff., 1269  
filter that preserves 645  
modified problem of 151f.  
problem of 83  
and quadrature formulas 791, 1328  
semi-invariants 608
- Monic polynomial 142f.
- Monotonicity constraint, in upwind differenc-  
ing 837
- Monte Carlo 155ff., 267  
adaptive 306ff., 1161ff.  
bootstrap method 686f.  
comparison of sampling methods 309  
exploration of binary tree 290  
importance sampling 306f.  
integration 124, 155ff., 295ff., 306ff.,  
1161  
integration, recursive 314ff., 1164ff.  
integration, using Sobol' sequence 304  
integration, VEGAS algorithm 309ff.,  
1161  
and Kolmogorov-Smirnov statistic 622,  
640  
partial differential equations 824  
quasi-random sequences in 299ff.  
quick and dirty 686f.  
recursive 306ff., 314ff., 1161, 1164ff.  
significance of Lomb periodogram 570  
simulation of data 654, 684ff., 690  
stratified sampling 308f., 314, 1164



- Moon, calculate phases of 1f., 14f., 936, 1010f.
- Mother functions 584
- Mother Nature 684, 686
- Moving average (MA) model 566
- Moving window averaging 644
- Mozart 9
- MS 1/xxii, 2/xix
- Muller's method 364, 372
- Multidimensional
- confidence levels of fitting 688f.
  - data, use of binning 623
  - Fourier transform 515ff., 1241, 1246, 1251
  - Fourier transform, real data 519ff., 1248f.
  - initial value problems 844ff.
  - integrals 124, 155ff., 295ff., 306ff., 1065ff., 1161ff.
  - interpolation 116ff., 1049ff.
  - Kolmogorov-Smirnov test 640, 1281
  - least squares fitting 675
  - minimization 402ff., 406ff., 413ff., 1208ff., 1214f., 1222ff.
  - Monte Carlo integration 295ff., 306ff., 1161ff.
  - normal (Gaussian) distribution 690
  - optimization 388f.
  - partial differential equations 844ff.
  - root finding 340ff., 358, 370, 372ff., 746, 749f., 752, 754, 1194ff., 1314ff.
  - search using quasi-random sequence 300
  - secant method 373, 382f., 1199f.
  - wavelet transform 595, 1267f.
- Multigrid method 824, 862ff., 1334ff.
- avoid SOR 866
  - boundary conditions 868f.
  - choice of operators 868
  - coarse-to-fine operator 864, 1337
  - coarse-grid correction 864f.
  - cycle 865
  - dual viewpoint 875
  - fine-to-coarse operator 864, 1337
  - full approximation storage (FAS) algorithm 874, 1339ff.
  - full multigrid method (FMG) 863, 868, 1334ff.
  - full weighting 867
  - Gauss-Seidel relaxation 865f., 1338
  - half weighting 867, 1337
  - importance of adjoint operator 867
  - injection operator 864, 1337
  - interpolation operator 864, 1337
  - line relaxation 866
  - local truncation error 875
  - Newton's rule 874, 876, 1339, 1341
  - nonlinear equations 874ff., 1339ff.
  - nonlinear Gauss-Seidel relaxation 876, 1341
  - odd-even ordering 866, 869, 1338
  - operation count 862
  - prolongation operator 864, 1337
  - recursive nature 865, 1009, 1336
  - relative truncation error 875
  - relaxation as smoothing operator 865
  - restriction operator 864, 1337
  - speeding up FMG algorithm 873
  - stopping criterion 875f.
  - straight injection 867
  - symbol of operator 866f.
  - use of Richardson extrapolation 869
  - V-cycle 865, 1336
  - W-cycle 865, 1336
  - zebra relaxation 866
- Multiple precision arithmetic 906ff., 1352ff.
- Multiple roots 341, 362
- Multiplication, complex 171
- Multiplication, multiple precision 907, 909, 1353f.
- Multiplier of linear congruential generator 268
- Multistep and multivalued methods (ODEs) 740ff.
- see also* Differential Equations; Predictor-corrector methods
- Multivariate normal distribution 690
- Murphy's Law 407
- Musical scores 5f.
- N**AG 1/xxiii, 2/xx, 26, 64, 205, 454
- Fortran 90 compiler 2/viii, 2/xiv
- Named constant 940
- initialization 1012
  - for Numerical Recipes 1361
- Named control structure 959, 1219, 1305
- National Science Foundation (U.S.) 1/xvii, 1/xix, 2/ix
- Natural cubic spline 109, 1044f.
- Navier-Stokes equation 830f.
- nearest() intrinsic function 952, 1146
- Needle, eye of (minimization) 403
- Negation, multiple precision 907, 1353f.
- Negentropy 811, 896
- Nelder-Mead minimization method 389, 402, 1208
- Nested iteration 868
- Neumann boundary conditions 820, 840, 851, 858
- Neutrino 640
- Neville's algorithm 102f., 105, 134, 182, 1043
- Newton-Cotes formulas 125ff., 140
- Newton-Raphson method *see* Newton's rule
- Newton's rule 143f., 180, 341, 355ff., 362, 364, 469, 1059, 1189
- with backtracking 376, 1196
  - caution on use of numerical derivatives 356ff.
  - fractal domain of convergence 360f.
  - globally convergent multidimensional 373, 376ff., 382, 749f., 752, 1196, 1199, 1314f.
  - for matrix inverse 49, 598
  - in multidimensions 370, 372ff., 749f., 752, 754, 1194ff., 1314ff.
  - in nonlinear multigrid 874, 876, 1339, 1341
  - nonlinear Volterra equations 787
  - for reciprocal of number 911, 1355
  - safe 359, 1190
  - scaling of variables 381

- singular Jacobian 386
  - solving stiff ODEs 740
  - for square root of number 912, 1356
  - Niederreiter sequence 300
  - NL2SOL 683
  - Noise
    - bursty 889
    - effect on maximum entropy method 567
    - equivalent bandwidth 548
    - fitting data which contains 647f., 650
    - model, for optimal filtering 541
  - Nominal variable (statistics) 623
  - Nonexpansive projection operator 805
  - Non-interfering directions *see* Conjugate directions
  - Nonlinear eigenvalue problems 455
  - Nonlinear elliptic equations, multigrid method 874ff., 1339ff.
  - Nonlinear equations, in MEM inverse problems 813
  - Nonlinear equations, roots of 340ff.
  - Nonlinear instability 831
  - Nonlinear integral equations 781, 787
  - Nonlinear programming 436
  - Nonnegativity constraints 423
  - Nonparametric statistics 633ff., 1277ff.
  - Nonpolynomial complete (NP-complete) 438
  - Norm, of matrix 50
  - Normal (Gaussian) distribution 267, 652, 682, 798, 1294
    - central limit theorem 652f.
    - deviates from 279f., 571, 1152
    - kurtosis of 607
    - multivariate 690
    - semi-invariants of 608
    - tails compared to Poisson 653
    - two-dimensional (binormal) 631
    - variance of skewness of 606
  - Normal equations (fitting) 26, 645, 666ff., 795, 800, 1288
    - often are singular 670
  - Normalization
    - of Bessel functions 175
    - of floating-point representation 19, 882, 1343
    - of functions 142, 765
    - of modified Bessel functions 232
  - not() intrinsic function 951
  - Notch filter 551, 555f.
  - NP-complete problem 438
  - nr.f90 (module file) 936, 1362, 1384ff.
  - nrerror() utility function 989, 995
  - nrtype.f90 (module file) 936f.
  - named constants 1361
  - nrutil.f90 (module file) 936, 1070, 1362, 1364ff.
  - table of contents 1364
  - Null hypothesis 603
  - nullify statement 953f., 1070, 1302
  - Nullity 53
  - Nullspace 25, 53f., 449, 795
  - Number-theoretic transforms 503f.
  - Numeric inquiry functions 2/xiv, 1107, 1231, 1343
  - Numerical derivatives 180ff., 645, 1075
  - Numerical integration *see* Quadrature
  - Numerical intrinsic functions 946, 951f.
  - Numerical Recipes
    - compatibility with First Edition 4
    - Example Book 3
    - Fortran 90 types 936f., 1361
    - how to get programs 1/xx, 2/xvii
    - how to report bugs 1/iv, 2/iv
    - interface blocks (Fortran 90) 937, 941f., 1084, 1384ff.
    - no warranty on 1/xx, 2/xvii
    - plan of two-volume edition 1/xiii
    - table of dependencies 921ff., 1434ff.
    - as trademark 1/xxiii, 2/xx
    - utility functions (Fortran 90) 936f., 945, 968, 970, 972ff., 977, 984, 987ff., 1015, 1071f., 1361ff.
  - Numerical Recipes Software 1/xv, 1/xxiiff., 2/xviiif.
  - address and fax number 1/iv, 1/xxii, 2/iv, 2/xix
  - Web home page 1/xx, 2/xvii
  - Nyquist frequency 494ff., 520, 543, 545, 569ff.
  - Nystrom method 782f., 789, 1325
    - product version 789, 1331
- O**
- Object extensibility 8
  - Objective function 424
  - Object-oriented programming 2/xvi, 2, 8
  - Oblateness parameter 764
  - Obsolete features *see* Fortran, Obsolescent features
  - Octal constant, initialization 959
  - Odd-even ordering
    - allows parallelization 1333
    - in Gauss-Seidel relaxation 866, 869, 1338
    - in successive over-relaxation (SOR) 859, 1332
  - Odd parity 888
  - OEM information 1/xxii
  - One-sided power spectral density 492
  - ONLY option, for USE statement 941, 957, 1067
  - Operation count
    - balancing 476
    - Bessel function evaluation 228
    - bisection method 346
    - Cholesky decomposition 90
    - coefficients of interpolating polynomial 114f.
    - complex multiplication 97
    - cubic spline interpolation 109
    - evaluating polynomial 168
    - fast Fourier transform (FFT) 498
    - Gauss-Jordan elimination 34, 39
    - Gaussian elimination 34
    - Givens reduction 463
    - Householder reduction 467
    - interpolation 100
    - inverse iteration 488
    - iterative improvement 48
    - Jacobi transformation 460
    - Kendall's tau 637

- linear congruential generator 268
  - LU decomposition 36, 39
  - matrix inversion 97
  - matrix multiplication 96
  - maximum entropy method 567
  - multidimensional minimization 413f.
  - multigrid method 862
  - multiplication 909
  - polynomial evaluation 97f., 168
  - QL method 470, 473
  - QR decomposition 92
  - QR method for Hessenberg matrices 484
  - reduction to Hessenberg form 479
  - selection by partitioning 333
  - sorting 320ff.
  - Spearman rank-order coefficient 638
  - Toeplitz matrix 83
  - Vandermonde matrix 83
  - Operator overloading 2/xiif., 7
  - Operator splitting 823, 847f., 861
  - Operator, user-defined 2/xii
  - Optimal feasible vector 424
  - Optimal (Wiener) filtering 535, 539ff., 558, 644
    - compared with regularization 801
  - Optimization *see* Minimization
  - Optimization of code 2/xiii
  - Optional argument 2/xiv, 947f., 1092, 1228, 1230, 1256, 1272, 1275, 1340
    - dim 948
    - mask 948, 968, 1038
    - testing for 952
  - Ordering Numerical Recipes 1/xxf., 2/xviiif.
  - Ordinal variable (statistics) 623
  - Ordinary differential equations *see* Differential equations
  - Orthogonal *see* Orthonormal functions; Orthonormal polynomials
  - Orthogonal transformation 452, 463ff., 469, 584, 1227
  - Orthonormal basis, constructing 58, 94, 1039
  - Orthonormal functions 142, 246
  - Orthonormal polynomials
    - Chebyshev 144, 184ff., 1076ff.
    - construct for arbitrary weight 151ff., 1064
    - in Gauss-Hermite integration 147, 1062
    - and Gaussian quadrature 142, 1009, 1061
    - Gaussian weights from recurrence 150, 1064
    - Hermite 144, 1062
    - Jacobi 144, 1063
    - Laguerre 144, 1060
    - Legendre 144, 1059
    - weight function  $\log x$  153
  - Orthonormality 51, 142, 463
  - Outer product Gaussian elimination 1017
  - Outer product of matrices (denoted by cross) 66, 420, 949, 969f., 989, 1000ff., 1017, 1026, 1040, 1076, 1200, 1216, 1275
  - outerand() utility function 989, 1002, 1015
  - outerdiff() utility function 989, 1001
  - outerdiv() utility function 989, 1001
  - outerprod() utility function 970, 989, 1000, 1017, 1026, 1040, 1076, 1200, 1216, 1275
  - outersum() utility function 989, 1001
  - Outgoing wave boundary conditions 820
  - Outlier 605, 653, 656, 694, 697
    - see also* Robust estimation
  - Overcorrection 857
  - Overflow 882, 1343
    - how to avoid in modulo multiplication 269
    - in complex arithmetic 171
  - Overlap-add and overlap-save methods 536f.
  - Overloading
    - operator 2/xiif.
    - procedures 940, 1015, 1083, 1094, 1096
  - Overrelaxation parameter 857, 1332
    - choice of 858
- P**ack() intrinsic function 945, 950, 964, 991, 1031
  - communication bottleneck 969
  - for index table 1176
  - for partition-exchange 1170
  - for selection 1178
  - for selective evaluation 1087
- Pack-unpack idiom 1087, 1134, 1153
- Padé approximant 194ff., 1080f.
- Padé approximation 105
- Parabolic interpolation 395, 1204
- Parabolic partial differential equations 818, 838ff.
- Parallel axis theorem 308
- Parallel programming 2/xv, 941, 958ff., 962ff., 965f., 968f., 987
  - array operations 964f.
  - array ranking 1278f.
  - band diagonal linear equations 1021
  - Bessel functions 1107ff.
  - broadcasts 965ff.
  - C and C++ 2/viii
  - communication costs 969, 981, 1250
  - counting do-loops 1015
  - cyclic reduction 974
  - deflation 977ff.
  - design matrix 1082
  - dimensional expansion 965ff.
  - eigensystems 1226, 1229f.
  - fast Fourier transform (FFT) 981, 1235ff., 1250
  - in Fortran 90 963ff.
  - Fortran 90 tricks 1009, 1274, 1278, 1280
  - function evaluation 986, 1009, 1084f., 1087, 1090, 1102, 1128, 1134
  - Gaussian quadrature 1009, 1061
  - geometric progressions 972
  - index loss 967f., 1038
  - index table 1176f.
  - interprocessor communication 981
  - Kendall's tau 1280
  - linear algebra 969f., 1000ff., 1018f., 1026, 1040, 1200, 1326
  - linear recurrence 973f., 1073ff.
  - logo 2/viii, 1009
  - masks 967f., 1006f., 1038, 1102, 1200, 1226, 1305, 1333f., 1368, 1378, 1382
  - merge statement 1010

- MIMD (multiple instruction, multiple data) 964, 985f., 1084
- MMP (massively multiprocessor) machines 965ff., 974, 984, 1016ff., 1226ff., 1250
- nrutil.f90 (module file) 1364ff.
- odd-even ordering 1333
- one-dimensional FFT 982f.
- parallel note icon 1009
- partial differential equations 1333
- in-place selection 1178f.
- polynomial coefficients from roots 980
- polynomial evaluation 972f., 977, 998
- random numbers 1009, 1141ff.
- recursive doubling 973f., 976f., 979, 988, 999, 1071ff.
- scatter-with-combine 984, 1002f., 1032f.
- second order recurrence 974f., 1074
- SIMD (Single Instruction Multiple Data) 964, 985f., 1009, 1084f.
- singular value decomposition (SVD) 1026
- sorting 1167ff., 1171, 1176f.
- special functions 1009
- SSP (small-scale parallel) machines 965ff., 984, 1010ff., 1016ff., 1059f., 1226ff., 1250
- subvector scaling 972, 974, 996, 1000
- successive over-relaxation (SOR) 1333
- supercomputers 2/viii, 962
- SVD algorithm 1026
- synthetic division 977ff., 999, 1048, 1071f., 1079, 1192
- tridiagonal systems 975f., 1018, 1229f.
- utilities 1364ff.
- vector reduction 972f., 977, 998
- vs. serial programming 965, 987
- PARAMETER attribute 1012
- Parameters in fitting function 651, 684ff.
- Parity bit 888
- Park and Miller minimal standard random generator 269, 1142
- Parkinson's Law 328
- Parseval's Theorem 492, 544
- discrete form 498
- Partial differential equations 818ff., 1332ff.
- advective equation 826
- alternating-direction implicit method (ADI) 847, 861f.
- amplification factor 828, 834
- analyze/factorize/operate package 824
- artificial viscosity 831, 837
- biconjugate gradient method 824
- boundary conditions 819ff.
- boundary value problems 819, 848
- Cauchy problem 818f.
- caution on high-order methods 844f.
- Cayley's form 844
- characteristics 818
- Chebyshev acceleration 859f., 1332
- classification of 818f.
- comparison of rapid methods 854
- conjugate gradient method 824
- Courant condition 829, 832ff., 836
- Courant condition (multidimensional) 846
- Crank-Nicolson method 840, 842, 844, 846
- cyclic reduction (CR) method 848f., 852ff.
- diffusion equation 818, 838ff., 846, 855
- Dirichlet boundary conditions 508, 820, 840, 850, 856, 858
- elliptic, defined 818
- error, varieties of 831ff.
- explicit vs. implicit differencing 827
- FACR method 854
- finite difference method 821ff.
- finite element methods 824
- flux-conservative initial value problems 825ff.
- forward Euler differencing 826f.
- Forward Time Centered Space (FTCS) 827ff., 839ff., 843, 855
- Fourier analysis and cyclic reduction (FACR) 848ff., 854
- Gauss-Seidel method (relaxation) 855, 864ff., 876, 1338, 1341
- Godunov's method 837
- Helmholtz equation 852
- hyperbolic 818, 825f.
- implicit differencing 840
- incomplete Cholesky conjugate gradient method (ICCG) 824
- inhomogeneous boundary conditions 850f.
- initial value problems 818f.
- initial value problems, recommendations on 838ff.
- Jacobi's method (relaxation) 855ff., 864
- Laplace's equation 818
- Lax method 828ff., 836, 845f.
- Lax method (multidimensional) 845f.
- matrix methods 824
- mesh-drift instability 834f.
- Monte Carlo methods 824
- multidimensional initial value problems 844ff.
- multigrid method 824, 862ff., 1009, 1334ff.
- Neumann boundary conditions 508, 820, 840, 851, 858
- nonlinear diffusion equation 842
- nonlinear instability 831
- numerical dissipation or viscosity 830
- operator splitting 823, 847f., 861
- outgoing wave boundary conditions 820
- parabolic 818, 838ff.
- parallel computing 1333
- periodic boundary conditions 850, 858
- piecewise parabolic method (PPM) 837
- Poisson equation 818, 852
- rapid (Fourier) methods 508ff., 824, 848ff.
- relaxation methods 823, 854ff., 1332f.
- Schrödinger equation 842ff.
- second-order accuracy 833ff., 840
- shock 831, 837
- sparse matrices from 64
- spectral methods 825
- spectral radius 856ff., 862
- stability vs. accuracy 830
- stability vs. efficiency 821
- staggered grids 513, 852
- staggered leapfrog method 833f.
- strongly implicit procedure 824

- successive over-relaxation (SOR) 857ff., 862, 866, 1332f.  
 time splitting 847f., 861  
 two-step Lax-Wendroff method 835ff.  
 upwind differencing 832f., 837  
 variational methods 824  
 varieties of error 831ff.  
 von Neumann stability analysis 827f., 830, 833f., 840  
 wave equation 818, 825f.  
*see also* Elliptic partial differential equations; Finite difference equations (FDEs)
- Partial pivoting 29  
 Partition-exchange 323, 333  
   and pack() intrinsic function 1170  
 Partitioned matrix, inverse of 70  
 Party tricks 95ff., 168  
 Parzen window 547  
 Pascal, Numerical Recipes in 2/x, 2/xvii, 1  
 Pass-the-buck idiom 1102, 1128  
 Path integration, for function evaluation 201ff., 263, 1138  
 Pattern multiply of sparse matrices 74  
 PBCG (preconditioned biconjugate gradient method) 78f., 824  
 PC methods *see* Predictor-corrector methods  
 PCGPACK 71  
 PDEs *see* Partial differential equations  
 Pearson's r 630ff., 1276  
 PECE method 741  
 Pentagon, symmetries of 895  
 Percentile 320  
 Period of linear congruential generator 268  
 Periodic boundary conditions 850, 858  
 Periodogram 543ff., 566, 1258ff.  
   Lomb's normalized 569f., 574f., 1258ff.  
   variance of 544f.
- Perl (programming language) 1/xvi  
 Perron's theorems, for convergence of recurrence relations 174f.
- Perturbation methods for matrix inversion 65ff.
- Phase error 831  
 Phase-locked loop 700  
 Phi statistic 625  
 Phillips-Twomey method 799ff.
- Pi, computation of 906ff., 1352ff., 1357f.
- Piecewise parabolic method (PPM) 837  
 Pincherle's theorem 175  
 Pivot element 29, 33, 757  
   in linear programming 428f.
- Pivoting 27, 29ff., 46, 66, 90, 1014  
   full 29, 1014  
   implicit 30, 38, 1014, 1017  
   in LU decomposition 37f., 1017  
   partial 29, 33, 37f., 1017  
   and QR decomposition 92  
   in reduction to Hessenberg form 478  
   in relaxation method 757  
   as row and column operations 32  
   for tridiagonal systems 43
- Pixel 519, 596, 803, 811  
 PL/1 2/x  
 Planck's constant 842
- Plane rotation *see* Givens reduction; Jacobi transformation (or rotation)
- Platykurtic distribution 606  
 Plotting of functions 342, 1182f.
- POCS (projection onto convex sets) 805  
 Poetry 5f.
- Pointer (Fortran 90) 2/xiiiif., 938f., 944f., 953ff., 1197, 1212, 1266  
   as alias 939, 944f., 1286, 1333  
   allocating an array 941  
   allocating storage for derived type 955  
   for array of arrays 956, 1336  
   array of, forbidden 956, 1337  
   associated with target 938f., 944f., 952f., 1197  
   in Fortran 95 961  
   to function, forbidden 1067, 1210  
   initialization to null 2/xv, 961  
   returning array of unknown size 955f., 1184, 1259, 1261, 1327  
   undefined status 952f., 961, 1070, 1266, 1302
- Poisson equation 519, 818, 852  
 Poisson probability function  
   cumulative 214  
   deviates from 281, 283ff., 571, 1154  
   semi-invariants of 608  
   tails compared to Gaussian 653
- Poisson process 278, 282ff., 1153
- Polak-Ribiere algorithm 390, 414ff., 1214
- Poles *see* Complex plane, poles in
- Polishing of roots 356, 363ff., 370f., 1193
- poly() utility function 973, 977, 989, 998, 1072, 1096, 1192, 1258, 1284
- Polymorphism 8
- Polynomial interpolation 99, 102ff., 1043  
   Aitken's algorithm 102  
   in Bulirsch-Stoer method 724, 726, 1305  
   coefficients for 113ff., 1047f.  
   Lagrange's formula 84, 102f.  
   multidimensional 116ff., 1049ff.  
   Neville's algorithm 102f., 105, 134, 182, 1043  
   pathology in determining coefficients for 116  
   in predictor-corrector method 740  
   smoothing filters 645  
   *see also* Interpolation
- Polynomials 167ff.  
   algebraic manipulations 169, 1072  
   approximate roots of Hermite polynomials 1062  
   approximate roots of Jacobi polynomials 1064  
   approximate roots of Laguerre polynomials 1061  
   approximating modified Bessel functions 230  
   approximation from Chebyshev coefficients 191, 1078f.
- AUTODIN-II 890  
 CCITT 889f.
- characteristic 368, 1193  
 characteristic, for digital filters 554, 559, 1257

- characteristic, for eigenvalues of matrix 449, 469
- Chebyshev 184ff., 1076ff.
- coefficients from roots 980
- CRC-16 890
- cumulants of 977, 999, 1071f., 1192, 1365, 1378f.
- deflation 362ff., 370f., 977
- derivatives of 167, 978, 1071
- division 84, 169, 362, 370, 977, 1072
- evaluation of 167, 972, 977, 998f., 1071, 1258, 1365, 1376ff.
- evaluation of derivatives 167, 978, 1071
- extrapolation in Bulirsch-Stoer method 724, 726, 1305f.
- extrapolation in Romberg integration 134
- fitting 83, 114, 191, 645, 665, 674, 1078f., 1291
- generator for CRC 889
- ill-conditioned 362
- masked evaluation of 1378
- matrix method for roots 368, 1193
- minimax 186, 198, 1076
- monic 142f.
- multiplication 169
- operation count for 168
- orthonormal 142, 184, 1009, 1061
- parallel operations on 977ff., 998f., 1071f., 1192
- primitive modulo 2 287ff., 301f., 889
- roots of 178ff., 362ff., 368, 1191ff.
- shifting of 192f., 978, 1079
- stopping criterion in root finding 366
- poly\_term() utility function 974, 977, 989, 999, 1071f., 1192
- Port, serial data 892
- Portability 3, 963
- Portable random number generator *see* Random number generator
- Positive definite matrix, testing for 90
- Positivity constraints 423
- Postal Service (U.S.), barcode 894
- PostScript 1/xvi, 1/xxiii, 2/xx
- Powell's method 389, 402, 406ff., 1210ff.
- Power (in a signal) 492f.
- Power series 159ff., 167, 195
- economization of 192f., 1061, 1080
- Padé approximant of 194ff., 1080f.
- Power spectral density *see* Fourier transform; Spectral density
- Power spectrum estimation *see* Fourier transform; Spectral density
- PowerStation, Microsoft Fortran 2/xix
- PPM (piecewise parabolic method) 837
- Precision
- converting to double 1362
- floating point 882, 937, 1343, 1361ff.
- multiple 906ff., 1352ff., 1362
- Preconditioned biconjugate gradient method (PBCG) 78f.
- Preconditioning, in conjugate gradient methods 824
- Predictor-corrector methods 702, 730, 740ff.
- Adams-Bashforth-Moulton schemes 741
- adaptive order methods 744
- compared to other methods 740
- fallacy of multiple correction 741
- with fixed number of iterations 741
- functional iteration vs. Newton's rule 742
- multivalued compared with multistep 742ff.
- starting and stopping 742, 744
- stepsize control 742f.
- present() intrinsic function 952
- Prime numbers 915
- Primitive polynomials modulo 2 287ff., 301f., 889
- Principal directions 408f., 1210
- Principal solution, of inverse problem 797
- PRIVATE attribute 957, 1067
- Prize, \$1000 offered 272, 1141, 1150f.
- Probability *see* Random number generator; Statistical tests
- Probability density, change of variables in 278f.
- Procedure *see* Program(s); Subprogram
- Process loss 548
- product() intrinsic function 948
- Product Nystrom method 789, 1331
- Program(s)
- as black boxes 1/xviii, 6, 26, 52, 205, 341, 406
- dependencies 921ff., 1434ff.
- encapsulation 7
- interfaces 2, 8
- modularization 7f.
- organization 5ff.
- type declarations 2
- typography of 2f., 12, 937
- validation 3f.
- Programming, serial vs. parallel 965, 987
- Projection onto convex sets (POCS) 805
- Projection operator, nonexpansive 805
- Prolongation operator 864, 1337
- Protocol, for communications 888
- PSD (power spectral density) *see* Fourier transform; Spectral density
- Pseudo-random numbers 266ff., 1141ff.
- PUBLIC attribute 957, 1067
- Puns, particularly bad 167, 744, 747
- PURE attribute 2/xv, 960f., 964, 986
- put\_diag() utility function 985, 990, 1005, 1200
- Pyramidal algorithm 586, 1264
- Pythagoreans 392
- QL** *see* Eigensystems
- QR *see* Eigensystems
- QR decomposition 91f., 382, 386, 1039f., 1199
- backsubstitution 92, 1040
- and least squares 668
- operation count 92
- pivoting 92
- updating 94, 382, 386, 1041, 1199
- use for orthonormal basis 58, 94
- Quadratic
- convergence 49, 256, 351, 356, 409f., 419, 906
- equations 20, 178, 391, 457

- interpolation 353, 364  
programming 436
- Quadrature 123ff., 1052ff.  
adaptive 123, 190, 788  
alternative extended Simpson's rule 128  
arbitrary weight function 151ff., 789,  
1064, 1328  
automatic 154  
Bode's rule 126  
change of variable in 137ff., 788, 1056ff.  
by Chebyshev fitting 124, 189, 1078  
classical formulas for 124ff.  
Clenshaw-Curtis 124, 190, 512f.  
closed formulas 125, 127f.  
and computer science 881  
by cubic splines 124  
error estimate in solution 784  
extended midpoint rule 129f., 135, 1054f.  
extended rules 127ff., 134f., 786, 788ff.,  
1326, 1328  
extended Simpson's rule 128  
Fourier integrals 577ff., 1261ff.  
Fourier integrals, infinite range 583  
Gauss-Chebyshev 144, 512f.  
Gauss-Hermite 144, 789, 1062  
Gauss-Jacobi 144, 1063  
Gauss-Kronrod 154  
Gauss-Laguerre 144, 789, 1060  
Gauss-Legendre 144, 783, 789, 1059,  
1325  
Gauss-Lobatto 154, 190, 512  
Gauss-Radau 154  
Gaussian integration 127, 140ff., 781,  
783, 788f., 1009, 1059ff., 1325, 1328f.  
Gaussian integration, nonclassical weight  
function 151ff., 788f., 1064f., 1328f.  
for improper integrals 135ff., 789, 1055,  
1328  
for integral equations 781f., 786, 1325ff.  
Monte Carlo 124, 155ff., 295ff., 306ff.,  
1161ff.  
multidimensional 124, 155ff., 1052, 1065ff.  
multidimensional, by recursion 1052,  
1065  
Newton-Cotes formulas 125ff., 140  
open formulas 125ff., 129f., 135  
related to differential equations 123  
related to predictor-corrector methods 740  
Romberg integration 124, 134f., 137, 182,  
717, 788, 1054f., 1065, 1067  
semi-open formulas 130  
Simpson's rule 126, 133, 136f., 583, 782,  
788ff., 1053  
Simpson's three-eighths rule 126, 789f.  
singularity removal 137ff., 788, 1057ff.,  
1328ff.  
singularity removal, worked example 792,  
1328ff.  
trapezoidal rule 125, 127, 130ff., 134f.,  
579, 583, 782, 786, 1052ff., 1326f.  
using FFTs 124  
weight function  $\log x$  153  
*see also* Integration of functions
- Quadrature mirror filter 585, 593
- Quantum mechanics, Uncertainty Principle  
600
- Quartile value 320
- Quasi-Newton methods for minimization 390,  
418ff., 1215
- Quasi-random sequence 299ff., 318, 881, 888  
Halton's 300  
for Monte Carlo integration 304, 309, 318  
Sobol's 300ff., 1160  
*see also* Random number generator
- Quicksort 320, 323ff., 330, 333, 1169f.
- Quotient-difference algorithm 164
- R**-estimates 694
- Radioactive decay 278
- Radix base for floating point arithmetic 476,  
882, 907, 913, 1231, 1343, 1357
- Radix conversion 902, 906, 913, 1357
- radix() intrinsic function 1231
- Radix sort 1172
- Ramanujan's identity for  $\pi$  915
- Random bits, generation of 287ff., 1159f.
- Random deviates 266ff., 1141ff.  
binomial 285f., 1155  
exponential 278, 1151f.  
gamma distribution 282f., 1153  
Gaussian 267, 279f., 571, 798, 1152f.  
normal 267, 279f., 571, 1152f.  
Poisson 283ff., 571, 1154f.  
quasi-random sequences 299ff., 881, 888,  
1160f.  
uniform 267ff., 1158f., 1166  
uniform integer 270, 274ff.
- Random number generator 266ff., 1141ff.  
bitwise operations 287  
Box-Muller algorithm 279, 1152  
Data Encryption Standard 290ff., 1144,  
1156ff.  
good choices for modulus, multiplier and  
increment 274ff.  
initializing 1144ff.  
for integer-valued probability distribution  
283f., 1154  
integer vs. real implementation 273  
L'Ecuyer's long period 271f.  
lagged Fibonacci generator 1142, 1148ff.  
linear congruential generator 267ff., 1142  
machine language 269  
Marsaglia shift register 1142, 1148ff.  
Minimal Standard, Park and Miller's 269,  
1142  
nonrandomness of low-order bits 268f.  
parallel 1009  
perfect 272, 1141, 1150f.  
planes, numbers lie on 268  
portable 269ff., 1142  
primitive polynomials modulo 2 287ff.  
pseudo-DES 291, 1144, 1156ff.  
quasi-random sequences 299ff., 881, 888,  
1160f.  
quick and dirty 274  
quicker and dirtier 275  
in Quicksort 324  
random access to  $n$ th number 293

- random bits 287ff., 1159f.
- recommendations 276f.
- rejection method 281f.
- serial 1141f.
- shuffling procedure 270, 272
- in simulated annealing method 438
- spectral test 274
- state space 1143f.
- state space exhaustion 1141
- subtractive method 273, 1143
- system-supplied 267f.
- timings 276f., 1151
- transformation method 277f.
- trick for trigonometric functions 280
- Random numbers *see* Monte Carlo; Random deviates
- Random walk 20
- random\_number() intrinsic function 1141, 1143
- random\_seed() intrinsic function 1141
- RANDU, infamous routine 268
- Range 53f.
- Rank (matrix) 53
  - kernel of finite 785
- Rank (sorting) 320, 332, 1176
- Rank (statistics) 633ff., 694f., 1277
  - Kendall's tau 637ff., 1279
  - Spearman correlation coefficient 634f., 1277ff.
  - sum squared differences of 634, 1277
- Ratio variable (statistics) 623
- Rational Chebyshev approximation 197ff., 1081f.
- Rational function 99, 167ff., 194ff., 1080f.
  - approximation for Bessel functions 225
  - approximation for continued fraction 164, 211, 219f.
  - Chebyshev approximation 197ff., 1081f.
  - evaluation of 170, 1072f.
  - extrapolation in Bulirsch-Stoer method 718ff., 726, 1306f.
  - interpolation and extrapolation using 99, 104ff., 194ff., 718ff., 726
  - as power spectrum estimate 566
  - interpolation and extrapolation using 1043f., 1080ff., 1306
  - minimax 198
- Re-entrant procedure 1052
- real() intrinsic function, ambiguity of 947
- Realizable (causal) 552, 554f.
- reallocate() utility function 955, 990, 992, 1070, 1302
- Rearranging *see* Sorting
- Reciprocal, multiple precision 910f., 1355f.
- Record, in data file 329
- Recurrence relation 172ff., 971ff.
  - arithmetic progression 971f., 996
  - associated Legendre polynomials 247
  - Bessel function 172, 224, 227f., 234
  - binomial coefficients 209
  - Bulirsch-Stoer 105f.
  - characteristic polynomial of tridiagonal matrix 469
  - Clenshaw's recurrence formula 176f.
  - and continued fraction 175
  - continued fraction evaluation 164f.
  - convergence 175
  - cosine function 172, 500
  - cyclic reduction 974
  - dominant solution 174
  - exponential integrals 172
  - gamma function 206
  - generation of random bits 287f.
  - geometric progression 972, 996
  - Golden Mean 21
  - Legendre polynomials 172
  - minimal vs. dominant solution 174
  - modified Bessel function 232
  - Neville's 103, 182
  - orthonormal polynomials 142
  - Perron's theorems 174f.
  - Pincherle's theorem 175
  - for polynomial cumulants 977, 999, 1071f.
  - polynomial interpolation 103, 183
  - primitive polynomials modulo 2 287f.
  - random number generator 268
  - rational function interpolation 105f., 1043
  - recursive doubling 973, 977, 988, 999, 1071f., 1073
  - second order 974f., 1074
  - sequence of trig functions 173
  - sine function 172, 500
  - spherical harmonics 247
  - stability of 21, 173ff., 177, 224f., 227f., 232, 247, 975
  - trig functions 572
  - weight of Gaussian quadrature 144f.
- Recursion
  - in Fortran 90 958
  - in multigrid method 865, 1009, 1336
- Recursive doubling 973f., 979
  - cumulants of polynomial 977, 999, 1071f.
  - linear recurrences 973, 988, 1073
  - tridiagonal systems 976
- RECURSIVE keyword 958, 1065, 1067
- Recursive Monte Carlo integration 306ff., 1161
- Recursive procedure 2/xiv, 958, 1065, 1067, 1166
  - as parallelization tool 958
  - base case 958
  - for multigrid method 1009, 1336
  - re-entrant 1052
- Recursive stratified sampling 314ff., 1164ff.
- Red-black *see* Odd-even ordering
- Reduction functions 948ff.
- Reduction of variance in Monte Carlo integration 299, 306ff.
- References (explanation) 4f.
- References (general bibliography) 916ff., 1359f.
- Reflection formula for gamma function 206
- Regula falsi (false position) 347ff., 1185f.
- Regularity condition 775
- Regularization
  - compared with optimal filtering 801
  - constrained linear inversion method 799ff.
  - of inverse problems 796ff.
  - linear 799ff.
  - nonlinear 813



- objective criterion 802
- Phillips-Twomey method 799ff.
- Tikhonov-Miller 799ff.
- trade-off curve 799
- two-dimensional 803
- zeroth order 797
- see also* Inverse problems
- Regularizing operator 798
- Reid, John 2/xiv, 2/xvi
- Rejection method for random number generator 281ff.
- Relaxation method
  - for algebraically difficult sets 763
  - automated allocation of mesh points 774f., 777
  - computation of spheroidal harmonics 764ff., 1319ff.
  - for differential equations 746f., 753ff., 1316ff.
  - elliptic partial differential equations 823, 854ff., 1332f.
  - example 764ff., 1319ff.
  - Gauss-Seidel method 855, 864ff., 876, 1338, 1341
  - internal boundary conditions 775ff.
  - internal singular points 775ff.
  - Jacobi's method 855f., 864
  - successive over-relaxation (SOR) 857ff., 862, 866, 1332f.
  - see also* Multigrid method
- Remes algorithms
  - exchange algorithm 553
  - for minimax rational function 199
- reshape() intrinsic function 950
  - communication bottleneck 969
  - order keyword 1050, 1246
- Residual 49, 54, 78
  - in multigrid method 863, 1338
- Resolution function, in Backus-Gilbert method 807
- Response function 531
- Restriction operator 864, 1337
- RESULT keyword 958, 1073
- Reward, \$1000 offered 272, 1141, 1150f.
- Richardson's deferred approach to the limit 134, 137, 182, 702, 718ff., 726, 788, 869
  - see also* Bulirsch-Stoer method
- Richtmyer artificial viscosity 837
- Ridders' method, for numerical derivatives 182, 1075
- Ridders' method, root finding 341, 349, 351, 1187
- Riemann shock problem 837
- Right eigenvalues and eigenvectors 451
- Rise/fall time 548f.
- Robust estimation 653, 694ff., 700, 1294
  - Andrew's sine 697
  - average deviation 605
  - double exponential errors 696
  - Kalman filtering 700
  - Lorentzian errors 696f.
  - mean absolute deviation 605
  - nonparametric correlation 633ff., 1277
  - Tukey's biweight 697
- use of a priori covariances 700
  - see also* Statistical tests
- Romberg integration 124, 134f., 137, 182, 717, 788, 1054f., 1065
- Root finding 143, 340ff., 1009, 1059
  - advanced implementations of Newton's rule 386
  - Bairstow's method 364, 370, 1193
  - bisection 343, 346f., 352f., 359, 390, 469, 698, 1184f.
  - bracketing of roots 341, 343ff., 353f., 362, 364, 369, 1183f.
  - Brent's method 341, 349, 660f., 1188f., 1286
  - Broyden's method 373, 382f., 386, 1199
  - compared with multidimensional minimization 375
  - complex analytic functions 364
  - in complex plane 204
  - convergence criteria 347, 374
  - deflation of polynomials 362ff., 370f., 1192
  - without derivatives 354
  - double root 341
  - eigenvalue methods 368, 1193
  - false position 347ff., 1185f.
  - Jenkins-Traub method 369
  - Laguerre's method 341, 366f., 1191f.
  - Lehmer-Schur algorithm 369
  - Maehly's procedure 364, 371
  - matrix method 368, 1193
  - Muller's method 364, 372
  - multiple roots 341
  - Newton's rule 143f., 180, 341, 355ff., 362, 364, 370, 372ff., 376, 469, 740, 749f., 754, 787, 874, 876, 911f., 1059, 1189, 1194, 1196, 1314ff., 1339, 1341, 1355f.
  - pathological cases 343, 356, 362, 372
  - polynomials 341, 362ff., 449, 1191f.
  - in relaxation method 754, 1316
  - Ridders' method 341, 349, 351, 1187
  - root-polishing 356, 363ff., 369ff., 1193
  - safe Newton's rule 359, 1190
  - secant method 347ff., 358, 364, 399, 1186f.
  - in shooting method 746, 749f., 1314f.
  - singular Jacobian in Newton's rule 386
  - stopping criterion for polynomials 366
  - use of minimum finding 341
  - using derivatives 355ff., 1189
  - zero suppression 372
  - see also* Roots
- Root polishing 356, 363ff., 369ff., 1193
- Roots
  - Chebyshev polynomials 184
  - complex  $n$ th root of unity 999f., 1379
  - cubic equations 179f.
  - Hermite polynomials, approximate 1062
  - Jacobi polynomials, approximate 1064
  - Laguerre polynomials, approximate 1061
  - multiple 341, 364ff., 1192
  - nonlinear equations 340ff.
  - polynomials 341, 362ff., 449, 1191f.
  - quadratic equations 178

- reflection in unit circle 560, 1257
  - square, multiple precision 912, 1356
  - see also* Root finding
  - Rosenbrock method 730, 1308
    - compared with semi-implicit extrapolation 739
    - stepsize control 731, 1308f.
  - Roundoff error 20, 881, 1362
    - bracketing a minimum 399
    - compile time vs. run time 1012
    - conjugate gradient method 824
    - eigensystems 458, 467, 470, 473, 476, 479, 483
    - extended trapezoidal rule 132
    - general linear least squares 668, 672
    - graceful 883, 1343
    - hardware aspects 882, 1343
    - Householder reduction 466
    - IEEE standard 882f., 1343
    - interpolation 100
    - least squares fitting 658, 668
    - Levenberg-Marquardt method 679
    - linear algebraic equations 23, 27, 29, 47, 56, 84, 1022
    - linear predictive coding (LPC) 564
    - magnification of 20, 47, 1022
    - maximum entropy method (MEM) 567
    - measuring 881f., 1343
    - multidimensional minimization 418, 422
    - multiple roots 362
    - numerical derivatives 180f.
    - recurrence relations 173
    - reduction to Hessenberg form 479
    - series 164f.
    - straight line fitting 658
    - variance 607
  - Row degeneracy 22
  - Row-indexed sparse storage 71f., 1030
    - transpose 73f.
  - Row operations on matrix 28, 31f.
  - Row totals 624
  - RSS algorithm 314ff., 1164
  - RST properties (reflexive, symmetric, transitive) 338
  - Runge-Kutta method 702, 704ff., 731, 740, 1297ff., 1308
    - Cash-Karp parameters 710, 1299f.
    - embedded 709f., 731, 1298, 1308
    - high-order 705
    - quality control 722
    - stepsize control 708ff.
  - Run-length encoding 901
  - Runge-Kutta method
    - high-order 1297
    - stepsize control 1298f.
  - Rybicki, G.B. 84ff., 114, 145, 252, 522, 574, 600
- S**-box for Data Encryption Standard 1148
- Sampling
    - importance 306f.
    - Latin square or hypercube 305f.
    - recursive stratified 314ff., 1164
    - stratified 308f.
    - uneven or irregular 569, 648f., 1258
  - Sampling theorem 495, 543
    - for numerical approximation 600ff.
  - Sande-Tukey FFT algorithm 503
  - SAVE attribute 953f., 958f., 961, 1052, 1070, 1266, 1293
    - redundant use of 958f.
  - SAVE statements 3
  - Savitzky-Golay filters
    - for data smoothing 644ff., 1283f.
    - for numerical derivatives 183, 645
  - scale() intrinsic function 1107
  - Scallop loss 548
  - Scatter-with-combine functions 984, 1002f., 1032, 1366, 1380f.
  - scatter\_add() utility function 984, 990, 1002, 1032
  - scatter\_max() utility function 984, 990, 1003
  - Schonfelder, Lawrie 2/xi
  - Schrage's algorithm 269
  - Schrödinger equation 842ff.
  - Schultz's method for matrix inverse 49, 598
  - Scope 956ff., 1209, 1293, 1296
  - Scoping unit 939
  - SDLC checksum 890
  - Searching
    - with correlated values 111, 1046f.
    - an ordered table 110f., 1045f.
    - selection 333, 1177f.
  - Secant method 341, 347ff., 358, 364, 399, 1186f.
    - Broyden's method 382f., 1199f.
    - multidimensional (Broyden's) 373, 382f., 1199
  - Second Euler-Maclaurin summation formula 135f.
  - Second order differential equations 726, 1307
  - Seed of random number generator 267, 1146f.
  - select case statement 2/xiv, 1010, 1036
  - Selection 320, 333, 1177f.
    - find  $m$  largest elements 336, 1179f.
    - heap algorithm 336, 1179
    - for median 698, 1294
    - operation count 333
    - by packing 1178
    - parallel algorithms 1178
    - by partition-exchange 333, 1177f.
    - without rearrangement 335, 1178f.
    - timings 336
    - use to find median 609
  - Semi-implicit Euler method 730, 735f.
  - Semi-implicit extrapolation method 730, 735f., 1310f.
    - compared with Rosenbrock method 739
    - stepsize control 737, 1311f.
  - Semi-implicit midpoint rule 735f., 1310f.
  - Semi-invariants of a distribution 608
  - Sentinel, in Quicksort 324, 333
  - Separable kernel 785
  - Separation of variables 246
  - Serial computing
    - convergence of quadrature 1060
    - random numbers 1141
    - sorting 1167
  - Serial data port 892

- Series 159ff.  
 accelerating convergence of 159ff.  
 alternating 160f., 1070  
 asymptotic 161  
 Bessel function  $K_\nu$  241  
 Bessel function  $Y_\nu$  235  
 Bessel functions 160, 223  
 cosine integral 250  
 divergent 161  
 economization 192f., 195, 1080  
 Euler's transformation 160f., 1070  
 exponential integral 216, 218  
 Fresnel integral 248  
 hypergeometric 202, 263, 1138  
 incomplete beta function 219  
 incomplete gamma function 210, 1090f.  
 Laurent 566  
 relation to continued fractions 163f.  
 roundoff error in 164f.  
 sine and cosine integrals 250  
 sine function 160  
 Taylor 355f., 408, 702, 709, 754, 759  
 transformation of 160f., 1070  
 van Wijngaarden's algorithm 161, 1070
- Shaft encoder 886
- Shakespeare 9
- Shampine's Rosenbrock parameters 732, 1308
- shape() intrinsic function 938, 949
- Shell algorithm (Shell's sort) 321ff., 1168
- Sherman-Morrison formula 65ff., 83, 382
- Shifting of eigenvalues 449, 470f., 480
- Shock wave 831, 837
- Shooting method  
 computation of spheroidal harmonics 772, 1321ff.  
 for differential equations 746, 749ff., 770ff., 1314ff., 1321ff.  
 for difficult cases 753, 1315f.  
 example 770ff., 1321ff.  
 interior fitting point 752, 1315f., 1323ff.
- Shuffling to improve random number generator 270, 272
- Side effects  
 prevented by data hiding 957, 1209, 1293, 1296  
 and PURE subprograms 960
- Sidelobe fall-off 548
- Sidelobe level 548
- sign() intrinsic function, modified in Fortran 95 961
- Signal, bandwidth limited 495
- Significance (numerical) 19
- Significance (statistical) 609f.  
 one- vs. two-sided 632  
 peak in Lomb periodogram 570  
 of 2-d K-S test 640, 1281  
 two-tailed 613
- SIMD machines (Single Instruction Multiple Data) 964, 985f., 1009, 1084f.
- Similarity transform 452ff., 456, 476, 478, 482
- Simplex  
 defined 402  
 method in linear programming 389, 402, 423ff., 431ff., 1216ff.  
 method of Nelder and Mead 389, 402ff., 444, 697f., 1208f., 1222ff.  
 use in simulated annealing 444, 1222ff.
- Simpson's rule 124ff., 128, 133, 136f., 583, 782, 788f., 1053f.
- Simpson's three-eighths rule 126, 789f.
- Simulated annealing *see* Annealing, method of simulated
- Simulation *see* Monte Carlo
- Sine function  
 evaluated from  $\tan(\theta/2)$  173  
 recurrence 172  
 series 160
- Sine integral 248, 250ff., 1123, 1125f.  
 continued fraction 250  
 series 250  
*see also* Cosine integral
- Sine transform *see* Fast Fourier transform (FFT); Fourier transform
- Singleton's algorithm for FFT 525
- Singular value decomposition (SVD) 23, 25, 51ff., 1022  
 approximation of matrices 58f.  
 backsubstitution 56, 1022f.  
 and bases for nullspace and range 53  
 confidence levels from 693f.  
 covariance matrix 693f.  
 fewer equations than unknowns 57  
 for inverse problems 797  
 and least squares 54ff., 199f., 668, 670ff., 1081, 1290f.  
 in minimization 410  
 more equations than unknowns 57f.  
 parallel algorithms 1026  
 and rational Chebyshev approximation 199f., 1081f.  
 of square matrix 53ff., 1023  
 use for ill-conditioned matrices 56, 58, 449  
 use for orthonormal basis 58, 94
- Singularities  
 of hypergeometric function 203, 263  
 in integral equations 788ff., 1328  
 in integral equations, worked example 792, 1328ff.  
 in integrands 135ff., 788, 1055, 1328ff.  
 removal in numerical integration 137ff., 788, 1057ff., 1328ff.
- Singularity, subtraction of the 789
- SIPSOL 824
- Six-step framework, for FFT 983, 1240
- size() intrinsic function 938, 942, 945, 948
- Skew array section 2/xii, 945, 960, 985, 1284
- Skewness of distribution 606, 608, 1269
- Smoothing  
 of data 114, 644ff., 1283f.  
 of data in integral equations 781  
 importance in multigrid method 865
- sn function 261, 1137f.
- Snyder, N.L. 1/xvi
- Sobol's quasi-random sequence 300ff., 1160f.
- Sonata 9
- Sonnet 9
- Sorting 320ff., 1167ff.  
 bubble sort 1168

- bubble sort cautioned against 321
- compared to selection 333
- covariance matrix 669, 681, 1289
- eigenvectors 461f., 1227
- Heapsort 320, 327f., 336, 1171f., 1179
- index table 320, 329f., 1170, 1173ff., 1176
- operation count 320ff.
- by packing 1171
- parallel algorithms 1168, 1171f., 1176
- Quicksort 320, 323ff., 330, 333, 1169f.
- radix sort 1172
- rank table 320, 332, 1176
- ranking 329, 1176
- by reshaping array slices 1168
- Shell's method 321ff., 1168
- straight insertion 321f., 461f., 1167, 1227
- SP, defined 937
- SPARC or SPARCstation 1/xxii, 2/xix, 4
- Sparse linear equations 23, 63ff., 732, 1030
  - band diagonal 43, 1019ff.
  - biconjugate gradient method 77, 599, 1034
  - data type for 1030
  - indexed storage 71f., 1030
  - in inverse problems 804
  - minimum residual method 78
  - named patterns 64, 822
  - partial differential equations 822ff.
  - relaxation method for boundary value problems 754, 1316
  - row-indexed storage 71f., 1030
  - wavelet transform 584, 598
  - see also* Matrix
- Spearman rank-order coefficient 634f., 694f., 1277
- Special functions *see* Function
- Spectral analysis *see* Fourier transform; Periodogram
- Spectral density 541
  - and data windowing 545ff.
  - figures of merit for data windows 548f.
  - normalization conventions 542f.
  - one-sided PSD 492
  - periodogram 543ff., 566, 1258ff.
  - power spectral density (PSD) 492f.
  - power spectral density per unit time 493
  - power spectrum estimation by FFT 542ff., 1254ff.
  - power spectrum estimation by MEM 565ff., 1258
  - two-sided PSD 493
  - variance reduction in spectral estimation 545
- Spectral lines, how to smooth 644
- Spectral methods for partial differential equations 825
- Spectral radius 856ff., 862
- Spectral test for random number generator 274
- Spectrum *see* Fourier transform
- Spherical Bessel functions 234
  - routine for 245, 1121
- Spherical harmonics 246ff.
  - orthogonality 246
  - routine for 247f., 1122
  - stable recurrence for 247
  - table of 246
  - see also* Associated Legendre polynomials
- Spheroidal harmonics 764ff., 770ff., 1319ff.
  - boundary conditions 765
  - normalization 765
  - routine for 768ff., 1319ff., 1323ff.
- Spline 100
  - cubic 107ff., 1044f.
  - gives tridiagonal system 109
  - natural 109, 1044f.
  - operation count 109
  - two-dimensional (bicubic) 120f., 1050f.
- spread() intrinsic function 945, 950, 969, 1000, 1094, 1290f.
  - and dimensional expansion 966ff.
- Spread matrix 808
- Spread spectrum 290
- Square root, complex 172
- Square root, multiple precision 912, 1356f.
- Square window 546, 1254ff.
- SSP (small-scale parallel) machines 965ff., 972, 974, 984, 1011, 1016ff., 1021, 1059f., 1226ff., 1250
- Stability 20f.
  - of Clenshaw's recurrence 177
  - Courant condition 829, 832ff., 836, 846
  - diffusion equation 840
  - of Gauss-Jordan elimination 27, 29
  - of implicit differencing 729, 840
  - mesh-drift in PDEs 834f.
  - nonlinear 831, 837
  - partial differential equations 820, 827f.
  - of polynomial deflation 363
  - in quadrature solution of Volterra equation 787f.
  - of recurrence relations 173ff., 177, 224f., 227f., 232, 247
  - and stiff differential equations 728f.
  - von Neumann analysis for PDEs 827f., 830, 833f., 840
  - see also* Accuracy
- Stabilized Kolmogorov-Smirnov test 621
- Stabilizing functional 798
- Staggered leapfrog method 833f.
- Standard (probable) errors 1288, 1290
- Standard deviation
  - of a distribution 605, 1269
  - of Fisher's z 632
  - of linear correlation coefficient 630
  - of sum squared difference of ranks 635, 1277
- Standard (probable) errors 610, 656, 661, 667, 671, 684
- Stars, as text separator 1009
- Statement function, superseded by internal subprogram 1057, 1256
- Statement labels 9
- Statistical error 653
- Statistical tests 603ff., 1269ff.
  - Anderson-Darling 621
  - average deviation 605, 1269
  - bootstrap method 686f.
  - chi-square 614f., 623ff., 1272, 1275f.

- contingency coefficient  $C$  625, 1275  
contingency tables 622ff., 638, 1275f.  
correlation 603f.  
Cramer's  $V$  625, 1275  
difference of distributions 614ff., 1272  
difference of means 609ff., 1269f.  
difference of variances 611, 613, 1271  
entropy measures of association 626ff., 1275f.  
F-test 611, 613, 1271  
Fisher's  $z$ -transformation 631f., 1276  
general paradigm 603  
Kendall's tau 634, 637ff., 1279  
Kolmogorov-Smirnov 614, 617ff., 640, 694, 1273f., 1281  
Kuiper's statistic 621  
kurtosis 606, 608, 1269  
L-estimates 694  
linear correlation coefficient 630ff., 1276  
M-estimates 694ff.  
mean 603ff., 608ff., 1269f.  
measures of association 604, 622ff., 1275  
measures of central tendency 604ff., 1269  
median 605, 694  
mode 605  
moments 604ff., 608, 1269  
nonparametric correlation 633ff., 1277  
Pearson's  $r$  630ff., 1276  
for periodic signal 570  
phi statistic 625  
R-estimates 694  
rank correlation 633ff., 1277  
robust 605, 634, 694ff.  
semi-invariants 608  
for shift vs. for spread 620f.  
significance 609f., 1269ff.  
significance, one- vs. two-sided 613, 632  
skewness 606, 608, 1269  
Spearman rank-order coefficient 634f., 694f., 1277  
standard deviation 605, 1269  
strength vs. significance 609f., 622  
Student's  $t$  610, 631, 1269  
Student's  $t$ , for correlation 631  
Student's  $t$ , paired samples 612, 1271  
Student's  $t$ , Spearman rank-order coefficient 634, 1277  
Student's  $t$ , unequal variances 611, 1270  
sum squared difference of ranks 635, 1277  
Tukey's trimean 694  
two-dimensional 640, 1281ff.  
variance 603ff., 607f., 612f., 1269ff.  
Wilcoxon 694  
*see also* Error; Robust estimation
- Steak, without sizzle 809  
Steed's method  
Bessel functions 234, 239  
continued fractions 164f.  
Steepest descent method 414  
in inverse problems 804
- Step  
doubling 130, 708f., 1052  
tripling 136, 1055
- Stieltjes, procedure of 151
- Stiff equations 703, 727ff., 1308ff.  
Kaps-Rentrop method 730, 1308  
methods compared 739  
predictor-corrector method 730  
r.h.s. independent of  $x$  729f.  
Rosenbrock method 730, 1308  
scaling of variables 730  
semi-implicit extrapolation method 730, 1310f.  
semi-implicit midpoint rule 735f., 1310f.
- Stiff functions 100, 399  
Stirling's approximation 206, 812  
Stoermer's rule 726, 1307  
Stopping criterion, in multigrid method 875f.  
Stopping criterion, in polynomial root finding 366
- Storage  
band diagonal matrix 44, 1019  
sparse matrices 71f., 1030
- Storage association 2/xiv
- Straight injection 867  
Straight insertion 321f., 461f., 1167, 1227  
Straight line fitting 655ff., 667f., 1285ff.  
errors in both coordinates 660ff., 1286ff.  
robust estimation 698, 1294ff.
- Strassen's fast matrix algorithms 96f.
- Stratified sampling, Monte Carlo 308f., 314
- Stride (of an array) 944  
communication bottleneck 969
- Strongly implicit procedure (SIPSOL) 824
- Structure constructor 2/xii
- Structured programming 5ff.
- Student's probability distribution 221f.
- Student's  $t$ -test  
for correlation 631  
for difference of means 610, 1269  
for difference of means (paired samples) 612, 1271  
for difference of means (unequal variances) 611, 1270  
for difference of ranks 635, 1277  
Spearman rank-order coefficient 634, 1277
- Sturmian sequence 469
- Sub-random sequences *see* Quasi-random sequence
- Subprogram 938  
for data hiding 957, 1209, 1293, 1296  
internal 954, 957, 1057, 1067, 1226, 1256  
in module 940  
undefined variables on exit 952f., 961, 1070, 1266, 1293, 1302
- Subscript triplet (for array) 944
- Subtraction, multiple precision 907, 1353
- Subtractive method for random number generator 273, 1143
- Subvector scaling 972, 974, 996, 1000
- Successive over-relaxation (SOR) 857ff., 862, 1332f.  
bad in multigrid method 866  
Chebyshev acceleration 859f., 1332f.  
choice of overrelaxation parameter 858  
with logical mask 1333f.  
parallelization 1333
- sum() intrinsic function 945, 948, 966
- Sum squared difference of ranks 634, 1277

- Sums *see* Series
- Sun 1/xxii, 2/xix, 886
- SPARCstation 1/xxii, 2/xix, 4
- Supernova 1987A 640
- SVD *see* Singular value decomposition (SVD)
- swap() utility function 987, 990f., 1015, 1210
- Symbol, of operator 866f.
- Synthetic division 84, 167, 362, 370
- parallel algorithms 977ff., 999, 1048, 1071f., 1079, 1192
- repeated 978f.
- Systematic errors 653
- T**ableau (interpolation) 103, 183
- Tangent function, continued fraction 163
- Target, for pointer 938f., 945, 952f.
- Taylor series 180, 355f., 408, 702, 709, 742, 754, 759
- Test programs 3
- Thermodynamics, analogy for simulated annealing 437
- Thinking Machines, Inc. 964
- Threshold multiply of sparse matrices 74, 1031
- Tides 560f.
- Tikhonov-Miller regularization 799ff.
- Time domain 490
- Time splitting 847f., 861
- tiny() intrinsic function 952
- Toeplitz matrix 82, 85ff., 195, 1038
- LU decomposition 87
- new, fast algorithms 88f.
- nonsymmetric 86ff., 1038
- Tongue twisters 333
- Torus 297f., 304
- Trade-off curve 795, 809
- Trademarks 1/xxii, 2/xixf.
- Transformation
- Gauss 256
- Landen 256
- method for random number generator 277ff.
- Transformational functions 948ff.
- Transforms, number theoretic 503f.
- Transport error 831ff.
- transpose() intrinsic function 950, 960, 969, 981, 1050, 1246
- Transpose of sparse matrix 73f.
- Trapezoidal rule 125, 127, 130ff., 134f., 579, 583, 782, 786, 1052, 1326f.
- Traveling salesman problem 438ff., 1219ff.
- Tridiagonal matrix 42, 63, 150, 453f., 488, 839f., 1018f.
- in alternating-direction implicit method (ADI) 861f.
- from cubic spline 109
- cyclic 67, 1030
- in cyclic reduction 853
- eigenvalues 469ff., 1228
- with fringes 822
- from operator splitting 861f.
- parallel algorithm 975, 1018, 1229f.
- recursive splitting 1229f.
- reduction of symmetric matrix to 462ff., 470, 1227f.
- serial algorithm 1018f.
- see also* Matrix
- Trigonometric
- functions, linear sequences 173
- functions, recurrence relation 172, 572
- functions,  $\tan(\theta/2)$  as minimal 173
- interpolation 99
- solution of cubic equation 179f.
- Truncation error 20f., 399, 709, 881, 1362
- in multigrid method 875
- in numerical derivatives 180
- Tukey's biweight 697
- Tukey's trimean 694
- Turbo Pascal (Borland) 8
- Twin errors 895
- Two-dimensional *see* Multidimensional
- Two-dimensional K-S test 640, 1281ff.
- Two-pass algorithm for variance 607, 1269
- Two-point boundary value problems 702, 745ff., 1314ff.
- automated allocation of mesh points 774f., 777
- boundary conditions 745ff., 749, 751f., 771, 1314ff.
- difficult cases 753, 1315f.
- eigenvalue problem for differential equations 748, 764ff., 770ff., 1319ff.
- free boundary problem 748, 776
- grid (mesh) points 746f., 754, 774f., 777
- internal boundary conditions 775ff.
- internal singular points 775ff.
- linear requires no iteration 751
- multiple shooting 753
- problems reducible to standard form 748
- regularity condition 775
- relaxation method 746f., 753ff., 1316ff.
- relaxation method, example of 764ff., 1319
- shooting to a fitting point 751ff., 1315f., 1323ff.
- shooting method 746, 749ff., 770ff., 1314ff., 1321ff.
- shooting method, example of 770ff., 1321ff.
- singular endpoints 751, 764, 771, 1315f., 1319ff.
- see also* Elliptic partial differential equations
- Two-sided exponential error distribution 696
- Two-sided power spectral density 493
- Two-step Lax-Wendroff method 835ff.
- Two-volume edition, plan of 1/xiii
- Two's complement arithmetic 1144
- Type declarations, explicit vs. implicit 2
- U**bound() intrinsic function 949
- ULTRIX 1/xxiii, 2/xix
- Uncertainty coefficient 628
- Uncertainty principle 600
- Undefined status, of arrays and pointers 952f., 961, 1070, 1266, 1293, 1302
- Underflow, in IEEE arithmetic 883, 1343
- Underrelaxation 857
- Uniform deviates *see* Random deviates, uniform

- Unitary (function) 843f.  
Unitary (matrix) *see* Matrix  
unit\_matrix() utility function 985, 990, 1006, 1216, 1226, 1325  
UNIX 1/xxiii, 2/viii, 2/xix, 4, 17, 276, 293, 886  
Upper Hessenberg matrix *see* Hessenberg matrix  
U.S. Postal Service barcode 894  
unpack() intrinsic function 950, 964  
    communication bottleneck 969  
Upper subscript 944  
upper\_triangle() utility function 990, 1006, 1226, 1305  
Upwind differencing 832f., 837  
USE statement 936, 939f., 954, 957, 1067, 1384  
USES keyword in program listings 2  
Utility functions 987ff., 1364ff.  
    add vector to matrix diagonal 1004, 1234, 1366, 1381  
    alphabetical listing 988ff.  
    argument checking 994f., 1370f.  
    arithmetic progression 996, 1072, 1127, 1365, 1371f.  
    array reallocation 992, 1070f., 1365, 1368f.  
    assertion of numerical equality 995, 1022, 1365, 1370f.  
    compared to intrinsics 990ff.  
    complex *n*th root of unity 999f., 1379  
    copying arrays 991, 1034, 1327f., 1365f.  
    create unit matrix 1006, 1382  
    cumulative product of an array 997f., 1072, 1086, 1375  
    cumulative sum of an array 997, 1280f., 1365, 1375  
    data types 1361  
    elemental functions 1364  
    error handling 994f., 1036, 1370f.  
    generic functions 1364  
    geometric progression 996f., 1365, 1372ff.  
    get diagonal of matrix 1005, 1226f., 1366, 1381f.  
    length of a vector 1008, 1383  
    linear recurrence 996  
    location in an array 992ff., 1015, 1017ff.  
    location of first logical “true” 993, 1041, 1369  
    location of maximum array value 993, 1015, 1017, 1365, 1369  
    location of minimum array value 993, 1369f.  
    logical assertion 994, 1086, 1090, 1092, 1365, 1370  
    lower triangular mask 1007, 1200, 1382  
    masked polynomial evaluation 1378  
    masked swap of elements in two arrays 1368  
    moving data 990ff., 1015  
    multiply vector into matrix diagonal 1004f., 1366, 1381  
    nrutil.f90 (module file) 1364ff.  
    outer difference of vectors 1001, 1366, 1380  
    outer logical and of vectors 1002  
    outer operations on vectors 1000ff., 1379f.  
    outer product of vectors 1000f., 1076, 1365f., 1379  
    outer quotient of vectors 1001, 1379  
    outer sum of vectors 1001, 1379f.  
    overloading 1364  
    partial cumulants of a polynomial 999, 1071, 1192f., 1365, 1378f.  
    polynomial evaluation 996, 998f., 1258, 1365, 1376ff.  
    scatter-with-add 1002f., 1032f., 1366, 1380f.  
    scatter-with-combine 1002f., 1032f., 1380f.  
    scatter-with-max 1003f., 1366, 1381  
    set diagonal elements of matrix 1005, 1200, 1366, 1382  
    skew operation on matrices 1004ff., 1381ff.  
    swap elements of two arrays 991, 1015, 1365ff.  
    upper triangular mask 1006, 1226, 1305, 1382  
**V**-cycle 865, 1336  
vabs() utility function 990, 1008, 1290  
Validation of Numerical Recipes procedures 3f.  
Valley, long or narrow 403, 407, 410  
Van Cittert’s method 804  
Van Wijngaarden-Dekker-Brent method *see* Brent’s method  
Vandermonde matrix 82ff., 114, 1037, 1047  
Variable length code 896, 1346ff.  
Variable metric method 390, 418ff., 1215  
    compared to conjugate gradient method 418  
Variable step-size integration 123, 135, 703, 707ff., 720, 726, 731, 737, 742ff., 1298ff., 1303, 1308f., 1311ff.  
Variance(s)  
    correlation 605  
    of distribution 603ff., 608, 611, 613, 1269  
    pooled 610  
    reduction of (in Monte Carlo) 299, 306ff.  
    statistical differences between two 609, 1271  
    two-pass algorithm for computing 607, 1269  
    *see also* Covariance  
Variational methods, partial differential equations 824  
VAX 275, 293  
Vector(s)  
    length 1008, 1383  
    norms 1036  
    outer difference 1001, 1366, 1380  
    outer operations 1000ff., 1379f.  
    outer product 1000f., 1076, 1365f., 1379  
Vector reduction 972, 977, 998  
Vector subscripts 2/xiif., 984, 1002, 1032, 1034  
    communication bottleneck 969, 981, 1250  
VEGAS algorithm for Monte Carlo 309ff., 1161  
Verhoeff’s algorithm for checksums 894f., 1345

- Viète's formulas for cubic roots 179  
 Vienna Fortran 2/xv  
 Virus, computer 889  
 Viscosity  
     artificial 831, 837  
     numerical 830f., 837  
 Visibility 956ff., 1209, 1293, 1296  
 VMS 1/xxii, 2/xix  
 Volterra equations 780f., 1326  
     adaptive stepsize control 788  
     analogy with ODEs 786  
     block-by-block method 788  
     first kind 781, 786  
     nonlinear 781, 787  
     second kind 781, 786ff., 1326f.  
     unstable quadrature 787f.  
 von Neuman, John 963, 965  
 von Neumann-Richtmyer artificial viscosity 837  
 von Neumann stability analysis for PDEs 827f., 830, 833f., 840  
 Vowellish (coding example) 896f., 902
- W**-cycle 865, 1336  
 Warranty, disclaimer of 1/xx, 2/xvii  
 Wave equation 246, 818, 825f.  
 Wavelet transform 584ff., 1264ff.  
     appearance of wavelets 590ff.  
     approximation condition of order  $p$  585  
     coefficient values 586, 589, 1265  
     contrasted with Fourier transform 584, 594  
     Daubechies wavelet filter coefficients 584ff., 588, 590f., 594, 598, 1264ff.  
     detail information 585  
     discrete wavelet transform (DWT) 586f., 1264  
     DWT (discrete wavelet transform) 586f., 1264ff.  
     eliminating wrap-around 587  
     fast solution of linear equations 597ff.  
     filters 592f.  
     and Fourier domain 592f.  
     image processing 596f.  
     for integral equations 782  
     inverse 587  
     Lemarie's wavelet 593  
     of linear operator 597ff.  
     mother-function coefficient 587  
     mother functions 584  
     multidimensional 595, 1267f.  
     nonsmoothness of wavelets 591  
     pyramidal algorithm 586, 1264  
     quadrature mirror filter 585  
     smooth information 585  
     truncation 594f.  
     wavelet filter coefficient 584, 587  
     wavelets 584, 590ff.  
 Wavelets *see* Wavelet transform  
 Weber function 204  
 Weighted Kolmogorov-Smirnov test 621  
 Weighted least-squares fitting *see* Least squares fitting
- Weighting, full vs. half in multigrid 867  
 Weights for Gaussian quadrature 140ff., 788f., 1059ff., 1328f.  
     nonclassical weight function 151ff., 788f., 1064f., 1328f.  
 Welch window 547, 1254ff.  
 WG5 (ISO/IEC JTC1/SC22/WG5 Committee) 2/xiff.  
 where construct 943, 1291  
     contrasted with merge 1023  
     for iteration of a vector 1060  
     nested 2/xv, 943, 960, 1100  
     not MIMD 985  
 While iteration 13  
 Wiener filtering 535, 539ff., 558, 644  
     compared to regularization 801  
 Wiener-Khinchin theorem 492, 558, 566f.  
 Wilcoxon test 694  
 Window function  
     Bartlett 547, 1254ff.  
     flat-topped 549  
     Hamming 547  
     Hann 547  
     Parzen 547  
     square 544, 546, 1254ff.  
     Welch 547, 1254ff.  
 Windowing for spectral estimation 1255f.  
 Windows 95 2/xix  
 Windows NT 2/xix  
 Winograd Fourier transform algorithms 503  
 Woodbury formula 68ff., 83  
 Wordlength 18  
 Workspace, reallocation in Fortran 90 1070f.  
 World Wide Web, Numerical Recipes site 1/xx, 2/xvii  
 Wraparound  
     in integer arithmetic 1146, 1148  
     order for storing spectrum 501  
     problem in convolution 533  
 Wronskian, of Bessel functions 234, 239
- X**.25 protocol 890  
 X3J3 Committee 2/viii, 2/xff., 2/xv, 947, 959, 964, 968, 990  
 XMODEM checksum 889  
 X-ray diffraction pattern, processing of 805
- Y**ale Sparse Matrix Package 64, 71
- Z**-transform 554, 559, 565  
 Z-transformation, Fisher's 631f., 1276  
 Zaman, A. 1149  
 Zealots 814  
 Zebra relaxation 866  
 Zero contours 372  
 Zero-length array 944  
 Zeroth-order regularization 796ff.  
 Zip code, barcode for 894  
 Ziv-Lempel compression 896  
 zroots\_unity() utility function 974, 990, 999