

Index

a

Accuracy 13, 53, 54, 66, 90, 93, 97, 117, 170, 176, 178, 228, 230, 245, 284, 416, 445, 451, 506, 535

Action potential 227

Activation function 230, 236, 246

Adams-Bashful-Moulton 156

Adder
 full 271–272, 276–277
 half 263, 271–272, 277

Advection 504–505, 508, 518, 521, 522

AI *see* Artificial intelligence (AI)

Airy functions 385, 386

Algorithm 3, 4, 9, 25, 45, 50, 51, 53, 55, 79–81, 84–89, 153–158, 280–283, 289–290, 295–298, 316–317, 325–326, 370–374, 398–402, 445–448, 456–463, 468–470, 484–487, 496–497, 506–507, 510, 525

Alias 175–179, 185

AnaConda 7, 8, 237, 266, 274

Analog filters 183

Animations 7, 30, 31–32, 38, 42–43, 248, 362, 396, 399, 400, 459, 484, 485, 496, 509, 511, 517, 545–547

Antiferromagnet 368

Architecture 17, 128

Arrays *see also* Matrices; Python
 vertical 240

Artificial intelligence (AI) 226, 249
 generative 226
 neuron *see* Neurons

Asymptotes 335

Attractors 334, 335, 359

predictable 355

strange 355

Autocorrelation function 180–183

Axon *see* Neurons

b

Backtracking 105–106, 127

Backward pass 241

Ballistic deposition 314–315, 319, 320, 323, 327
 correlated 320

Basic machine language 9, 10

Beating 148, 161, 356, 357, 471

Bell states 260, 265, 273, 277

Bessel functions 50, 56–59, 154

Bias 14–16, 228, 229, 232, 246

Bifurcation 334, 335, 338, 340, 359, 361
 diagram 336
 dimension of 322

Billiards 361–363, 489
 quantum 488–489

Binary numbers *see* Numbers, binary

Binary point 14

Binning 337

Bisection algorithm 102, 103, 105, 107, 121, 297–298

Bits 11, 257
 quantum *see* Qubits
 reversal 189–191

Black holes 410, 413, 414, 421

Bloch sphere 258, 264

Boltzmann distribution 106, 369, 370, 374

Boolean 19–21, 260

Bound states 101–103, 293–298, 301, 305–308, 363, 378–379, 427–431, 435, 489

Boundary conditions 112, 151, 294, 295, 371, 373, 375, 384–386, 397, 408–409, 436, 441–444, 448–450, 455–456, 458, 461, 467–470, 477–478, 494, 497, 507, 515, 517, 522–523, 525, 528–531, 533, 538

Box counting 84–85, 316–319, 321

Bra 256–257, 258

Bra-ket 256

Break command 451

Burgers' equation 505, 507

Butterfly operation 188, 189, 191

Byte 11, 12, 30, 129, 143, 247

Byte code 11

C

Cache programming 129

Canonical ensemble 369, 393, 394

Capacitors 449, 451

Catenary 473–475, 481

Cauchy principal value 433

Cellular automata 322, 323

Central difference algorithm 80–81

Chaos 338, 340, 350, 353, 357, 359, 360, 487, 489

Fourier analysis of 359

of pendulum 350–353

phase space 353, 354, 358

Chi-squared measure 115, 116

Christoffel symbols 411–413

Cirq 266, 267, 276

definition 266

install 266–267

X and H gates 267–268

C language 6, 9, 10, 17–19, 130, 135, 142

Clustering 63, 240, 242–246

Codes, tables of 4–6, 31, 32, 38, 144, 157, 272, 393, 459, 545–547

Column-major order 129

Command-line interpreter 10

Command shell 237, 266

Compilers 10, 18

Complex numbers 6, 17, 19, 20, 30, 134, 176, 187–189, 191, 192, 258, 259

Compression 195

lossless 199

PCA 216

wavelets 195

Computational

physics 3–4

science 3–4

thinking 4

Computer languages 6, 10, 13, 21, 26, 130

Control structures 18, 20–21

Convolution 181, 183, 184, 202, 206, 207, 209

Conway's Game of Life 322

Correlations 180, 181, 319, 323

auto 180

coefficient 117

growth 319–320

PCA 215–221

Cosmological constant 410, 413, 418

Cost *see* Loss

Courant stability condition 493, 494, 506

see also von Neumann

Covariance 117, 217–221

Covector space 257

Crank–Nicolson method 460–463

Cubic splines 110–113, 121 *see also* Splines

Curie temperature 107, 367, 368, 370, 374

Curvature tensor 411, 413

Curve fitting *see* Data, fitting

d

Data

compression 195

fitting 101–123

types 13

Dataflow graphs 236

Decay

exponential 71, 113–114

simulation 71–72

spontaneous 113

Deep learning 226, 229, 246, 249

see also Machine, learning

Deep net *see* Machine, learning

Density matrix 260, 275

Density of states 369, 374, 375

- Deposition 314
 ballistic 314–315
- Derivatives 79–83, 150
 central difference 379
 forward difference 153
 second 112, 152, 296, 297, 398
- DFT *see* Discrete Fourier transform (DFT)
- Differential equations 148–165, 293, 303
 algorithms 153–158
 boundary conditions 151
 dynamical form 151–153
 Euler's rule 153
 initial conditions 151, 153
 order 150, 151
 partial 150–151, 441 *see also* PDE's
 Runge-Kutta algorithm 154
 types 150, 441
- Differentiation 79–100, 153, 372, 403, 446, 497
- Diffuser algorithm 282
- Diffusion-limited aggregation 320
- Dimension
 array 129
 fractional 309, 311, 316
 Hausdorf-Besicovitch 309
 physical 129
 schemes 131
- Dirac notation 256–257, 274
 QC version 274
- Direct product 134, 218, 257–261, 266, 279–281
- Discrete Fourier transform (DFT) 4, 169, 174–180, 183, 192, 212, 277, 278
- Dispersion 216, 503, 504, 507–509, 512–514
 relation 503, 504, 508
- Double(s) 14–17, 29, 88, 156
 pendulum 360, 361
 precision 14, 29
- Drag 301–302 *see also* Friction
- Driving force 149, 161, 351, 355, 357, 359, 360, 365, 515
- Dual adjoint space 257
- Duffing oscillator 365
- e**
- Edges 235, 236, 379, 397, 449, 450, 488, 489, 516, 517
- Eigenvalues 128, 137–139, 141, 219–221, 262, 284, 286, 293–308, 429–431, 478, 482
- Einstein 30, 68, 410–416, 420
 field equations 410–414
- Electrostatic potential *see* Laplace's equation
- Elliptic integrals 351–352, 370
- Ellis metric 411
- Entangled states 259–262, 265, 277, 286
- Entropy 338, 340, 347, 374, 376
- Equations 509
 Burgers' 505
 differential 148–165, 293
 discrete 70, 332
 heat 454–455
 integral 427–438 *see also* Integral equations
 Korteweg-de Vries 508
 Laplace's 441, 452, 534, 540
 Lippmann-Schwinger 431–432
 motion 302, 303
 Navier-Stokes 504, 520–522, 527
 Poisson's 441, 443, 447, 533
 Schrödinger 482–483
 Sine-Gordon 514–517
 telegraph 497
 Van der Pool 365
 wave 466
- Errors 45, 56–58, 82, 83
 algorithmic 46, 50, 87
 approximation 50 *see also* Errors, algorithmic
 empirical 50
 integration 88, 94
 minimum 52
 multiplicative 49
 N-D integration 95–97
 random 46
 roundoff 46, 48–57, 61, 85, 88, 95, 96, 153, 154, 510
 total 50, 51
 types 45–50
- Euler's rule 153–155, 379

Event horizons 413–414
 Exchange energy 368, 371
 Executive system 10
 Exponential decay 69–72, 94, 113–115
 Extrapolated difference 81–84

f

Factoring algorithm 283–285
 Fast Fourier transform 169, 176, 187–194
 Feigenbaum constants 337–338
 Ferromagnet 367–368, 371, 373
 Feynman
 path integrals 376–386
 postulates 376
 propagator 376
 FFT *see* Fast Fourier transform
 Filters 181, 184
 analog 183
 digital 185, 211
 sinc 186
 windowed 185
 Finite
 difference equation 70
 difference time domain 491–494
 differences 70, 446, 484, 524, 528
 elements 533–540
 2D elements 539–540
 Fitting
 best 108
 global 115
 goodness 116
 least-squares 114–119
 linear least square 116, 119
 local 115
 Newton-Raphson 120
 nonlinear 119–120
 Fixed-point numbers 12
 Fixed points in maps 334, 355
 Floating-point numbers 12–17, 28, 33, 46,
 132, 145, 337
 Floats *see* Floating-point numbers
 FLOPS 158
 Fluid dynamics 504–505, 520–526, 528,
 530
 Fortran 6, 9–10, 129, 142
 Forward difference *see* Derivatives

Fourier
 analysis 169
 autocorrelation relation 183
 components in chaos 360
 decomposition 170
 discrete transform 174–176 *see also*
 Discrete Fourier transform (DFT)
 fast transform 187–191 *see also* Fast
 Fourier transform
 integral 172–173
 quantum transform 277–280
 sawtooth 171–172
 series 169–172
 series as algorithm 445
 short-time transform 200
 theorem 170
 transform 169, 172–173

Fractals 309–330
 coastline 315–319
 dimension 309 *see also* Dimension
 plants 312–313
 Pollock painting 321–322
 trees 314

Friction 159, 160, 355, 357, 520, 528
 in oscillations 160
 in pendulum 350–353, 355
 in projectile motion 301–302
 in waves 471–472

Functional integration 380 *see also* Path
 integration

g

Galerkin decomposition 535–536
 Game of Life 322, 323, 328
 Garbage 45, 46, 57
 Gates
 AND, NAND, NOT, NOR, XOR, OR, state,
 U, Pauli, NOT X, Y, Z, R ϕ , S, T
 262–264
 controlled NOT, CNOT 265
 controlled Z, CZ 265
 Hadamard H 263, 267
 logic 260, 262
 measurement 264
 2 qubit 264
 3 qubit 266

- SWAP 264
 Toffoli, CCNOT 266, 270
 Gaussian
 distribution 72–74
 elimination 434
 quadrature 90–92
 quadrature derivation 91–92
 Gauss-Seidel method 448
 General relativity 410–426
 Geodesic 411–415, 418
 Geodesic equation 411, 412, 414, 415, 418
 Gibbs overshoot 172, 186, 445
 Gradient tape 241
 Gravitational
 constant 410
 curvature 410
 lensing 415–416
 Green's function 376, 378, 379–382
 Grid points 324, 325, 430, 431, 435, 493, 507,
 510, 516, 524
 Grover's search algorithm 280–283
 Growth models 309–330, 332
- h**
- Half-wave function 171–172, 203
 Hamilton's principle 376–378, 380
 Harmonics 170, 173, 179
 Heat bath 394, 442, 460
 Heat equation 38, 454–456, 458–460, 463,
 464, 468–470
 Hidden layer 230, 234–236
 Hilbert space 256, 258, 259, 261, 263, 280
 Hilbert transform 433
 Huygens's principle 376
 Hydrogen hyperfine structure 140
- i**
- IBM Quantum Computer 256, 266, 272–275,
 283
 IEEE floating-point 12–15
 Image processing 195, 246–248, 323
 Importance sampling 97–98 *see also* von
 Neumann
 Initial conditions 151, 153–154, 157–158,
 301, 303–304, 335, 343–344, 346,
 354–359, 362, 373, 387, 402–403, 415,
 417–418, 442, 456, 458, 461, 464,
 466–471, 475–477, 489–490, 493–497,
 509–511, 517–519
 Integral equations 427–438, 536
 Integration 79–100
 error 87–89, 94–95
 Gaussian quadrature 90–92
 mapping points 91
 mean value 95–97
 Monte Carlo 92–96
 multi-dimensional 96
 rejection techniques for 92
 scaling 91
 Simpson's rule 86–87, 89
 splines 112
 trapezoid rule 85–86, 89
 variance reduction 97
 von Neumann rejection 98
 Integro-differential equation 427
 Intermittency 335
 Interpolation
 Lagrange 109, 110
 splines 111
 Interpreter 17
 Inverse matrix 128, 136, 137, 212
 Ising model 367–371, 373–375, 382
 2D 370, 374
- j**
- Jacobi method 448
 Jupyter notebook 7, 31, 237, 238, 274,
 425–426
- k**
- Keras deep learning 246, 254–255
 Kernel 10, 186
 Kerr metric 413–414 *see also* Metric
 Ket 256, 260, 263–264
 Kmeans 243, 244, 251, 253
 Korteweg-de Vries equation 503, 505 *see*
 also Equations
- l**
- Lagrange interpolation 109–111, 113
 Lag time 180, 184, 358

- Languages
 - BASIC 10
 - compiled 10–11, 17
 - computer 9
 - high-level 9
 - interpreted 11
 - Python 6–8
 - Laplace's equation 441, 443–447, 449, 452, 455, 456, 460, 525, 527, 534, 535, 540–542
 - Lattice computations 368, 379–383, 384
 - Lattice points *see* Grid points
 - Lax-Wendroff algorithm 506–507
 - Leap frog algorithm *see* Time stepping
 - Learning rate 234, 244, 245
 - Least-squares fitting 101, 108, 114–119
 - Length of coastline 315–319
 - Lifetime 71, 113–115, 420
 - Light deflection 414–416
 - Limit cycles 342, 344–346, 355, 358, 365
 - Linear
 - algebra 117–119, 128, 135
 - congruent method 62
 - least-square fitting 116
 - regression 116
 - superposition 151
 - Linux 7, 10
 - Lippmann-Schwinger equation 431–432, 435
 - Load module 10
 - Logic gates 262–266, *see also* Gates
 - Logistic map 331–336, 338–341, 344, 346, 347, 359
 - Loss 230–232, 241
 - Lotka-Volterra model 341–345
 - Lyapunov coefficients 338–340, 347
- m**
- Machine
 - learning 226
 - learning data 249
 - numbers 13, 46
 - precision 29–30
 - Magnetic materials 106, 368
 - Mantissa 12, 14–16, 28, 29, 46, 52
 - Matplotlib 7, 30–42, 245, 268, 424, 541
 - Matrices 124, 127, 133, 140, 145
 - column-major order 129
 - computing 124–147
 - equations 431
 - inversion 127, 128, 434
 - Pauli 141, 260
 - subroutine libraries 138
 - tri-diagonal 462
 - Maxwell's Equations 460, 490–492, 499–501
 - McCulloch-Pitts neuron 228
 - Mean value theorem 95
 - Memory
 - architecture 128
 - pages 129
 - Metric
 - Ellis 411, 421
 - Kerr 413
 - Schwarzschild 412–414, 418
 - tensor 410, 411
 - Metropolis algorithm 98, 367, 370–374, 378, 382–384, 387
 - Microcanonical ensemble 369, 393
 - Miller's device 58
 - ML *see* Machine, learning
 - Mode locking 161, 355, 356
 - Molecular dynamics (MD) 393–409
 - Momentum space 427–436
 - Monte Carlo
 - error in 96
 - integration 92–95
 - simulations 60–78, 319, 367, 370, 382, 394, 396
 - techniques 60, 68
 - Multiresolution analysis 206, 207
- n**
- NAN 17
 - Navier-Stokes equation 504, 520–522, 525–529
 - Neural net 228, 230, 234
 - Neural network 226–255 *see also* Neural net
 - Neurons 66, 67, 226–230, 235, 236, 246
 - code for AI 229
 - Newton-Cotes method 85

- Newton-Raphson search 103–106, 120
 - algorithm 103, 298
 - with backtracking 105
 - Nodes 111, 112, 180, 228, 230, 234–236, 294, 298, 446, 456, 494, 534–536, 538, 540
 - Noise 323
 - Perlin 323
 - reduction 180–182
 - Nonlinear
 - dynamics 331, 334, 350
 - limit cycles 355
 - maps 333, 338
 - ODE 150
 - oscillations 148–165 *see also* Oscillations
 - Nonlocal potentials 427, 431
 - Nonstationary signals 195, 203
 - Normal
 - mode expansions 467–468
 - numbers 14
 - Notebook *see* Jupiter
 - Numbers
 - base 12
 - binary 11
 - complex 134
 - fixed-point 12
 - floating-point 12–15
 - hexadecimal 11
 - IEEE 14
 - machine 13
 - normal 14
 - octal 11
 - ranges of 11
 - representation of 11–17
 - subnormal 14
 - uniform 72
 - Numerical precision 430
 - Numerov method 296, 305
 - NumPy 131
 - optimization 142
 - Nyquist criterion 177–179
 - Nyquist-Shannon interpolation 186
- O**
- Objects code 10, 31, 160
 - Octal numbers 11
 - ODE's 150–151, 153–158, 293–308
 - second order 300
 - One cycle population 334
 - OpenCV 246–248
 - Operating system 10, 129
 - Optimization 90, 245
 - Oracle algorithm 280–283
 - Orbits *see* Planetary
 - Oscillations
 - anharmonic 149, 158, 170
 - damped 160
 - double pendulum 361
 - driven 161
 - due to errors 108, 445
 - electromagnetic 491
 - from errors 110
 - Fourier analysis of 169–172
 - harmonic 157, 158, 170
 - isochronous 157, 158
 - nonlinear 148–150, 157–160, 161, 169
 - in phase space 354
 - populations 334, 344
 - quantum 378, 382
 - Output layer 229
 - Overflows 12, 13, 17, 28, 53, 62, 79, 300, 395, 445
 - Over relaxation *see* Relaxation
- p**
- Padding of signal 178
 - Paging *see* Memory
 - Panda 7, 244, 253
 - Partial differential equations *see* PDE's
 - Path integration 379–386, 391
 - Pauli matrices 141, 260
 - PDE's 150, 441–454, 466, 533
 - elliptic 443
 - explicit solution 484
 - hyperbolic 466–467
 - implicit solution 484
 - parabolic 441, 454–456
 - types 441
 - weak form of 534–535
 - Pendulum 359, 361
 - analytic solution 351–352
 - bifurcation diagram 359

- Pendulum (*contd.*)
 - chaotic 350–353, 356, 359
 - coupled 512
 - double 360–361
 - Perceptrons 228, 229, 244, 245, 251
 - Period doubling 334 *see also* Bifurcation
 - Periodic boundary conditions 371, 373, 375, 397, 408, 493, 494
 - Perlin noise 323–326
 - Phantom bit 14, 15
 - Phase estimation algorithm 284, 285
 - Phase space 301, 338, 342–345, 350, 353–361, 363–365, 511–512
 - Phase transition 345, 346, 367–369, 374, 528
 - pip 240, 267, 528
 - Pixels 235, 247, 337
 - Planetary orbits 303–305, 416–420
 - Poisson's equation 443, 446–449, 527, 533
 - Population dynamics 331–349
 - Population extinction 335
 - Potentials
 - delta shell 430–431
 - Lennard-Jones 395
 - momentum space 430
 - nonlocal 427, 431
 - Pov-Ray 325, 326, 329
 - Power
 - PCA component 216
 - residue method 61
 - spectrum 173, 182, 360
 - PowerShell 8, 237, 266
 - Precession 303, 418–420
 - Precision 45
 - empirical 50
 - machine 29–30
 - tests of 159
 - Predator-prey models 340–346
 - Predictor-corrector methods 156, 164
 - Principal
 - components analysis 215–221
 - value 433
 - value integrals 433
 - Problem solving paradigm 3
 - Programming 10, 18, 27
 - design 26–27
 - quantum 256–257
 - reproducible 26
 - structured 26
 - Projectile motion 26, 27, 160, 301–303, 308
 - Propagator 376, 377, 380, 381
 - Protein folding 68–69
 - Pseudocode 26–28, 30, 54, 71
 - Pseudorandom *see* Random, numbers
 - Pulsions 515
 - Pyramid scheme 207–211, 213
 - Python 129
 - algebraic tools 24–25
 - arrays 21–23, 137
 - Canopy distribution 6
 - distributions 6
 - I/O 23–24
 - language 6
 - libraries 6
 - linear algebra 135–137
 - lists 21–23
 - packages 6
 - references 6
 - Visual package 31
- q**
- QC *see also* Quantum, computing
 - simulator 275
 - QFT 278–280, 284, 286 *see also* Quantum, Fourier Transform (QFT)
 - Qiskit 274–282
 - Quadrature *see* Integration
 - Quantum 101
 - bits *see* Qubits
 - bouncer 385–386
 - computing 256–290
 - computing operators 257
 - Fourier transform (QFT) 277–280
 - mechanics 293
 - scattering 431–436
 - simulator 274
 - wave packets 482–502
 - Quantum Composer 272–274, 277
 - Qubits 256–260, 263–271, 273–284, 286–290
- r**
- Radioactive decay 60, 61, 69, 71, 72, 321
 - Radix 12

- RAM 129
- Random 60–64
 brain walks 66–68
 generators 61–63
 linear congruent 61
 nonuniform 96
 numbers 49, 60, 61, 74, 313
 pseudo 61
 self-avoiding walk 68
 sequences 60, 61, 63–64
 tests of 72–74
 walks 64–69, 320
- Ray tracing 325–326, 329
- Recursion 50, 56–59, 154
- Registers 29, 273, 284, 285
- Regression 116, 239, 240, 246
- Rejection techniques 97–98, 370
- Relaxation 441–453, 456, 460, 469, 524, 525, 528, 529, 531
- Resonances 110, 119–120, 148, 160–162, 356, 357, 435
 nonlinear 160–162
- Reynolds number 528, 529, 531
- Ricci curvature tensor 411, 413
- Riemann tensor 412, 413
- rk algorithm 156, 165
- rk4 154, 156–158, 162, 295–298, 300–302, 304, 306, 352, 398, 442
- Romberg extrapolation 89
- Root mean square 64, 65, 400
- Roundoff errors *see also* Errors
 roundoff 46–47
- Row-major order 129
- Runge-Kutta 154–157, 296
- S**
- Sampling 93, 95–98, 174, 176–179, 187, 207, 210, 214, 361, 369, 370, 374–376
 importance 97–98
- Sawtooth function 169, 171, 172
- Scalar curvature 411
- Scattering 108, 110, 293–308, 362–363, 427, 431–438, 488–490, 498–499
 quantum chaos 487–490
- Schrödinger equation 150, 293, 294, 296, 297, 305, 306, 382, 385, 427–431, 435, 460, 482–484, 486, 487, 491, 498
 time dependent 482–483
- Schwarzschild metric 412–414, 416, 418
- Scikit-learn 240–242
- Searching 101–127, 296, 344 *see also* Trial and error
- Secular equation 128
- Seeds 61–63, 65, 74, 245, 320, 321, 333, 335, 373, 384
- Self
 affine connection 312–313
 affinity 312–314
 limiting 365
 similar 311, 312, 337
- Separable states 259–262
- Separatrix 159, 352, 354, 358, 512, 515
- Series summation 47, 55, 172
- Shannon entropy 338, 340, 347
- Shells 9, 10, 309
- Shock waves 457, 466, 504–507
- Shor's algorithm 282–285, 289
- Sierpiński gasket 310–312, 323
- Sigmoid function 228–230, 232, 233
- Signal processing 185
- Sign bit 12, 15, 17
- Significant figures/parts 12, 46, 48, 93, 107, 539
- Simpson's rule 86–90, 94, 95
- Simulation 4, 24, 30, 49, 60–78, 160, 161, 228, 257, 268, 301, 314–316, 319, 323, 331, 335, 354, 356, 361, 367–392, 393–532
- Sinc filter 177, 185–187
- Sine-Gordon equation 503, 514–517
- Single precision 13, 15–17, 28, 29, 88, 94
- Singular integrals 427, 432–433
- SkLearn 237–242, 244, 251
- Solitons 331, 503, 504, 508–515, 518, 520
 crossing 511–512
 KdeV 509
 ring 517
 Sine-Gordon 515
 water wave 508
- Specular reflection 55–56, 362

Spin states 140–142, 256, 369
 Splines 111
 cubic 110–113
 natural 112
 Spontaneous decay 60, 69–72, 78, 113, 114
 Stable states 335
 Statistical mechanics 323, 340, 369–370,
 373, 393, 396
 Stochastic gradient descent 234, 245–246,
 253
 Stochastic processes 69, 113
 Strange attractors 355
 Stress-energy tensor 411
 Stride 129, 130, 142–145
 Subnormal numbers 14, 15
 Subroutines 85, 90, 108, 110, 114, 128, 129,
 138, 363, 434, 435
 libraries/packages 128, 135
 Subscripts *see also* Dimension
 schemes 129
 Subtractive cancellation 47–48, 54, 57, 58,
 79, 80, 82, 113, 117, 153, 432
 Successive over-relaxation *see* Relaxation
 Supervised learning 242, 245

t

TensorFlow 236–239, 242, 246, 252
 Tensor product 258, 412–413
 Texturing images 326, 329
 Thermodynamics 340, 367–392, 394, 396
 Three-body problem 303, 363, 487, 489
 Time delay 64, 301, 490
 Time stepping 454, 456–459, 462, 468–470,
 485, 490, 492
 Top-down programming 27
 Training AI 226, 230, 231
 Transients 161, 169, 333, 335–337, 357, 359,
 360, 364, 365
 Transpile 275
 Trapezoid rule 85–86, 88, 89, 94, 95, 98, 175
 Trial and error 31, 101–124, 230, 295, 386,
 448, 451
 Trivial solutions 128, 429
 Two cycle 334
 Two's complement 12, 29

u

Ueda oscillator 365
 Uncertainty principle 197–199, 205, 206
 Underflows 13, 17, 28–29
 Uniform
 distribution 61–63, 72–74, 90
 sequences 62, 72
 tests of 72–74
 Unix 10

v

Van der Pool equation 365
 Variance 97, 117, 216–220, 245, 370
 reduction 97, 370
 Vectors 33, 36, 137–138, 152, 199, 215–220,
 256–257, 259–260, 266, 278, 280,
 324–325, 412, 434, 530
 Velocity-Verlet algorithm 398–400, 402
 Verlet algorithm 398–402
 Vertical arrays 240
 Virtual memory 129
 Viscosity 472, 520–523, 528
 Visualization 6, 7, 9, 24, 26, 30–38, 69, 72,
 172, 237, 268, 274, 275, 337, 369, 410,
 420, 421, 450–452, 457–459, 483, 506,
 530
 of vectors 452
 Volume rendering 30
 von Neumann
 rejection 97–98, 370
 stability assessment 400, 451, 457–459,
 462, 463, 469–471, 492, 493
 Vorticity 525–529, 530
 VPython 7, 30–32, 38, 39, 362, 425

w

Wang-Landau Sampling (WLS) 369,
 374–376
 Wave
 on catenary 473–475
 electromagnetic 495
 equation 466–468, 472, 475
 functions 378, 383, 431, 434
 packets 172, 466, 482, 486
 shallow water 509

- on string 466–481
- telegraph 497
- Wavelets 195, 196, 222
 - basis 200–203
 - continuous 203–204
 - Daubechies 211–214
 - discrete transform 205–214
 - multiresolution analysis 206
 - pyramid scheme 207–211
 - transform 200–204
- Weak form of PDE 534–535
- Windows 8, 10, 72, 196, 237, 266, 274, 337
- Word length 11, 79
- Working registers 29
- Wormholes 410, 420–422, 425

