Index

(1 + 1)-ES, 213
(µ + 1)-ES, 214
(µ + λ)-ES, 221
(µ, λ)-ES, 221
α-cut, 461
α-cuts, 269
λ-branching factor, 375
τ(µ/ρ, κ, λ)-ES, 233
r-continuous matching rule, 428
z-score normalization, 104
gbest PSO, 290, 292
lbest PSO, 291, 292
2-opt heuristic, 407
3-opt heuristic, 407

absolute fitness, 133, 193, 277
acceleration coefficients, 290, 312
  linear adaptive, 313
  nonlinear adaptive, 313
activation function, 6, 18
  adaptive, 115
  Gaussian function, 20
  hyperbolic tangent function, 20
  linear function, 18
  ramp function, 18
  sigmoid function, 20
  step function, 18
active learning, 116
  definition, 118
  expected misfit, 121
  incremental learning, 119, 120
  pseudocode algorithm, 123
  selective learning, 119, 120
adaptive activation function, 115
adaptive task allocation, 395
affinity, 416
  antigen, 427
  artificial lymphocyte, 431
age, 270
age subcaste, 392
aggregation methods
  bang-bang, 571
dynamic, 571
aiNet, 442
allele, 8, 129, 130
allopatric speciation, 568
analysis of performance, 98
  confidence interval, 99
angle modulated differential evolution, 253
angle modulation, 253
annealing schedule, 558
ant algorithm, 359
  ant colony optimization, 360
  cemetery organization, 384
  division of labor, 391
ant algorithms, 9
ant clustering
  basic model, 385
  behavioral switches, 389
  different moving speeds, 388
  dissimilarity measures, 389
  heterogeneous ants, 390
  Lumer–Faieta, 386
  minimal model, 391
  short-term memory, 389
ant colony optimization, 360
ant colony system, 372
ant system, 368
ant-Q, 378
antabu, 380
ANTS, 381
AS-rank, 380
continuous, 396
dynamic environment, 402
fast ant system, 379
max-min ant system, 375
multi-objective, 398
parameters, 383
quadratic assignment problem, 407
simple ACO, 364
stigmergy, 363
termination condition, 366
transition probability, 365, 368, 369, 372
transition rule, 378
traveling salesman problem, 406
ant colony system, 372
ant system, 368
ant-cycle, 370
ant-density, 370
ant-quantity, 370
ant system-rank, 380
ant-Q, 378
antabu, 380
antibodies, 416
antigen, 9, 415, 416
affinity, 427
antigen presenting cells, 423
ANTS, 381
approximate reasoning, 10
architecture selection, 109
construction, 111
objective, 114
particle swarm optimization, 356
pruning, 111
regularization, 110
using sensitivity analysis, 114
artificial immune network, 436
artificial immune system, 10, 413, 425
basic algorithm, 426
classical view, 428
clonal selection, 431
danger theory, 445
negative selection, 12, 427
network theory, 436
artificial intelligence, 3, 11
definition, 4
artificial lymphocyte, 426
artificial neural network, 5, 7, 15
definition, 16
artificial neuron, 6, 17
activation function, 18
augmented vectors, 23
bias unit, 23
definition, 17
error-correction, 25
generalized delta, 25
geometry, 20, 51
gradient descent, 24
learning, 21
net input signal, 17
weights, 6
Widrow-Hoff, 25
artificial recognition balls, 436
associative memory, 55
asynchronous updates, 310
attraction, 326
attractive and repulsive PSO, 327
augmented vectors, 23
autocatalytic behavior, 361
average award model, 85
B-Cell, 417, 418
dynamic weighted, 441
backpropagation, 38
backward propagation, 38
feedforward pass, 38
backpropagation-through-time, 34
backward propagation, 38
bagging, 52
bang-bang aggregation, 571
barebones PSO, 320
basic ant clustering, 385
batch learning, 37, 41, 65, 108
batch map, 65
beam search, 139, 556
behavioral switches, 389
belief cells, 271
belief space, 262
fuzzy, 269
knowledge components, 264
domain, 265
history, 265
normative, 266
situational, 264, 266
topographical, 265
best matching neuron, 66
bias, 17
bias unit, 23
binary bridge experiment, 361
binary differential evolution, 254
binary encoding, 130
binary PSO, 340
biological neural systems, 5
biomorphs, 161
Boltzmann selection, 138
Boltzmann–Gibbs distribution, 557
Boolean logic, 451
Index

boosting, 53
boundary constraints, 256, 561
building-blocks, 159, 184

cascade network, 35
output, 35
Cauchy mutation, 191, 201
Cauchy mutation PSO, 325
cemetery organization, 384
ant clustering, 385
central limit theorem, 99
chaos factors, 335
charged PSO, 337
cheap PSO, 322
chromosome, 8, 129
chromosome representation
finite-state machine, 207
function optimization, 209
routing optimization, 174
classical evolutionary programming, 200
classical optimization, 141
classical view, 415, 428
negative selection, 428
classification, 15
clonal proliferation, 419
clonal selection, 10, 421, 431
CLONALG, 431
dynamic, 433
multi-layered AIS, 433
CLONALG, 431
clustering, 59
ant algorithm, 385
Lumer–Faieta, 386
Ward clustering, 69
coevolution, 8, 229, 275
competitive, 275, 276
competitive fitness sharing, 278
cooperative, 275, 276, 281
cooperative genetic algorithm, 282
fitness sampling, 277
fitness sharing, 278
function optimization, 282
game learning, 280
genetic algorithm, 164
hall of fame, 278
neural network, 280
predator–prey, 275
shared niching, 167
symbiosis, 275
tournament fitness, 278
coevolutionary algorithm, 275
cognition-only model, 310
cognitive component, 290, 293
collective intelligence, 285
combinatorial optimization problem, 552
competitive coevolution, 275, 276
competitive fitness sharing, 278
competitive learning, 62
competitive particle swarm optimization
predator–prey PSO, 332
computational intelligence, 4
paradigms, 4
computational swarm intelligence, 285
confidence interval, 99
conjugate gradient, 45, 203
direction vectors, 45
Fletcher-Reeves, 46
Hestenes-Stiefer, 47
Polak-Ribiere, 46
scale factors, 46
connectionist Q-learning, 89
conscience factor, 61
constrained optimization, 552, 562
cultural algorithm, 271
definition, 561
differential evolution, 256
evolution strategies, 229
evolutionary programming, 206
genetic algorithm, 169
Lagrangian, 206, 229, 256
linear equality constraints, 561
methods, 561
particle swarm optimization, 342
penalty function, 169
penalty methods, 256, 271, 563
constraints, 551
boundary, 256, 561, 570
equality, 561, 570
handling methods, 562
inequality, 561, 570
constriction
coefficient, 309
consuming energy pruning, 112
context layer, 32
continuous ACO
  crossover, 397
  mutation, 397
  trail diffusion, 397
continuous optimization problem, 552
control, 15
control parameters, PSO, 312
convergence
  evolutionary algorithm, 140
  neural network, 98
  PSO, 300
cooperative coevolution, 275, 276, 281
genetic algorithm, 330
cooperative coevolutionary genetic algorithm, 282, 330
  ALC training, 430
  cooperative particle swarm optimization
  attractive and repulsive PSO, 327
division of labor PSO, 328
  life-cycle, 329
  split PSO, 330
correlation coefficient, 95
craziness, 334
crossover, 8, 139, 397
  arithmetic, 148
  binary representation, 145
  binomial, 239
  blend, 148
  diagonal, 153
differential evolution, 239
discrete recombination, 146, 222
  evolution strategies, 222
  exponential, 240
  floating-point representation, 146
gene scanning, 152
genetic algorithm, 144
genetic programming, 180
  geometrical, 148
  global, 222
  hillclimbing, 146
  intermediate recombination, 148, 222
  linear, 148
  local, 222
  majority mating, 146
  multi-parent, 146
  one-point, 145
  parent-centric, 150
  simplex, 150
  simulated binary, 149
two-point, 145
  uniform, 145
  unimodal distributed, 149
cultural algorithm, 262
  acceptance function, 263, 265
  fuzzy, 269
  age, 270
  belief cells, 271
  belief space, 262, 263
  constrained optimization, 271
  dynamic environment, 273
  fuzzy, 268
  fuzzy belief space, 269
  influence function, 267
  fuzzy, 270
  knowledge components, 264
  multi-objective optimization, 272
  particle swarm optimization, 263
  penalty method, 271
  population space, 262
  self-adaptive, 273
cultural evolution, 8, 261
danger theory, 10, 13, 422, 445
  adaptive mailbox, 446
  intrusion detection, 448
  mobile ad-hoc networks, 445
Darwin, Charles, 127
Darwinism, 127
data mining, 15
data preparation, 99
  input coding, 100
  missing values, 100
  noise injection, 105
  normalization, 104
  outliers, 100
  scaling, 102
  training set manipulation, 105
decision boundaries, 51
decision rule, 362
decision space, 570
decision system, 482
decision tree, 180
decision vector, 570
INDEX 585

defuzzification, 471
  averaging, 471
collapsed center of gravity, 471
min-max, 471
root-sum-square, 471
dentritic injection, 441
derating function, 166
differential evolution, 8, 237
  angle modulated, 253
binary, 254
binary-valued, 253
binomial crossover, 239
constraints, 256
crossover, 239
difference vectors, 238
discrete-valued, 252
dynamic environments, 257
dynamic parameters, 251
exponential crossover, 240
gradient-based, 245
Lagrangian, 256
multi-objective, 256
multi-population, 250
multiple populations, 257
mutation, 239
neural networks, 259
Pareto-based, 257
particle swarm optimization, 250
penalty methods, 256
PSO, 325
selection, 240
selection operator, 256
self-adaptive, 250, 252
self-adaptive parameters, 251
self-adaptive Pareto, 252
vector evaluated, 257
differential Hebbian learning, 58
differential path length, 362
direct weights, 40
discernibility, 482
discernibility function, 483
discernibility matrix, 482
discrete optimization problem, 552
discrete recombination, 146, 222, 239
dispersibility, 483
dissimilarity measures, 389
dissipative PSO, 335
diversity, 297, 334
division of labor, 391
  adaptive task allocation, 395
  individual variability, 395
  juvenile hormone, 393
  multiple tasks, 395
  plasticity, 393
  PSO, 328
  reproductive, 392
  response threshold, 393
  single task, 394
  specialization, 395
  temporal polyethism, 392
  worker polymorphism, 392
  workers, 392
domination
  definition, 572
  weak, 572
dual problem, 565
dynamic aggregation, 571
dynamic clonal selection, 433
dynamic environment
  genetic algorithm, 173
dynamic environments
  ant colony optimization, 402
  cultural algorithm, 273
differential evolution, 257
evolutionary programming, 206
evolutionary strategies, 233
  particle swarm optimization, 346
  spatial severity, 576
  temporal severity, 576
  types, 576
dynamic learning rate, 59, 68
dynamic neighborhood PSO, 343
dynamic optimization, 576
dynamic pattern selection, 122
elitism, 8, 139, 194, 278
Elman recurrent neural network, 32
context layer, 32
output, 33
emergence, 286
empirical error, 37, 94
enhanced artificial immune network, 440
ensemble neural network, 51
  bagging, 52
  boosting, 53
entropy, 258
epoch, 38
equality constraints, 561
error
  empirical, 94
  mean squared, 41, 94
  quantization, 61, 65
  sum squared, 24, 38, 94
  true, 94
error function, 24
  empirical, 37
  true, 37
error-correction, 25
Eugène Marais, 359, 363
eusocial insects, 392
evolution
  biological, 127
evolution of evolution, 213
evolution operator
  mutation, 153
  reproduction, 134, 139
  selection, 134
evolution strategies, 8, 213
  (1 + 1)-ES, 213
  (μ + 1)-ES, 214
  (μ + λ), 221
  (μ, λ), 221
  τ(μ/ρ, κ, λ), 233
  constraints, 229
  crossover, 222
dynamic environments, 233
dynamic niche ES, 234
fast ES, 224
incremental, 228
multi-objective optimization, 230
mutation, 224
niching, 233
Pareto archived, 231
polar, 226
selection, 214, 221
self-adaptation, 216
steady-state, 215
strategy parameters, 216
evolutionary algorithm, 8, 132
  binary encoding, 130
coevolution, 275
components, 128
convergence, 140
cultural algorithm, 262
cultural evolution, 262
decoding function, 133
definition, 128
differential evolution, 237
evolutionary programming, 187
fitness function, 133
generation, 129
generation gap, 158
 genetic algorithm, 143
genetic programming, 177
interactive evolution, 161
mapping function, 130
mutation, 153
objective function, 133
population, 132
reproduction, 134
scaling function, 133, 135
selection, 134
stopping conditions, 140
evolutionary algorithm strategies, 213
evolutionary computation, 8, 11, 128
evolutionary programming, 8, 187
  accelerated, 201
  age, 202
  classical, 200
  constraints, 206
  dynamic, 190
  dynamic environments, 206
  exponential, 201
  fast, 201
  finite-state machine, 207
  fitness function, 188
  function optimization, 208
  improved fast, 201
  local search, 203
  mass extinction, 203
  momentum, 202
  multi-objective optimization, 206
  mutation, 189
  neural networks, 209
  non-adaptive, 190
  particle swarm optimization, 204
  relative fitness, 188
  self-adaptive, 190, 198
  strategy parameters, 189, 190,
INDEX

evolutionary programming particle swarm optimization
  Cauchy mutation, 325
  Gaussian mutation, 324
experiential knowledge, 290
exploitation, 303
evolutionary programming, 201
exploration, 303
exploration–exploitation trade-off, 84, 189, 303
fast ant system, 379
fast evolution strategies, 224
fast evolutionary programming, 201
feedforward neural network, 28, 38
  output, 28
  feedforward pass, 38
finite-state machine, 207
finite-horizon model, 85
finite-state machine
  chromosome representation, 207
  fitness function, 208
  mutation, 208
fitness function, 8, 133, 180, 291
  absolute fitness, 133, 193, 277
  evolutionary programming, 188
  finite-state machine, 208
  function optimization, 209
  relative fitness, 133, 188, 193, 277, 278
  routing optimization, 174
fitness sampling, 277
fitness sharing, 165, 231, 278
fitness-based spatial neighborhoods, 317
Fletcher-Reeves conjugate gradient, 46
foraging behavior
  ants, 360
forgetting factor, 57
  unsupervised learning, 57
fully informed PSO, 319
function evaluation, 296
function optimization
  chromosome representation, 209
  fitness function, 209
functional link neural network, 29
  functional unit, 29
  output, 30
  functional unit, 29
fuzzification, 469
fuzziness, 10, 462
fuzzy controller, 475
  components, 475
  Mamdani, 477
  table-based, 477
  Takagi-Sugeno, 478
fuzzy cultural algorithm, 268
fuzzy inferencing, 465, 468, 470
  defuzzification, 471
  fuzzification, 469
fuzzy logic, 10, 451, 465
fuzzy operators, 457
  complement, 457
  containment, 457
  equality, 457
  intersection, 457
  s-norm, 459
  t-norm, 457
  union, 459
fuzzy rule, 467
fuzzy sets, 10, 451, 453, 454
  o-cut, 461
  cardinality, 461
  characteristics, 459
  continuous, 454
  core, 461
  discrete, 454
  height, 461
  linguistic variable, 453, 466
  membership, 454
  membership function, 454
  normality, 461
  normalization, 461
  support, 461
  unimodality, 461
fuzzy systems, 10
fuzzy variable, 466
game learning, 280
  particle swarm optimization, 356
Gaussian activation, 20
Gaussian kernel, 64
Gaussian mutation, 191
Gaussian mutation PSO, 324
gene, 8, 129, 130
generalization, 37, 93, 97
generalization factor, 96, 122
generalized delta, 25
generalized Hebbian learning, 59
generation, 129
generation gap, 158
generational genetic algorithm, 158
genetic algorithm, 8, 143
canonical, 143
  cellular, 162
  constrained optimization, 169
  control parameters, 156
  cooperative coevolutionary, 164
  crossover, 144
dynamic environment, 173
  fast messy, 160
generation gap method, 158
generational, 158
  interactive evolution, 161
  island, 162
  messy, 159
  multi-objective, 170
  niched Pareto, 172
  niching, 165
  nondominated sorting, 172
  parallel, 162
  representation, 130
  self-adjusting parameters, 156
  steady state, 158
  vector evaluated, 172
  genetic algorithm based particle swarm
  optimization
  cheap PSO, 322
  reproduction PSO, 322
  genetic programming, 8, 177
  building-block, 184
  crossover, 180
  decision tree, 180
  fitness function, 180
  mutation, 182
  population, 179
genome, 130
  genotype, 130
  global best position, 291
  global minimum, 553
  global optimization, 37
  global-best, 373, 375
  goodness factor pruning, 112
  gradient descent, 24, 38, 77, 109, 203
  artificial neuron, 24
  feedforward neural network, 38
  lambda-gamma learning, 115
  product unit neural network, 42
  reinforcement learning, 88
  gradient-based differential evolution, 245
Grassé, Pierre-Paul, 359
Gray coding, 131
  growing neighborhoods, 318
  growing SOM, 65
  guaranteed convergence PSO, 316
  hall of fame, 139, 278
  Hamiltonian path, 371
  Hamming cliffs, 131
  Hamming distance, 131, 431
  Hebbian learning, 56
  differential Hebbian learning, 58
  generalized, 59
  normalized Hebbian learning, 58
  Sejnowski, 57
hedges, 466
  concentration, 466
  contrast intensification, 467
  dilation, 467
  probabilistic, 467
  vague, 467
helper-T-Cell, 419
heredity, 127
Hestenes-Stiefer, 47
  heterogeneous ants, 390
  hidden units, 49
  hillclimbing, 146, 203
history, 11
  artificial immune systems, 12
  artificial neural networks, 11
  evolutionary computation, 11
  fuzzy systems, 12
  swarm intelligence, 12
hope criterion, 335
Huber’s function, 101
hyper-mutation, 433
hyperbolic tangent activation, 20
hypercube social network, 319
  immune system, 415
  affinity, 416
  antibodies, 416
antigen presenting cells, 423
B-Cell, 418
classical view, 415
clonal proliferation, 419
clonal selection, 421
danger theory, 422
helper T-Cell, 419
immunity types, 421
learning, 421
lymphocytes, 415
memory cells, 419
natural-killer-T-Cell, 420
network theory, 422
non-self, 415, 416
plasma cell, 419
self, 415
somatic hyper-mutation, 422

immune system models
classic view, 10
clonal selection, 10
danger theory, 10, 13
network theory, 10, 13

incremental evolution strategies, 228
incremental learning, 119, 120, 123
dynamic pattern selection, 122
information-based functions, 121
integrated squared bias, 121
optimal experiment design, 120
query by committee, 122
query-based learning, 122
selective incremental learning, 121
selective sampling, 122

independent variables, 551
indiscernibility relation, 482
individual, 8
individual variability, 393
inequality constraints, 561
inertia, 293
inertia weight, 306
fuzzy adaptive, 308
increasing, 309
linear decreasing, 307
nonlinear decreasing, 307
random, 307
infinite-horizon discounted model, 85
infinite-valued logic, 452
information sharing
barebones PSO, 320
fully informed PSO, 319
information-based functions, 121
informative pattern, 122
initialization
gradient descent, 106
particle positions, 297
particle velocities, 297
personal best position, 297
PSO, 296
self-organizing feature map, 63
integrated squared bias, 121
intelligence, 3
interactive evolution, 161
intermediate recombination, 148, 222
iteration
PSO, 296
iteration-best, 373, 375
iterations, 312
Jordan recurrent neural network, 33
output, 34
state layer, 33
juvenile hormone, 393

kernel functions, 75
Lagrange multipliers, 206, 565
Lagrangian, 206, 229, 256, 565
Lamarck, Jean-Baptiste, 127
Lamarckism, 127
lambda-gamma learning, 115
law of the excluded middle, 451
laws of thought, 451
LeapFrog, 49, 559
learning
accuracy, 93
artificial neuron, 21
batch, 37, 41, 108
competitive learning, 62
generalization, 93, 97
overfitting, 41, 95, 97
Q-learning, 86
reinforcement, 21, 83
stochastic, 37, 38, 41, 108
stopping criteria, 41
supervised, 21, 27
temporal difference, 86
unsupervised, 21, 55
learning rate, 24, 58, 68, 107
  dynamic, 59, 68
learning rule
  coevolutionary, 280
  conjugate gradient, 45, 47
  error-correction, 25
  evolutionary programming, 209
  generalized delta, 25
  generalized Hebbian learning, 59
  gradient descent, 24, 38
  Hebbian learning, 56
  lambda-gamma, 115
  LeapFrog, 49
  LVQ-I, 59
  normalized Hebbian learning, 58
  particle swarm optimization, 49
  principal components, 58
  radial basis function network, 76
  self-organizing feature map, 62
  Widrow-Hoff, 25
learning vector quantizer, 59, 73
  LVQ-I, 59
  LVQ-II, 73
life-cycle PSO, 329
linear activation, 18
linear separability, 20, 22
linguistic fuzzy rule, 467
linguistic variable, 453, 466
local best position, 292
local minimum, 553
local optimization, 37
local optimum, 553
local search
  2-opt heuristic, 407
  3-opt heuristic, 407
  conjugate gradient, 203
  gradient descent, 203
  hillclimbing, 203
Lumer–Faieta algorithm, 386
lymphocytes, 10, 415, 417
  B-Cell, 417, 418
  T-Cell, 417
madaline, 25
magnitude-based pruning, 112
major histocompatibility complex molecules, 417
mapping function, 130
mass extinction, 203, 335
max-min ant system, 375
mean squared error, 41, 94
membership function, 454
  fuzzy sets, 454
  rough sets, 484
meme, 263
meme pool, 263
memory cells, 419
messy genetic algorithm, 159
  fast, 160
migration rate, 162
min-max problem, 565
minimal ant clustering, 391
missing values, 100
model selection, 116
model-free reinforcement learning, 86
momentum, 108, 293
multi-layered artificial immune system, 433
multi-modal optimization problem, 552
multi-objective optimization, 552
  ant colony optimization, 398
  cultural algorithm, 272
  definition, 570
  differential evolution, 256
  evolution strategies, 230
  evolutionary programming, 206
  genetic algorithm, 170
  niched Pareto genetic algorithm, 172
  nondominated sorting genetic algorithm, 172
  Pareto ranking, 231
  particle swarm optimization, 343
  self-adaptive Pareto DE, 252
  vector evaluated genetic algorithm, 172
  weighted aggregation, 170, 257
  weighted aggregation, 571
multi-objective optimization
  Pareto archived ES, 230
multi-objective problem
  definition, 570
multi-phase PSO, 327
multi-start particle swarm optimization, 333
  convergence tests, 335
craziness, 334
dissipative PSO, 335
mass extinction, 335
self-organized criticality, 335
multiple colonies
sharing mechanisms, 399
multiple task allocation, 395
mutation, 8, 139, 153, 397
adapative mean mutation, 192
artificial immune system, 433
biased, 229
binary representation, 154
Cauchy, 191, 201, 325
domino, 192
differential evolution, 239
directed, 224, 227
evolution strategies, 224
evolutionary programming, 189
exponential, 191, 201
floating-point representation, 155
function node mutation, 182
Gaussian, 154, 182, 191, 324
genetic programming, 182
grow mutation, 182
headless chicken, 156
inorder, 154
Lévy, 191
mean mutation operator, 192
random, 154
rate, 156
swap mutation, 182
terminal node mutation, 182
trunc mutation, 182
uniform, 154, 155, 190
natural immune system, 9, 415
  lymphocytes, 10
  models, 10
natural selection, 127
natural-killer-T-Cell, 420
negative selection, 12, 427, 428
neighborhood
  gbest PSO, 290
  lbest PSO, 292
neighborhood best position, 292
neighborhood function
  Gaussian, 64, 67
  self-organizing feature map, 64
neighborhood size, 312
neighborhood topology
  four-clusters, 301
  pyramid, 301
  ring, 291, 301
  star, 290, 301
  Von Neumann, 303
  wheels, 301
net input signal, 17
  product unit, 18, 30
  summation unit, 17
network theory, 10, 13, 422, 436
  aiNet, 442
  artificial immune network, 436
  artificial recognition balls, 436
  enhanced artificial immune network, 440
  self stabilizing AIS, 438
neural networks
  performance measures, 93
niched Pareto genetic algorithm, 172
NichePSO, 351
niching
  categories, 568
  coevolutionary shared niching, 167
  crowding, 166
  deterministic crowding, 167
dynamic niche clustering, 168
dynamic niche ES, 234
dynamic niche sharing, 165
dynamic niche ES, 234
evolution strategies, 233
  fitness sharing, 165
genetic algorithm, 165
  parallel, 568
  enhanced artificial immune network, 440
  self stabilizing AIS, 438
  performance measures, 93
niching methods
  defined, 567
noise injection, 105
  non-dominated solutions, 570
  non-dominated sorting, 257
non-self, 9
nondominated sorting
  genetic algorithm, 172
  normalization, 104
z-score, 104
Z-axis, 104
nostalgia, 293

objective function, 24, 133, 551
objective function slope, 300
objective space, 570
objective vector, 570
Ockham, 109, 116
offline learning, 37
offspring, 8
online learning, 37
optima types, 553
optimal experiment design, 120

optimality conditions
  global minimum, 553
  local minimum, 553
  local optimum, 553

optimization, 15
  combinatorial problem, 552
  conjugate gradient, 45
  constrained, 169, 206, 229
  constrained problem, 552, 561
  constraints, 551
  continuous problem, 552
  deterministic, 554
  discrete problem, 552
  dynamic environment, 173, 576
  global, 37
  global minimum, 553
  gradient descent, 38
  independent variables, 551
  LeapFrog, 49
  local, 37
  local minimum, 553
  local optimum, 553
  methods, 554
  multi-modal problem, 552
  multi-objective, 170
  multi-objective problem, 552, 570
  niching, 567
  objective function, 551
  optima types, 553
  particle swarm optimization, 49
  problem characteristics, 552
  problem classification, 552
  random search, 204
  scaled conjugate gradient, 47
  unconstrained, 555
  unconstrained problem, 552
  uni-objective problem, 552
  unimodal problem, 552

optimization methods
  beam search, 139, 556
  global search, 554
  LeapFrog, 559
  local search, 554, 556
  simulated annealing, 138, 557
  stochastic, 554
  tabu search, 556

outliers, 100
  Huber’s function, 101
overfitting, 41, 95, 97, 110
  early stopping, 95
  generalization factor, 96, 122

parallel niching, 568
parapatric speciation, 568
Pareto archived evolution strategy, 230
Pareto ranking, 231
Pareto-optimal
  definition, 573
  front, 573
  set, 573
partial truth, 453
particle, 9, 289
  position, 290
  velocity, 290, 292
particle swarm optimization, 9, 49, 289
  gbest, 290
  lbest, 291
  acceleration coefficients, 312
  architecture selection, 356
  asynchronous updates, 310
  attractive and repulsive, 327
  barebones, 320
  binary, 340
  Cauchy mutation PSO, 325
  charged, 337
  cheap PSO, 325
  cognition-only model, 310
  constrained, 342
  constriction model, 309
  convergence, 300
  cultural algorithm, 263
differential evolution, 250, 325
dissipative PSO, 335
division of labor, 328
dynamic environments, 346
dynamic neighborhood, 343
evolutionary programming, 204
fully informed, 319
game learning, 356
Gaussian mutation, 324
gbest, 292, 295
growing neighborhoods, 318
guaranteed convergence, 316
hypercube social network, 319
intertia weight, 306
lbest, 292, 295
life-cycle, 329
life-cycle model, 329
mass extinction, 335
multi-objective, 343, 344
multi-phase, 327
multi-start, 333
neural networks, 354
NichePSO, 351
niching, 350
parameters, 312
particle, 9
predator–prey, 332
product unit neural network, 355
recurrent neural network, 355
repelling methods, 337
reproduction, 322
selection, 321
self-organized criticality, 335
selfless model, 311
social-only model, 311
spatial extension, 339
spatial social networks, 317
split PSO, 330
sub-swarms, 326
synchronous updates, 310
unsupervised learning, 355
vector evaluated, 344
velocity models, 310

problems, 563
performance factors, 99
active learning, 116
adaptive activation function, 115
architecture selection, 109
data preparation, 99
learning rate, 107
momentum, 108
optimization method, 109
weight initialization method, 106

performance issues
accuracy, 93
analysis, 98
computational complexity, 98
confidence interval, 99
convergence, 98
correlation coefficient, 95
generalization, 97
generalization factor, 96
measures, 93
overfitting, 95, 110
personal best position, 290, 297
phenotype, 8, 130
phenotypic evolution, 8, 187
pheromone
smoothings, 378
pheromone evaporation, 367
pheromone trails, 360
pleiotropy, 130
Polak-Ribiere, 46
polar evolution strategies, 226
polygeny, 130
population, 8, 132, 179
position update, basic, 290
positive feedback, 361
predator–prey PSO, 332
predator-prey, 275
primal problem, 565
principal component analysis, 58, 113
principal component learning, 58
generalized Hebbian learning, 59
normalized Hebbian learning, 58
Oja, 58
probability, 462
definition, 462
product unit, 18, 30
distortion factor, 30
net input signal, 31
product unit neural network, 30, 42
   gradient descent, 42
   output, 31
   particle swarm optimization, 355
proportional selection, 135, 194
pruning
   consuming energy, 112
   evolutionary computation, 112
   goodness factor, 112
   hypothesis testing, 113
   information matrix, 113
   intuitive, 112
   magnitude-based, 112
   principal component analysis, 113
   sensitivity analysis, 114
   singular value decomposition, 113
Q-learning, 86
   connectionist, 89
quadratic assignment problem, 407
quantization error, 61, 65
quasi-sequential niching, 568
query by committee, 122
query-based learning, 122
quickprop, 109
radial basis function network, 73
   kernel functions, 75
   learning rules, 76
      fixed centers, 76
      gradient descent, 77
      unsupervised, 77
   normalized hidden unit activation, 80
      soft-competition, 80
   radial basis functions, 75
   ramp activation, 18
random search, 204
random selection, 135
rank-based selection, 137
re-hope criterion, 335
recruitment, 360
recurrent neural network, 32
   Elman, 32
   Jordan, 33
   particle swarm optimization, 355
regularization, 110
   weight decay, 110
reinforcement learning, 21, 83
   connectionist Q-learning, 89
   eligibility, 86, 88, 90
   evolution strategies, 220
   gradient descent, 88
   model, 84
   model-free, 86
   policy, 84, 85
   Q-learning, 86
   resilient propagation, 87
   reward function, 84
   temporal difference, 86
   value function, 84
      average award, 85
      finite-horizon, 85
      infinite-horizon discounted, 85
reinforcement signal, 83
relative discernibility function, 483
relative fitness, 133, 193, 277, 278
relative fitness function
   simple fitness, 278
replacement strategy, 158
representation
   binary, 130, 145, 154, 340
   binary-valued, 130, 253
   continuous, 396
   continuous-valued, 130
   discrete-valued, 252
   floating-point, 146, 155
   genetic algorithm, 130
   Gray coding, 131
   Hamming cliffs, 131
   tree, 177
reproduction, 134, 139
   crossover, 139
   mutation, 139
   PSO, 322
   replacement strategy, 158
repulsion, 326, 328
resilient propagation, 87
response threshold, 393
reward function, 84
rotation matrix, 224
rough sets, 12, 452, 481
   lower approximation, 481, 483
   membership function, 484
   uncertainty, 484
upper approximation, 482, 483
vagueness, 483
roulette wheel selection, 136
routing optimization
  chromosome representation, 174
  fitness function, 174
s-norm, 459
scaled conjugate gradient, 47
scaling, 102
  amplitude scaling, 103
  disadvantage, 103
  linear, 103
  mean centering, 103
  variance, 103
Sejnowski, 57
selection, 134
  \((\mu + \lambda), 139\)
Boltzmann, 138
differential evolution, 240, 256
elitism, 139, 194, 278
evolution strategies, 221
hall of fame, 139, 278
nonlinear ranking, 194
proportional, 135, 194
PSO, 321
random, 135
rank-based, 137
  deterministic, 139
  linear, 138
  non-deterministic linear sampling, 137
  non-linear, 138
relative ranking, 265
roulette wheel, 136
selective pressure, 135
stochastic universal sampling, 136
thresholding, 160
tournament, 137, 194, 273
selective incremental learning, 121
selective learning, 119, 120, 123
selective pressure, 135
selective sampling, 122
self, 9
self stabilizing artificial immune system, 438
self-adaptive differential evolution, 250
self-adjusting parameters, 156, 198, 251, 263
  additive, 198
  lognormal, 199
  multiplicative, 198
reinforcement learning, 220
self-organized criticality PSO, 335
self-organizing feature map, 62
  batch map, 65
  best matching neuron, 66
  clustering, 69
  growing SOM, 66
  initialization, 63
  learning rate, 68
  missing values, 100
  neighborhood function, 64
  shortcut winner search, 68
  stochastic learning, 62
  visualization, 69
self-tolerant, 426
selfless model, 311
sentry particle, 347
sequential niching, 166, 568
severity
  spatial, 576
  temporal, 576
sharing mechanisms, 399
  global, 400
  local, 399
short-term memory, 389
shortcut winner search, 68
sigmoid activation, 20
simple ant colony optimization, 364
simulated annealing, 138, 557
  annealing schedule, 558
  Boltzmann–Gibbs distribution, 557
single task allocation, 394
social component, 290, 294
  ring neighborhood, 291
  star neighborhood, 290
social network, 300
  fitness-based spatial, 317
  growing neighborhoods, 318
  hypercube structure, 319
  spatial, 317
social-only model, 311
soft computing, 4
soft-competition, 80
spatial extension PSO, 339
spatial networks, 317
spatial severity, 576
specialization, 395
speciation
   allopatric, 568
   parapatric, 568
   sympatric, 568
split factor, 330
split PSO, 330
state layer, 33
steady state genetic algorithm, 158
steady-state evolution strategies, 215
step activation, 18
stigmergy, 286, 359, 361, 363
   definition, 363
   sematectonic, 363
   sign-based, 364
stimulus–response agent, 363
stochastic learning, 37, 38, 41, 62, 108
stochastic universal sampling, 136
stopping conditions
   ACO, 366
   PSO, 298
stopping criteria
   LVQ-I, 61
   supervised learning, 41
strategy parameters, 8, 189, 216
deviations, 216
dynamic, 195
evolution strategies, 216
evolutionary programming, 195
rotation angles, 217
self-adaptive, 198
static, 195
sum squared error, 24, 38, 94
summation unit, 17
supervised learning, 21, 27
   batch learning, 108
   conjugate gradient, 45
differential evolution, 259
   gradient descent, 38, 109
LeapFrog, 49
   learning problem, 36
   particle swarm optimization, 49, 354
   performance issues, 93
   quickprop, 109
   stochastic, 37
   stochastic learning, 108
   weight initialization, 106
supervised network
   cascade network, 35
   ensemble neural network, 51
   feedforward neural network, 28
   functional link neural network, 29
   product unit neural network, 30
   recurrent neural networks, 32
   time-delay neural network, 34
swarm, 285, 289
   radius
   normalized, 299
   size, 312
swarm intelligence, 9, 285
   ant algorithms, 359
   ant colony optimization, 360
   cemetery organization, 384
   division of labor, 391
   particle swarm optimization, 289
symbiosis, 275
   sympatric speciation, 568
   synapse, 6
   synchronous updates, 310
T-Cell, 417
t-norm, 457
tabu search, 556
temporal difference learning, 86
temporal polyethism, 392
temporal severity, 576
three-valued logic, 452
time-delay neural network, 34
   output, 35
tournament fitness, 278
tournament selection, 137, 194, 273
   trail diffusion, 397
   training set manipulation, 105
   trajectories
   convergence condition, 314
transition probability
   ACS, 372
   ant system, 368, 369
   simple ACO, 365
transition rule
   ACS, 372
INDEX

Ant-Q, 378
traveling salesman problem, 406
trust parameters, 312
Turing, 3, 11
Turing test, 3

uncertainty, 484
  nonstatistical, 10
  statistical, 10
unconstrained optimization, 552
  benchmark functions, 559
  definition, 555
uni-objective optimization, 552
unimodal optimization problem, 552
unsupervised learning, 21, 55
  associative memory, 55
  coevolution, 280
  definition, 56
differential Hebbian learning, 58
generalized Hebbian learning, 59
Hebbian learning, 56
LVQ-I, 59
normalized Hebbian learning, 58
principal components, 58
self-organizing feature map, 62
velocity

vector evaluated differential evolution, 257
vector evaluated genetic algorithm, 172
vector evaluated PSO, 344
velocity clamping, 304
cognition-only model, 310
cognitive component, 293
components, 293
constriction, 309
geometric illustration, 294
inertia, 306
inertia component, 293
LeapFrog, 50
selfless model, 311
social component, 294
social-only model, 311
velocity update
  gbest PSO, 290
  lbest PSO, 292
cognitive component, 290
social component, 290

Wallace, Alfred, 127
Ward clustering, 69
weak domination, definition, 572
weight decay, 110
weight elimination, 110
weighted aggregation, 571
Widrow-Hoff, 25
worker polymorphism, 392