Index

'\<', 14  
'\>\>\>', 55  
'\>', 14  
'\<', 14  
'\', 6  
'\%', 9, 37, 176  
'\&\&', 58, 150  
'\:', 52, 79  
'\*', 8, 22, 150  
'\+++\+', 10  
'\+\+', 10  
\in\ complex, 68  
\in\ dynamic\ vector, 672  
\in\ matrix, 670  
\in\ point, 63  
\in\ sparse\ matrix, 692  
'\--\--\-', 10  
'\-\-\-', 10  
\in\ dynamic\ vector, 670  
\in\ sparse\ matrix, 692  
\in\ vector, 666  
'\-=\>\>', 56  
'\///<\>', 8  
'\/<\>', 10  
\in\ complex, 82  
'\<\=\=', 14  
'\=\=\=', 14  
'\>\=\=', 14  
'\&\&\=', 14  
'\&&\=', 14  
'\|\|\=', 14  
'\|=\=', 14  
'\(', 11, 12  
'\[\], 23  
'\%c\=', 20, 37  
'\%d\=', 13  
'\%f\=', 13  
': :', 50  
'\?', 14  
'*=', 10  
\in\ complex, 82  
\in\ sparse\ matrix, 692  
acceleration\ technique, 421, 441, 479, 512  
code, 700  
accuracy, 278  
adaptive  
\algorithm, 590  
discretization, 258  
\mesh (see\ also\ refinement), 258, 448  
refinement (see\ also\ refinement), 379  
address, 22  
of\ nodes, 361  
to\ pass\ an, 24, 25, 54, 57  
to\ temporary\ object, 54  
virtual, 150  
in\ Harwell–Boeing, 475  
of\ nodes, 153, 158  
of\ nonzeroes, 475  
adequacy, 278, 349  
in\ Helmholtz, 521, 523, 573  
in\ Riemann, 293  
in\ Stokes, 511  
ADI (alternating\ direction\ implicit), 298  
algebraic\ multigrid (see\ also\ multigrid), 660  
algebraic\ object, 146  
algebraic\ system, 626  
\algorithm, 3, 166, 173  
adaptive-, 590  
inherently\ sequential, 460  
no-memory, 190, 191  
parallelizable, 460
prime number, 187, 188, 190
complexity, 187, 189, 190
RSA, 193, 202
allocate (see also memory), 5, 51
alternating
direction, 298
Schwarz relaxation, 463
AMG (algebraic multigrid; see also multigrid), 434
AMGe, 445
AMGM, 445
anisotropic, 329, 349
in Stokes, 511
application (see also problem, PDE), xxxi
in three dimensions, 551
in two dimensions, 485
approximate inverse, 450
implementation of, 451, 454
architecture, 460, 470
parallel, 463, 475
sequential, 475
argument
by address, 24, 54
by name, 24, 57, 699
by reference, 59, 73
by value, 24, 54, 57, 59, 73
congrete, 11, 16
constant, 60
in template, 74
input, 51
local, 24, 54
local reference, 58
dummy, 11, 16, 149
local (see also variable), 11
which is a pointer, 24
Aristotle, 136, 140
arithmetic
expression, 36
operation, 9, 260
linear, 148
on complex, 67
on dynamic vector, 99
on matrix, 90
on polynomial, 168
on sparse matrix, 691
on vector, 75
priority order of, 9
array, 23, 150
of addresses, 360
of edges, 153
of nodes, 152
of same-size objects, 117
two-dimensional, 23, 28
assembling, 343, 372, 417
in elasticity, 710
in parallel, 480
in quadratic FE, 396
assignment, 8
assignment operator (see also operator), 60
automaton, 12, 51, 149
axiom, 145, 148
back substitution, 89, 427, 695
bandwidth, 650
base class, 79, 122, 263
basis function, 393, 399
code, 723
high-order, 604, 615, 616, 618
in a tetrahedron, 615, 616
in Navier–Stokes, 658
nodal, 603
in reference tetrahedron, 603, 604
in Stokes, 511
in the three-dimensional mesh, 618
bilinear form, 331, 339, 374, 491
in Maxwell equations, 631
in Navier–Stokes, 514
induced by A, 90
binary representation, 21, 27, 466, 665
bisection, 30
block
in a matrix, 276
of a function, 11
of class, 70
of instructions, 4, 15
relaxation, 462, 474, 477
boundary
condition, 254, 330, 707
as a linear operator, 628
Dirichlet (first kind), 245, 254, 487,
488, 500, 501, 508, 516, 624,
656, 710, 740
implementation, 710, 720, 722, 735, 738, 740
in elasticity, 710
in Maxwell, 740
mixed (third kind), 246, 251, 519, 521, 568, 656, 720, 722, 735, 738
Neumann (second kind), 245, 487, 494, 501, 516, 519, 521, 525, 536, 574
conditions, 602
curved, 161, 389
irregular, 161, 377, 488
layer, 248
matrix, 596, 602
refinement, 387, 388, 490
in elasticity, 501
in Stokes, 510
term, 595
boundary-value problem, 331
cache, 461
oriented, 461, 462
chain rule
in high-order finite elements, 609
in image processing, 316
in inverse problem, 643, 644
in linear finite elements, 342
in Maxwell equations, 742
in Navier–Stokes equations, 742, 745
in Riemann, 284, 296
"char", 7, 39
character (see also "char"), 7
characteristic, 284, 292, 295, 297
Chomsky, 146
class, 48, 147
code, 3
object-oriented, 577
coding, 193, 209, 223
coercion, 333
in elasticity, 495
color image (see also digital), 310
column pointer, 475
comment, 8
common divisor, 44, 191, 666
communication, 465
commutative law, 148
compilation
error, 22
ambiguity, 84
constant, 50
temporary, 54, 60
time, 4, 5
in recursion, 25
in template, 72
compiler, 9
GNU Version 3.2, 5, 87, 169, 370, 383, 409, 416, 554
in assignment, 60
in constructor, 51, 52, 54
in conversion, 63
in function, 12, 17
in inheritance, 81
in operator, 64, 66, 67
in pointer, 22
in template, 72
complex number, 67
implementation of, 68
(has a), 78
(is a), 79
complexity, 459, 470
in graph, 152
in triangulation, 158, 159
prime number, 187, 189, 190
composite function, 607
composition
of functions, 607
of polynomials, 558
computable problem, 3
in polynomial time, 4
computational problem, 3, 165, 459, 470
computational task, 3, 459
computer, 460
digital, 3
parallel, 459
sequential, 459
concrete object (see also argument), 359
concrete variable (see also argument), 16
conformal, 157, 337
conformity, 337, 350, 381, 382
in three dimensions, 579
conjugate gradient, 439
preconditioned, 439, 700
squared, 441, 701
connection machine, 465
conservation law, 283, 297
system of, 297
consistent scheme, 279
"const", 9
argument, 60
current object, 50, 56, 62
in template, 73
returned variable, 54, 56, 695, 696
constant (see also "const"), 9
constraint, 624, 625
homogeneous, 626
constructor, 51, 365
default, 51
in dynamic vector, 122
in inheritance, 80, 266
in list, 263, 264, 679
in template, 74
in assembling, 417
in elasticity, 710
in dynamic vector, 97, 122
context-free, 143
context-sensitive language, 143
convection-diffusion, 251, 676
conversion, 9
explicit, 53
of pointers, 372, 383, 384, 386, 410–412
implicit, 53
in inheritance, 84
inverse, 62
convolution, 199, 216
Cooley, 209
coprime, 191
copy constructor, 59, 71, 365
default, 53, 679
in dynamic vector, 122
in template, 73
in dynamic vector, 98, 122
in inheritance, 679
in linked list, 105
in list, 103
in template, 73
in vector, 75
Cramer formula, 122, 645, 670
Crank–Nicolson (see also semi-implicit scheme), 257
cryptography, 192, 209, 217
cubic (see also function), 396
curl, 505
current object (see also object), 54
Darwin, 138
data (see also data structure), 639
data access
  cache, 461
  edge-to-node, 153
  node-to-edge, 154
  node-to-triangle, 159
  primary memory, 460
  secondary memory, 460
  triangle-to-node, 159, 161
data structure, 95, 150
  for mesh, 327
  for sparse matrix, 405
  to store triangles, 159
  uses pointers, 155
debug, 5
declaration, 50, 57, 66, 678
decoding, 209, 223
decomposition
  ILU (see also ILU), 427
  LU (see also LU decomposition), 124
deduction, 137
defect correction, 535
degenerate triangle, 340, 354
degree
  of freedom, 617
  of polynomial, 604
"delete []", 97
"delete", 55
  in template, 365
delete (see also "delete"), 55
denoising, 307, 687
color, 311, 687
in a surface, 314
Wiener filter, 312
derererencing, 150
derivative
  normal, 606, 612
derived class, 79, 122, 262
Index

destructor, 55, 365
default, 68, 365
  in dynamic vector, 98
  in inheritance, 81
  in vector, 75
determinant (see also matrix), 88, 123, 125
diagonally dominant, 274, 340, 348
difference operator, 265
  in two dimensions, 678
difference scheme (see also finite), 230
differential operator, 507, 514
  nonlinear, 303
  quasi-linear, 303
diffusion
  coefficient, 349, 487
  convection-, 251, 676
  equation, 487
  nonlinear, 308
  problem, 329
  solver, 707
  strong, 350
  time-dependent, 308, 330, 491
  weak, 350
digital image, 307, 687
  color, 310, 687
  grayscale, 307
direct method, 421
  in inverse problem, 648
Dirichlet (see also boundary, condition), 245
discretization (see also finite difference),
  252, 309
discretization error, 278, 568
  in Helmholtz, 522, 523, 570
  in Riemann, 294
distributed memory, 464
distributive law, 148
divergence, 504
  equation, 742
  free, 506
  in Maxwell equations, 529, 629
  zero, 506, 529
divisor, 44, 191, 666
"do", 18
domain
  circular, 352
  complicated, 377, 487
  decomposition, 442
  in Stokes, 515
  irregular, 337, 377
  nonconvex, 389
  rectangular, 269, 308, 344
  time-space, 245, 255
    in Riemann, 284
    in two dimensions, 297, 685
    the implementation of, 259
domain decomposition (see also domain), 515
"(double)", 9
"double", 7
double precision (see also "double"), 7
dynamic matrix, 121
  code, 672
  in convection, 677
  in denoising, 687
  parallel, 705
dynamic vector (see also vector), 96
dec
  array of, 153
  in graph, 119, 150
  in mesh, 617, 729
  in triangulation, 156
elasticity
  linear, 493, 507
  general, 506, 511
  solver, 710
electric field, 528
electricity equations, 633, 734, 742
electromagnetic, 519, 528
"else", 14
eelse, 14
encoding, 193
energy inner product, 356
energy norm, 440, 477, 510, 512
  of matrix, 356
Enzensberger, 139
equation (see also PDE)
  in three dimensions, 551
  in two dimensions, 485

error, 568
  in Helmholtz, 570
  minimizing the, 640
error estimate, 350, 423
  computational, 232
  discretization, 280
  Taylor scheme, 236
Euclid's algorithm, 44, 191, 666
Euler, 204
execute, 3
execution, 12
existence
  in ODE, 225, 234, 239
  in PDE, 334
explicit scheme, 255, 276, 685
exponent function, 39
  of matrix, 89
exponential time, 3
factorization
  ILU (see also ILU), 427
  LU (see also LU decomposition), 124
  prime, 44, 665
FEM (finite element method), 327
Fermat, 203
FFT, 165, 199, 209, 212
  implementation of, 213
  in cryptography, 217
"FILE", 25, 476
file
  of instructions, 465
  open a, 25
  output, 6
  pointer, 25, 476
  print on, 25
  read from, 25
  static, 39
  variable, 25, 476
fill-in, 403, 421, 650
  in ILU, 427, 433, 442, 456, 491
  implementation, 695
filter, 312
finite difference, 252, 676
  in Helmholtz, 521, 569
  in ODE, 230
finite element (FE), 327, 359
  adaptive, 577, 579, 590
  bilinear, 522
  constant, 511, 658
  cubic, 396
  high-order, 393, 398, 446, 603
  code, 723
  implementation, 729
  in elasticity, 496
  in Maxwell equations, 631
  in Navier–Stokes, 658, 744
  in three dimensions, 718
  linear, 337, 658
  mesh (see also refinement), 488
  nonlinear, 527
  of order 5, 398, 603
  quadratic, 394
  the implementation of, 364
fixed-point iteration, 45
fixed-point problem, 45
"(float)", 42
"float", 7
float number (see also "float"), 7
"fopen", 25, 476
"for", 18
for, 18
form
  bilinear (see also bilinear form), 90
  weak (see also weak formulation), 630
formal language, 145, 146
forward elimination, 89, 427, 695
FOSLS (first-order-system-least-squares), 513
Fourier, 520
  coefficient, 530
  cosine, 570, 575
  decomposition, 536
  matrix, 210
  sine, 349
  transform, 199, 209, 530
  discrete, 209
  fast (see also FFT), 212
  implementation of, 213
  inverse, 210
"fprintf", 25
friend, 57
Index

"fscanf", 25, 476
function, 4, 8, 11
  argument in, 23
  basis (see also basis function), 603
  composite, 607
  composition of, 607
  elemental basis, 511, 658
  friend, 57
in a tetrahedron, 607, 608, 610, 612
in the three-dimensional mesh, 607, 608, 610, 612
interface, 48, 49
  constructor is an, 51
  current object in, 54
  parallelized, 469
  returned object in, 54
language, 149
member, 55
nodal basis, 342, 603, 742
  conformity in, 382
  in elasticity, 497
  in time marching, 492
  linear, 348, 393, 658, 742
  quadratic, 394
overloaded, 15, 713
three dimensions, 357
typical nodal
  bilinear, 522
  linear, 341
fusion, 533, 713
  algorithm, 539
  problem, 535
Gauss elimination, 88, 403
Gauss–Newton iteration, 642
Gauss–Seidel relaxation, 424, 461, 653, 681
  block, 463, 474
  Newton–, 652
  symmetric, 426, 474, 477
GCD (greatest common divisor), 44, 191, 666
geometric multigrid, 660
Gersgorin theorem, 273, 685
"getchar", 39
global
  array, 182
  function, 260
    in parallelism, 479
    integer, 705
    refinement, 377, 392, 488
GMRES (general minimal residual), 442, 512, 703
GNU, 5, 87, 169, 370, 383, 409, 416, 540, 554
God, 136, 147
Godunov scheme, 286, 290, 295
  explicit, 291, 298
  implicit, 304
golden-ratio algorithm, 33–35, 640, 653
gradient, 308, 503, 625
  continuous, 399
  in high-order FE, 608
  of cubic function, 397
  of divergence, 506
  of nodal basis function, 343
  of nodal function, 343, 373, 417
  of quadratic function, 396
  vanishes, 348
Gram–Schmidt, 90
graph, 119
  coloring, 150
grayscale image, 307
greatest common divisor, 44, 191, 666
Green
curl formula, 632, 635
  divergence formula, 331, 635
    in elasticity, 494
    in Navier–Stokes, 656
    in Riemann, 284, 287
function, 340
grid, 161
  in ODE, 229
  in PDE, 252, 263
    in two dimensions, 269, 677
  rectangular, 254
time-space, 276
  in two dimensions, 677
  the implementation of, 263
Hahn–Banach theorem, 626
Harwell–Boeing collection, 154, 475
  numerical results, 477
  read matrix, 476
"has a", 47, 78, 369
heap memory, 127
heat equation, 246, 280
Helmholtz equation, 444, 521, 530, 567, 597
error estimate, 567, 570
in inverse problem, 642, 654
in one dimensions, 568
in three dimensions, 530, 567, 574, 593
nonlinear, 567, 574, 593, 597, 641
Hermitian, 633
adjoint, 418, 456
in Maxwell equations, 633
Hessian
in high-order finite elements, 608, 610, 619, 622
in image processing, 316
in inverse problem, 652
in Newton iteration, 301
hidden
in inheritance, 78
in parallelism, 472, 705
in polynomial, 171
in recursion, 35
hidden storage, 96, 173
high-level code
in ODE, 232, 236
in parallelism, 469
high-level language, 4, 460
high-level object, 160
high-level programming, 166
in inheritance, 81
Horner algorithm, 174, 558
in composition, 558
in exponent, 40
in Fourier transform, 211
in ODE, 230, 232, 237
in power, 176
in Taylor series, 179
human language, 136, 142, 145, 146
hypercube, 466, 472
I/O (see also input/output), 4
"if", 13, 14
if (see also "if"), 13
ILU (incomplete LU)
decomposition, 427
factorization, 427
iteration, 695
no fill-in
in multigrid, 433, 442, 491
the implementation of, 695
image processing (see also digital), 307, 533
implementation, 3, 155, 165, 173, 258
downward, 152, 158
in fusion, 540
of matrix, 599
parallel, 459, 460, 705
low-level, 469, 472
upward, 152
implicit scheme, 256, 276, 491
in denoising, 309
impressionism, 139
include, 13, 20
"include", 13, 20
incomplete factorization (see also ILU), 427
infinite integral, 560
infinite matrix, 512
infinite problem, 509, 537
indexing
direct, 104, 117
indirect, 104, 117
of edges in mesh, 617, 729
of finite elements
in Stokes, 511
of nodes, 362
in finite element, 367
in mesh, 370
of sides in mesh, 617, 732
induction, 137
hypothesis, 145
mathematical, 145
information, 160, 167
inheritance, 78
initial-boundary-value problem, 251
initialization list, 52, 68, 259, 437
in dynamic vector, 98
in inheritance, 80
initialize, 8, 48, 51
inner product, 77
  real, 91, 412
input/output, 3, 13, 24, 460
"(int)", 9
"int", 7, 11
  long, 187
integer
  long, 195
integer (see also "int"), 7
integral
  indefinite, 560
  over interval, 184, 561
  over unit tetrahedron, 562, 715
  over unit triangle, 184, 561
interval
  integral over, 184, 561
inverse
  approximate-, 450, 451, 454
  conversion (see also conversion), 62
  of a matrix, 88, 124, 126, 570
  problem, 551, 639
"is a", 47, 78, 369
isotropic, 347
iteration, 534
  fixed point, 45
  Gauss–Newton, 642
  ILU, 695
  in inverse problem, 653
  Kacmarz, 427, 468, 694
  multigrid (see also multigrid), 696
  Newton (see also Newton), 599
  Picard, 45
  Schwarz, 462
iterative method (see also iteration), 421
  in inverse problem, 650
Jacobi relaxation, 425, 472, 474, 477
  block-, 474, 477
Jacobian, 534
  in elasticity, 742
  in finite elements, 342
  in high-order finite elements, 608
  in image processing, 316
  in inverse problem, 644
  in Maxwell equations, 637
  in Navier–Stokes, 655, 663
  in Newton iteration, 301
  in nonlinear Helmholtz, 567, 599, 602
  tensor, 644
Jordan, 227
  form, 229, 274, 686
  matrix, 280, 304
Kacmarz iteration, 427, 468, 694
Kant, 144
Krylov, 439, 440, 700, 703
Kuramoto–Sivashinsky, 235
L-matrix, 340
Lacan theory, 148
Lagrange multiplier, 626
language, 148
  formal, 145, 146, 148
  human, 136, 142, 145, 146
  natural, 142, 145, 146, 148
Laplace equation, 340
Laplacian, 504
  discrete, 745
  in fusion, 536
  vector, 504, 506, 514
  weak form, 745
Levinas, 138
linear arithmetic, 148
linear convergence, 302
linear elasticity (see also elasticity), 710
linear operation, 148
linear system (see also matrix), 403
  in implicit scheme, 257
  solvers, 421, 488
linearization, 534, 625
  in denoising, 310
  in inverse problem, 644
  in Navier–Stokes, 514, 659
  in Riemann, 292, 293
linked list, 104, 117
  flexibility of, 117, 161
  in row, 409
  in sparse matrix, 155, 405
  in triangulation, 159, 161, 369
  of edges, 154
  of integers, 156, 360
  of nodes, 360
of triangles, 161, 361, 369
linked list (see also connected), 104
Lispector, 137
list, 101, 117, 262
of instructions, 3
of linked lists, 159
of nodes, 366
of operations, 165
of rows, 405, 413
of variable-size objects, 117
local
argument (see also variable), 11
in parallelism, 479
maximum, 30
object (see also variable), 167
refinement (see also refinement), 377
variable (see also variable), 12
logical
and, 14, 62
if, 7
not, 69
operator, 14, 62
priority order of, 14, 62
or, 14
"long int", 187
long integer, 187, 195
long number, 195
loop, 17, 19
nested, 20, 429
in array, 23, 28
over edges, 154
over triangles, 159, 162
over vertices, 373
subloop, 481, 705
low-level
in parallelism, 459, 469, 472
language, 4
object, 233, 372
programming, 166
in polynomial, 171
low-level object, 160
LU decomposition, 88, 124, 427
block, 512
in inverse problem, 650
in PDEs, 507
LU factorization (see also LU decomposition), 124
M-matrix, 340, 347
M-matrix, 340, 347
magnetic field, 528
"main", 12
manifold
invariant, 234, 238
stable, 234, 238, 239
mass matrix (see also matrix), 596
code, 720
"math.h", 17
math.h, 17
mathematical
formulation, 642
induction, 145
mathematics, 145, 148
MATLAB, 312
matrix, 85
bandwidth, 650
boundary, 596, 602
code, 668
dense, 405
determinant of, 88, 123, 125, 670
dynamic-, 121
code, 672
in convection, 677
in denoising, 687
parallel, 705
element, 406
exponent of, 89
indefinite, 512
inverse of, 88, 124, 126, 670
L-, 340
M-, 340, 347
mass, 596
code, 720
nonlinear, 597
minor of, 122
negative definite, 512
positive definite, 340
rectangular, 432
sparse, 405
coloring of, 152, 155
multiplication of, 468
operators on, 691
the implementation of, 413
transpose of, 693
SPD, 340
stiffness-, 337, 339, 596, 722
code, 720
high-order, 620
in elasticity, 497, 710
in Navier–Stokes, 659, 744
in parallelism, 480
in three dimensions, 595
symmetric, 339
to assemble, 343, 372, 417
symmetric, 151, 339, 340
symmetric part of, 442
transpose of, 670
tridiagonal-, 257, 265, 353, 405, 462
in Helmholtz, 569
Jordan form, 686
maximum, 30
Maxwell equations, 528, 623, 650
implementation, 734
in inverse problem, 642
nonlinear, 623, 634
Maxwell system (see also Maxwell equations), 642
member, 55
  private, 56, 62, 68, 72, 80
    in tree, 119
  protected, 80, 410
  public, 66, 72
    in inheritance, 80, 81
    in linked list, 105
memory, 3, 460
  allocation, 5, 33, 68
    in dynamic vector, 97
distributed, 464
heap, 127
in array, 23
in constructor, 51, 53
in destructor, 55
in recursion, 25
in template, 74
long, 180, 237, 271
primary, 3, 127, 135, 460
secondary, 3, 127, 135, 460
shared, 463
short, 180, 232, 271
stack, 127
merging linked lists, 113
mesh, 161
  adaptive (see also refinement), 448
class, 369, 689
function in the, 607
in ODE, 227, 230
nonuniform, 337, 359, 377
refinement, 384
  in high-order, 620
  in three dimensions, 581, 620
the implementation of, 369
distributed, 464
three-dimensional, 718
two-dimensional, 706
uniform, 344
unstructured, 337, 359
meshsize
  in ODE, 227, 230
  in PDE, 252
  in two dimensions, 269
midpoint scheme (see also semi-implicit scheme), 257
Miller, 206
MIMD (multiple instruction and multiple data), 465
minimization problem, 332, 623
  constrained, 624
  in elasticity, 495
  in inverse problem, 644
  of the error, 640
minor of matrix, 122
mixed (see also boundary, condition), 656
model
  circular, 526
  physical, 258
  rectangular, 525
modular, 5
modulus, 192
molecule, 445
multidimensional scaling, 316
multigrid, 431, 435, 442, 489, 696
  algebraic, 434, 442, 489, 660, 698
  black-box, 444
  for adaptive mesh, 448
  for finite elements, 446, 448
  for fusion, 533, 539, 713
<table>
<thead>
<tr>
<th>770 Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>for nonlinear equation, 534</td>
</tr>
<tr>
<td>for nonsymmetric, 442</td>
</tr>
<tr>
<td>for system, 446</td>
</tr>
<tr>
<td>for systems of PDEs, 498, 509, 660, 747</td>
</tr>
<tr>
<td>geometric, 660</td>
</tr>
<tr>
<td>in elasticity, 498</td>
</tr>
<tr>
<td>in Navier–Stokes, 660, 747</td>
</tr>
<tr>
<td>in Stokes, 509, 515, 747</td>
</tr>
<tr>
<td>parallel, 478</td>
</tr>
<tr>
<td>multilevel</td>
</tr>
<tr>
<td>programming, 166</td>
</tr>
<tr>
<td>Nabla, 503</td>
</tr>
<tr>
<td>natural language, 142, 145, 146</td>
</tr>
<tr>
<td>Navier–Stokes equations, 514, 655, 744</td>
</tr>
<tr>
<td>negative definite, 509, 512</td>
</tr>
<tr>
<td>Neumann (see also boundary, condition), 245</td>
</tr>
<tr>
<td>&quot;new&quot;, 127, 162, 365, 422</td>
</tr>
<tr>
<td>dynamic vector, 97</td>
</tr>
<tr>
<td>graph, 120</td>
</tr>
<tr>
<td>linked list, 105</td>
</tr>
<tr>
<td>row, 429, 468</td>
</tr>
<tr>
<td>new (see also &quot;new&quot;), 97</td>
</tr>
<tr>
<td>Newton</td>
</tr>
<tr>
<td>binomial, 29, 181, 204</td>
</tr>
<tr>
<td>Gauss–, 642</td>
</tr>
<tr>
<td>Gauss–Seidel, 652</td>
</tr>
<tr>
<td>iteration, 44, 299, 305, 599, 734</td>
</tr>
<tr>
<td>convergence rate, 300</td>
</tr>
<tr>
<td>divergence, 301</td>
</tr>
<tr>
<td>error estimate, 300</td>
</tr>
<tr>
<td>for PDE, 303, 310, 567, 599, 734</td>
</tr>
<tr>
<td>for vector equation, 301, 316, 534, 567, 599, 734</td>
</tr>
<tr>
<td>Hessian, 301</td>
</tr>
<tr>
<td>implementation, 735, 739, 741</td>
</tr>
<tr>
<td>in denoising, 310, 311</td>
</tr>
<tr>
<td>in Helmholtz, 567, 598, 599, 620</td>
</tr>
<tr>
<td>in inverse problem, 642, 646</td>
</tr>
<tr>
<td>in Maxwell, 635, 734</td>
</tr>
<tr>
<td>in Navier–Stokes, 514</td>
</tr>
<tr>
<td>in Riemann, 293, 294</td>
</tr>
<tr>
<td>in system, 298</td>
</tr>
<tr>
<td>linear convergence, 302</td>
</tr>
<tr>
<td>relaxed, 302</td>
</tr>
<tr>
<td>superlinear convergence, 300, 302</td>
</tr>
<tr>
<td>Newton–Raphson (see also Newton), 44, 293, 299</td>
</tr>
<tr>
<td>no-memory, 190, 191</td>
</tr>
<tr>
<td>nodal basis function (see also function, basis), 742</td>
</tr>
<tr>
<td>node, 161</td>
</tr>
<tr>
<td>array of, 152</td>
</tr>
<tr>
<td>in graph, 119, 150</td>
</tr>
<tr>
<td>in triangulation, 156</td>
</tr>
<tr>
<td>the implementation of, 362</td>
</tr>
<tr>
<td>nonlinear</td>
</tr>
<tr>
<td>differential operator, 303</td>
</tr>
<tr>
<td>equation, 534</td>
</tr>
<tr>
<td>Helmholtz equation, 567, 593, 597, 641</td>
</tr>
<tr>
<td>Maxwell equations, 623, 634, 642</td>
</tr>
<tr>
<td>optics, 593</td>
</tr>
<tr>
<td>system, 533</td>
</tr>
<tr>
<td>nonlinear mass matrix (see also matrix), 597</td>
</tr>
<tr>
<td>nonlinear PDE (see also PDE), 283</td>
</tr>
<tr>
<td>nonsymmetric system, 433, 442</td>
</tr>
<tr>
<td>nonuniform mesh (see also mesh), 377</td>
</tr>
<tr>
<td>normal derivative, 606, 612</td>
</tr>
<tr>
<td>normal equation, 426, 468, 694</td>
</tr>
<tr>
<td>number</td>
</tr>
<tr>
<td>long, 195</td>
</tr>
<tr>
<td>numerical</td>
</tr>
<tr>
<td>approximation, 273</td>
</tr>
<tr>
<td>in Helmholtz, 521</td>
</tr>
<tr>
<td>in ODE, 229, 235</td>
</tr>
<tr>
<td>in PDE, 249, 340, 382, 421</td>
</tr>
<tr>
<td>in Stokes, 511</td>
</tr>
<tr>
<td>example</td>
</tr>
<tr>
<td>in elasticity, 499</td>
</tr>
<tr>
<td>scheme (see also semi-implicit scheme), 161</td>
</tr>
<tr>
<td>solution</td>
</tr>
<tr>
<td>in ODE, 229, 240</td>
</tr>
<tr>
<td>of linear system, 403</td>
</tr>
<tr>
<td>object, 5, 47, 146, 262</td>
</tr>
<tr>
<td>abstract, 359</td>
</tr>
<tr>
<td>algebraic, 146</td>
</tr>
<tr>
<td>concrete (see also argument), 359</td>
</tr>
</tbody>
</table>
Index

(current, 49, 54
"const", 62
"this", 56, 58, 64
in inheritance, 80, 169
in template, 74
nonconstant, 65, 70
reference to, 61
temporary, 67
implementation, 147
local (see also variable), 167
returned, 54, 65, 174
constructed, 167
nonreference, 69, 71
temporary, 54
type of, 60
segmentation, 313
temporary, 67, 170
nonconstant, 65
pointer to, 54
returned, 67
to change, 60, 64, 170
object-oriented, 360
analysis, 234
code, 577
implementation, 165, 578
in nonlinear Helmholtz, 599
language, 5, 47, 149
programming, 65, 67, 136, 577, 599
ODE (ordinary differential equation), 225
Helmholtz, 568
nonlinear, 234
quasi-linear, 247
stable, 226
system of, 226
stable, 227
one dimension (see also ODE), 568
one-dimensional, 269
OOP (see also object-oriented), 577
open a file, 25
operating system, 127
UNIX, 5
Windows, 6, 127
operation (see also operator), 9
operator, 62
arithmetic (see also arithmetic), 67
assignment, 60
of complex, 68
of dynamic vector, 99
of linked list, 107
of list, 103
binary, 65
curl, 505
differential, 507, 514
nonlinear, 303
quasi-linear, 303
divergence (see also divergence), 504
gradient (see also gradient), 503
Laplacian, 504
logical (see also logical), 14
Nabla, 503
rotor, 505
unary, 63
ordering linked list, 116
output, 12
overloading, 17, 713
Padé, 41, 90
parallel, 651
architecture, 463
computer, 459
implementation, 459, 472, 705
line and plane, 615
multigrid, 478
parallelism, 459, 470
global part, 479
local part, 479
parallelizable, 460, 470
partial derivative, 605
code, 717
Pascal
calculation machine, 3
triangle, 28, 182
PCG (preconditioned conjugate gradient; see also conjugate), 439
PDE (partial differential equation), 161, 245
elliptic, 246
Helmholtz, 567
hyperbolic, 247
in three dimensions, 551, 574
in two dimensions, 485
nonlinear, 283, 567
   in denoising, 308
   system, 514
   system of, 297, 311
parabolic, 247
quasi-linear, 283, 514
system of, 297, 446, 493, 506, 528, 567
three-dimensional, 530
time-dependent, 492	
two-dimensional, 269, 507, 676
Picard iteration, 45
Plato, 136
poetry, 139
pointer, 22
   as argument, 24
   in human language, 138
   in linked list, 104
   to character, 22
   to constant, 22, 56, 368
   to constant point, 56
   to double, 22, 23, 97
   to file, 25, 476
   to integer, 22, 24
   to linked list
      converted from, 383, 384, 386, 410, 412
      to mesh, 383
      converted to, 372, 383, 384, 386
      local, 690
   to multigrid, 435
to node
   in triangle, 361, 365
to nonconstant, 22, 368
to point, 56
to "point" object
   is returned, 56
to pointers, 23
to row
   converted to, 410–412
to static file, 39
to T, 101
to temporary object, 54
Poisson equation, 246
   in a circle, 352, 706
   in FOSLS, 513
Jacobi iteration for, 426
   one-dimensional, 354
   stiffness matrix in, 373
   ratio, 493, 499, 501
   in Stokes, 510
polynomial, 168, 553
   adding, 555
calculation of, 172, 174, 558
   composition
      Horner algorithm, 558
   composition of, 558
   Horner algorithm, 558
   in composition, 558
   implementation of, 168, 553
   integration of, 184, 560–562, 715
   multiplication of, 171, 557
   multiplying by scalar, 171, 556
      of degree 5, 398, 603
      of three variables, 222, 560
      integration, 562, 715
      of two variables, 182, 492, 559, 673, 676
      cubic, 396
      integration, 184, 561
      quadratic, 394
      partial derivative, 717
      sparse, 674
time, 3, 4
positive definite, 340, 509
positive semidefinite, 339, 537
preconditioner, 423, 441, 473, 487
   in elasticity, 493
   in Stokes, 511
pressure function, 515, 655, 660, 662
primary memory (see also memory), 3, 460
prime factors, 44, 665
prime number, 186, 190
print (see also "printf", "fprintf"), 13
   "printf", 13
   "private:", 50
   "private", 49
private (see also "private"), 49
private member (see also member), 56
problem
   boundary value, 331
   computational, 3, 165, 459, 470
Index 773

diffusion (see also diffusion), 308
  in three dimensions, 551, 574
  in two dimensions, 485
indefinite, 509
initial-boundary value, 251
inverse, 639
minimization, 332, 623
  constrained, 624
  in elasticity, 495
  in inverse problem, 644
  of the error, 640
quasi-linear, 308
saddle-point, 509
  the measuring, 524
process, 149
processor, 3, 460
  main, 465
processors, 459, 463
program (see also "main"), 3, 12
  executable, 465
programming, 3
  object-oriented, 577, 599
prolongation, 432, 434, 442, 697
  in Stokes, 516
"protected:", 80
"protected"
  in dynamic vector, 97, 122
  in linked list, 104
  in list, 262, 265, 475, 682
  in polynomial, 169
protected (see also "protected"), 80
protected member (see also member), 80
".public", 79
"public:", 49, 68, 72
public (see also ".public"), 49
public member (see also member), 66
quadratic (see also function), 394
quadratic form, 333, 335, 339
  in elasticity, 495
  in FOSLS, 513
quasi-linear
  differential operator, 303
  in Stokes, 514
ODE, 247
PDE, 283
  problem, 308
Rabin, 206
random-choice scheme, 289
rarefaction wave, 284, 295
read (see also "fscanf"), 24
real time, 127
rectangular
  domain, 269, 308, 344
  grid, 254
  matrix, 432
recursion, 25, 146
  Horner algorithm, 558
  in arithmetic expression, 36
  in binary representation, 27
  in FFT, 209, 213
  in linked list, 109
  in local maximum, 35
  in mesh refinement, 384
  in multigrid, 435
  in row, 411
reference, 57
  tetrahedron, 593
to pass a
  to finite element, 369
to node, 382
to row, 695
to vector, 412, 426, 699
to return a, 59, 65, 69, 430
reference element, 522
reference triangle
  cubic, 396
  linear, 340, 394
  quadratic, 394
referencing, 150
refinement, 384
  adaptive, 379, 706
    in elasticity, 498
    in Helmholtz, 577, 579, 590
    in three dimensions, 577, 579, 590
  boundary, 377, 387, 388
  global, 377, 392, 488
  in high-order, 620
  in three dimensions, 581, 620
  local, 377
  step, 581, 620
regularity, 385
relaxation (see also Jacobi, Gauss–Seidel), 302, 461
reserved word, 4
"return", 12
return, 11, 12, 32
  by reference, 59, 65, 69, 430, 696
  by value, 59, 65, 69, 430, 695, 696
returned (see also object, "const"), 54
returned object (see also object), 54
Reynolds number, 514
RGB image, 310, 320
Richardson extrapolation, 653
Riemann problem, 283
  linearized, 293
  N-wave, 290
  singularly perturbed, 291, 292, 294, 297
Rilke, 140
rotor, 505
Rousseau, 149
row object, 409
RSA algorithm, 193, 202
run, 3
  time, 4, 25, 127
    in dynamic vector, 96
    in linked list, 107
    in list, 101
saddle-point problem, 509
scan (see also "fscanf"), 24
"scanf", 24
scheme (see also finite difference,
    implicit scheme, semi-implicit
    scheme), 161
Schur complement, 509, 512
  in PDEs, 507
  preconditioner, 637
Schwarz iteration, 462
scope, 15
secondary memory, 3, 460
segmentation, 313
semi-implicit scheme, 257, 276, 491
semidefinite, 339, 537
sequential
  algorithm, 460
  computer, 459
shape, 156
shared memory, 463
Shimborska, 135
shock wave, 285, 295
side
  in mesh, 617, 732
SIMD (single instruction and multiple data), 17
singular perturbation, 291
"sizeof", 42
sizeof, 42
skew-symmetric, 645, 646
solution
  asymptotic, 238
  irregular, 514
  numerical (see also numerical), 229
  unique, 335
soul, 138
sparse matrix (see also matrix), 152
sparse polynomial, 674
sparsity, 398
SPD (symmetric positive definite), 340, 440, 473, 537, 660, 700
Spinoza, 138
stability, 273, 276, 685
stable ODE (see also ODE), 226
stack memory, 127
standard I/O (see also "stdio.h"), 13
state machine, 12, 51, 149
"static", 39
static file, 39
"stdio.h", 13
stiffness matrix (see also matrix), 337, 596, 722
code, 720
stiffness system (see also matrix), 338
Stokes equations, 508, 511
storage, 51, 167
  in inheritance, 81
string, 36
  as input, 36
  to copy a, 36
  to print a, 13, 24
strong formulation, 331
  in elasticity, 493
  in Navier–Stokes equations, 655
subshape, 156
subspace
  invariant, 228
  stable, 228
  Krylov, 439, 440, 700, 703
superlinear convergence, 300, 302
symmetric
  bilinear form, 331, 336
differencing, 252, 257
matrix, 151
part of matrix, 442
PDE, 327
skew-, 645, 646
  stiffness matrix, 339, 340, 512
system (see also PDE, linear, matrix), 257, 533
  algebraic, 626, 658
discrete, 658
  stiffness, 658
tangent
to plane, 615
task
  assigning, 465
  computational, 3, 459
  modularity in, 4
  recursion in, 36
Taylor
  approximation, 90	error, 178, 233
  expansion, 40, 178
  polynomial, 40
  scheme, 231, 234, 236, 240
template, 71, 96
  in dynamic vector, 97
  parameter, 214
tensor, 609, 610
  in inverse problem, 643
  Jacobian-, 644
tetrahedron, 357, 364, 369, 590
  adjacent, 579
general, 607, 608
  integral over, 562, 715
  reference, 593, 603
TFQMR (transpose-free quasi-minimal residual), 442, 701

theorem
  Gersgorin, 273, 685
  Hahn–Banach, 626
"this", 56, 58
this (see also "this"), 56
three dimensions (see also problem, PDE), 551
three-dimensional (see also problem, PDE), 551
time
  compilation (see also compilation), 4
  exponential, 3
  polynomial, 3, 4
  real-, 127
  run (see also run), 4
time level, 254, 275, 491, 677
time marching (see also implicit scheme, semi-implicit scheme), 254, 276, 491
time step, 254, 275
time-space domain (see also domain), 245
time-space grid (see also grid), 263
Toeplitz matrix, 354
trace of matrix, 238, 635, 656
tree, 118
triangle
  integral over, 184, 561
triangulation, 156, 337
tridiagonal matrix, 257, 265, 353, 405, 462
  in Helmholtz, 569
  Jordan form, 686
truncation error (see also discretization error), 568
Tukey, 209
Turing, 3
  machine, 3, 166
two dimensions (see also problem, PDE), 485
two-dimensional (see also problem, PDE), 485
type (see also variable), 7
"typedef"
cubic triangle, 397
  matrix, 87, 670
index
point, 78
quadratic triangle, 395
triangle, 368
typedef (see also "typedef"), 78

uncomputable problem
practically, 3
uniqueness, 335
UNIX, 5
unsolvable problem
practically, 3
unstructured mesh (see also mesh), 359
upwind scheme, 253

variable (see also object, current, "const"),
7, 15, 54
congcrete (see also argument), 16
local, 12, 15, 58
in constructor, 54
in function, 39
in loop, 19
return, 59, 65, 430
returned, 69
pass by address, 57
vector, 75, 117
code, 666
dynamic, 96, 117
code, 670
velocity function, 655, 660, 662
Verlaine, 139
virtual address (see also address), 150
"void", 11, 12
void, 11, 12
Von Neumann, 3

wave equation, 519
weak formulation, 330
discrete, 338
in elasticity, 494
in Maxwell equations, 630
in Navier–Stokes equations, 656
weak sense, 284
well-posed, 331, 332, 337
in elasticity, 494, 495
in Navier–Stokes equations, 657
"while", 18
while (see also "while"), 18
Whitman, 140

Wiener filter, 312
Windows, 6, 127
Wittgenstein, 136
word, 136, 138
write (see also "printf", "fprintf"), 13