

Index

- Abelson, H., 222
Abortion, 449
Ackley, D., 333, 334, 452
Age of Spiritual Machines, The, 182–183
Agency, 414–415, 439
consciousness, 389–390, 401–405
Hayek, 253, 259
sovereign, 386–387
Agent program, 250
Alaskan brown bear, 335, 363, 398
Alex, 371
Algorithm, 5–6, 33, 435
block-stacking, 175–176
genetic algorithms approach, 124
heuristic, 109
learning, 25
neural networks, 155–157
NP-hard problem, 21–22
pseudo-polynomial time, 272
reinforcement learning, 156
self-reproducing automaton, 50–51
Turing machine as, 37, 40–41
Algorithmic Information Theory (AIT), 426–430
Allele, 345
Altruism, 398
Alu, 55
Amino acid, 54–57
Animal Mind, The, 158
Animals, 158–159
behavior, 351–360
communication, 421–422
culture, 335
evolution, 306–307
and humans, 374–378
inductive bias, 325–329
language, 368, 370–378, 380–381
learning, 360–365
modularity, 349–350
number sense, 320–321
problem-solving, 182
reasoning, 301, 372–374
Ansatz, 5, 443. *See also* Self-consistent (model of consciousness)
Ape, 371–372
Applegate, D., 112, 114
Argument, 179, 221, 223
Armstrong, D., 245
Artificial Economy. *See* Economic model
Artificial intelligence (AI), 6, 167–168
expert systems, 199–200
exploiting structure, 208–211
optimization process, 10
planning algorithms, 18–19, 273
reductionist procedure, 209–210
Artificial neural network. *See* Neural network
Aserinsky, E., 419
Atkin, I. R., 191
Attention, 417–418
Auction, 250
Auditory cortex, 231, 315
Autism, 216
Automaton, reproducing, 47–52
Awareness, 408–424. *See also* Consciousness
attention, 417–418
central module, 415–416
decision-making, 409–410, 413–415
defined, 423
dreams, 419–420
lying, 420–421
semantics, 438–439
upper-level, 423–424
verbal, 416
Backgammon, 150–153, 365
Back-propagation, 116–118, 123, 125
linear structure, 152
overfitting, 138–139
Bacteria, 351–354
Baldwin, J. Mark, 331
Baldwin effect, 230, 324, 332–337, 343–346
Ban, A., 191
Banzhaf, W., 124, 233, 236
Barkow, J. H., 216, 217, 303
Barto, A. G., 149, 150
Bassler, B. L., 353
Baum, E. B., 91, 122, 175, 233, 236, 244, 256, 260,
261, 335, 404, 451
Baxt, W. G., 130
Baxter, J., 92
Bayes' law, 97–98, 104
Bayesian statistics, 95–102, 105
minimum description length, 100–102
probability, 99–100, 104
Bear, 335, 363, 398
Beauty, 396–397
Beaver, 335–336, 363, 380–381
Bee, 326, 354–357, 361, 368, 380
Beehive, 356–357
Behavior, 145
animal, 351–360
consciousness, 389–390
and genome, 395, 401
innate, 354
word learning, 381–382
Bell-shaped curve, 118
Berlekamp, E., 203
Berliner, H., 192
Bickerton, D., 372, 374, 381

- “Biochemical Pathways,” 59
 Biological evolution, 1, 4, 68. *See also* Learning as algorithm, 6 behavior, 351–360 brain, 44 computational resources, 108, 305–306, 443, 445 constraint propagation, 301 cooperation, 20, 218, 248–249, 269 culture, 335–337 decision-making, 431–433 development, 26, 62–65, 313–314 DNA, 29 early stopping, 134, 140–141 encryption, 339–340 equilibrium distribution, 161 eye, 71, 238 feedback loops, 243 fitness landscape, 109–111, 120, 123–124 genetics, 55, 120–125 grammar, 339–340, 379–380 hill climbing, 109, 120, 123, 125, 332 humans vs. animals, 27–28 inductive bias, 63, 305, 316–329 input search, 108 intelligence, 32 intentionality, 71 irrationality 226–228 language, 28, 337–346, 350–351, 378–382 and life learning, 331–335, 395–396 of mind, 3, 63–64, 161 modularity, 134, 218–220, 231–232, 240 morality, 433–434 multiple birth, 447 mutation, 182 natural problems, 289 NP-hard problem, 21 Occam’s razor, 79 optimal solution, 399–401 propagation, 388–389 reactive/reflexive systems, 321–322 real-time performance, 321–323 reasoning, 226–227 reinforcement learning, 12, 146, 151 reward function, 146, 153, 392–398 semantics, 141 sex, 122–123 simulating, 209, 333–334 speed of, 239 topological bias, 321 Birds, 56, 327, 338, 372 Birth rate, 399, 401 Bischiach, E., 417 Bit, 23 Bixby, R., 112 Black, D. L., 56 Black lily, 425 Blakemore, C., 312 Blakeslee, S., 216, 314, 417 Block-stacking problem, 18, 154 Blocks World, 174–187, 288 AI solution, 184–187, 273 computer scientist’s solution, 177–183 economic model, 240–243 evolutionary programming, 233–235, 237–238, 250, 252–255 layperson’s solution, 174–177 NP class, 274–275, 280–281, 451 plan compilation, 213–214 Post production systems, 263–264 recursion, 178–183 Bloom, P., 307, 368 Blue tit, 182, 363–364 Blum, Avrim, 185, 212, 293–294, 296, 299 Blumer, A., 93 Body, 405–406 Boneh, D., 122, 236, 244 Bonobo, 371, 373 Boolean logic, 283 Bottleneck, 85–86 protein, 140, 444 Brahe, Tycho, 94 Brain bacterial, 351–353 compact representation, 141–142 computer simulation of, 44, 70 damage, 215–216, 417–418 finite number of states, 34–35 imaging, 216, 220 long-term memory, 64 as multiprocessor, 43 neural networks, 82–83 speed of, 208–209 size of, 135, 141 split-brain patients, 416–417 synapses, 135 Branch-and-bound, 113–114, 165, 447 chess, 189–191, 196 TSP, 273 Branden, C., 54 Brother John, 373 Byte, 23–24
- C. elegans*, 311–312 C (language), 176, 413, 415 Cambrian explosion, 451 Cancer, 248 Carroll, S. B., 55, 61, 62, 63, 121, 323, 324, 329 Caruana, R., 139

- Cat, 312–314
Catalyst, 58, 257–258
Categories, 170–174. *See also* Natural kind; Object
Causality, 173, 200–201, 205, 321
Cell. *See also* Neuron
cooperation, 248
development, 60–61
Chaining, 246
Chalmers, David, 7, 31, 67
Chaos, 35
Cheating, 218–220
Chemistry, 1, 104
Chenn, A., 121, 324
Chess, 187–197, 391–392
Chickadee, 363
Child learning, 364–365, 376–377
Chimpanzee, 316, 364, 371–372, 376, 377
Chinese Room, 71–76
Chomsky, Noam, 307, 338, 340, 343, 370
Chromosome, 53, 248
Church, Alonzo, 33, 41
Church–Turing thesis, 39, 45, 46, 181
Chvátal, V., 112
Class of instances, 271
Classifier Systems, 246
Clause, 282–284
Cleaner, 253
“Clever Hans,” 158, 359
Closer, 253
Coase, Ronald, 251
Code
discovery, 27
of mind program, 437–438
modular, 15
padded/unpadded, 272
source, 13, 133–134
Code reuse, 16, 63, 132–133, 156
DNA, 171
game analysis, 204
and intention, 162
metaphor, 220–222
modularity, 231
Codon, 54, 56
Coleman and Mandula theorem, 446
Cognitive science, 216
Comment statement, 137
Communication, 374–378, 421–422
Compact program
DNA as, 23–24
evolving, 19–21
modular code, 15–16
problem domains, 204
syntax, 9–10
- Compact representation
of brain, 141–142
concepts, 212
data, 107, 125–127
evolution, 324
and generalization, 141
MDL, 318–319
and naive representation, 272–273
natural numbers, 165–166
necessary/sufficient, 135–137
neural networks, 136
NP-hardness, 286–287
objects, 168–174
polynomials, 138–139
understanding, 130
Compact structure, 11, 13–14. *See also* Compact representation
Competition, 247
Compiler, 133
Complexity theory, 21, 272
Compound symbol, 34
Compression, 10–12
code reuse, 162
DNA, 134, 305
learning, 136
neural networks, 130
objects, 173–174
random search, 119
semantics, 102
and understanding, 10, 79–80, 104–105, 132
Computation, models of. *See* Models of computation
Computational power, 209, 268, 440
Computer program
compression, 10–12
modules, 4–5
Computer science, 165
Concept, 162, 212–213
Conditional probability, 96–98
Conjugate gradient procedure, 139
Consciousness, 29–31, 67, 228, 362, 385–436
agency, 386–387, 389–390, 401–405
argument from, 71–72, 74
awareness, 408–424
and behavior, 389–390
decision-making, 390–391
free will, 426–436
qualia, 424–426
self, 403–408
theory of, 438–440
wanting, 387–403
Consciousness Explained, 408, 412, 415
Conservation of money, 20, 242–244, 246, 251
Constraint propagation, 22, 293–302

- Conway, J. H., 201–203, 448
 Cook, S. A., 281, 450
 Cook, W., 112
 Cooper, G. F., 312
 Cooperation, 247–249, 269
 Copeland, J., 425, 453
 Copernican theory, 67, 68, 79
 Cormen, T. H., 177
 Cosmides, L., 216, 217, 303
 Cover, T. M., 101
 Credit assignment, 415
 hill climbing, 119–120, 124–125
 meta-agents, 260
 modularity, 240–241
 Creole, 342
 Crick, F., 1, 47, 385, 419, 420, 452, 453
 Crossover, 121–122, 124–125
 genetic programming, 233, 236–239
 S-expressions, 260
 Cryptography, 45, 277–278
 Cubic curve, 81
 Culture, 306, 335–337
 Curve fitting, 8–9, 80–81, 102, 317
 Cylinder data, 290
 Damasio, A. R., 216, 453
 Darwin, Charles, 159
 Data
 and classifications, 145
 compact representation of, 107, 125–127
 cylinder, 290
 wall, 290
 Davidson, E. H., 60
 Dawkins, R., 398
 Deacon, T. W., 374
 Deaf children, 342
 Debugging, 419
 Deception, 420–421
 Decision-making, 390–391, 409–410, 413–415
 Decryption, 339
 Deep Blue, 187–188
 Deep Fritz, 189
 Deep Junior, 189
define statement, 258–260
 Dennett, D. C., 30, 373, 386, 408, 411, 413, 444
 Depth perception, 313, 345
 Descartes, René, 169
 Desire. *See* Wanting
 De Souza, S. J., 55, 122
 Development, 26, 61
 evolution, 26, 62–65, 313–314
 interaction, 309–310
 language, 338
 and learning, 304, 308–316
 modularity, 63, 232
 semantics, 62
 sensations and reflexes, 311, 313
 Devlin, K., 321, 373
 Dickinson, B., 39
 Diligenti, M., 256
 Discount rate, 446
 Discrete logarithm problem, 278
 Divide and conquer, 241
 DNA, 3–7, 12
 cells, 60–61, 248
 code reuse, 171
 as compact program, 23–24, 52–58, 156
 compression, 134, 305
 development, 308–315
 evolution, 29, 303
 “extra” coding, 205
 gene expression, 61, 329–331
 information content (*see* DNA, size)
 junk, 55–56, 137, 141
 language, 307
 and learning, 25–27, 172–173, 304–305, 387–388
 memory, 61
 microarrays, 329–331
 modularity, 292, 301, 315, 336
 pattern matching, 65
 proteins, 140
 reinforcement learning, 146
 research, 441
 reward function, 398–400
 RNA, 54
 size, 24, 57, 135
 as source code, 13, 133
 von Neumann’s figure, 47–48
 Doberman, Louis, 358
 Dogs, 307, 325–326, 358–360, 363, 366, 368, 372–373, 380, 403
 Dolphin, 370–371, 372
 Donald, M., 373, 378
 Dream, 419–420, 453
 Drescher, G., 72
 Dretske, F. I., 457
 Drexler, K. E., 243, 247, 449
 Dreyfus, Hubert, 7, 10, 76–78, 102, 146, 206
Drosophila, 63
 Durdanovic, Igor, 175, 233, 256, 260, 261, 404
 Dwarf honeybee, 357
 Dynamic programming, 152
E. coli, 60, 311, 321–322, 351–353
 Early stopping, 134, 139
 Early vision, 12
 Economic model, 240–249, 251, 268–269
 conservation of money, 20, 242–244, 246

- and ecosystem, 247–249
Post production systems, 265
property rights, 20, 242–247, 249
Tragedy of the Commons, 244–246
Economy of agents, 20
Effective procedure, 6, 33
Ehrenfeucht, A., 142
Einstein, Albert, 138, 373
Einstein’s theory of general relativity, 94, 103, 119, 434
Electroencephalography (EEG), 216
Electromagnetism, 79, 162
Electron, 14, 211, 432
Ellington, A. D., 257–258
Emlen, Steve, 314
Encoding length, 272
Encryption, 277–278, 317, 339–340
Entropy, 1
Environmental Protection Agency (EPA), 245
Enzyme
gating reactions, 58
metabolism, 59–60
patterns, 65
Equilibrium distribution, 161
Erol, K., 451
Esch, H. E., 355
Euclid, 279
Euler, Leonhard, 429, 448
Euprymna scolopes, 353
Eurisko, 243
Evaluation function, 147
chess, 187–189, 196, 391
DNA, 27, 365
Go, 197
Hayek Machine, 254
internal (*see DNA*)
planning problems, 185
Evolution. *See also* Biological evolution
early stopping, 134, 140–141
and modularity, 134
and neural networks, 10
of programs, 13, 19–21, 308
reproducing automaton, 52
robotics, 289–291
speed of, 446–447
Evolutionary programming, 233–269, 309, 440
Blocks World, 233–235, 237–238, 250, 252–255
chicken-and-egg problem, 381–382
computational depth, 323
economic model, 240–249
genetic programming, 233–239, 256
Hayek Machine, 250–266
meta-learning, 260–261
Post production systems, 261–266
problem/program space, 183
property rights, 246–247
reinforcement learning, 161–163, 242
understanding, 266–267
Evolutionary Robotics, 289
Exclusion relations, 213–214
Executable, 13, 133–134, 443
Exhaustive search, 107–108
chess, 187, 196
TSP, 271
Exon, 54–55, 121–123
Experience. *See* Pain; *Qualia*; Sensation
Expert system, 10, 199–200
Exploiting structure, 13–19, 165–212
AI, 208–211
block-stacking problem, 174–187
concepts, 212–213
games, 187–205
human problem-solving, 192, 196, 200–201
modularity, 19–20, 177–178
objects, 168–174
reductionist approach, 210
supertree, 201–202
understanding, 292
Exponential search, 108, 119, 183–186, 272
Exponential slowdown, 46
Eye, 238, 312, 323, 345, 352. *See also* Visual cortex
Ey gene, 62, 120–121, 323
Factorization, 45–46, 277–278
Feedback loop, 155, 243–244
Feinstein, D. I., 420
Feist, M., 191
Fermat, Pierre de, 279
Ferret, 231, 314–315
Fibonacci numbers, 43–44, 443–444
Fitness landscape, 109–111, 119, 445
biological evolution, 123–124
evolutionary programming, 240, 332
Fixation point, 412
Floreano, Dario, 289
Flowchart, 58–59
Fly eye, 62, 312
Fodor, J. A., 444
Fong, Sandiway, 338
Forest, 245
Franklin, S., 354
Free will, 426–436, 439
Freud, S., 453
Frustration, 445–446
Fudge, 358–360
Fukushima, K., 137
Function, 15

- Function class, 92–93
 Functional magnetic resonance imaging (fMRI), 216, 220
 Furst, M., 185, 212
 Gage, Phineas, 216
 Gagen, M. J., 56
 Galef, Bennett, Jr., 363
 Galileo, 67, 68, 79
 Galvanic skin response, 406, 421
 Games, 187–205
 chess, 187–197, 447–448
 game tree, 190–192, 201–202
 Go, 197–205, 448
 sums of, 201–203
 Garbage collection, 291
 Garden-path sentences, 299–300
 Garey, M. R., 284, 450
 Garnsey, S. M., 300
 Garrett, C., 122, 236, 244
 Gauss, Karl Friedrich, 182, 279
 Gavagai problem, 367–370
 Gazelle, 109–110
 Gazzaniga, M., 417
 Gene, 1
 chromosomes, 53
 crossover, 121–122, 124–125
 expression, 61, 329–331
 ey, 62, 120–121, 323
 genetic code, 54
 Hox, 23, 55, 62, 120
 imprinting, 449
 inductive bias, 329
 pleitropic, 63, 232
 regulatory networks, 60–64, 232, 323
 semantics, 120–121
 sexual reproduction, 248–249, 396–397
 as subroutine, 53–54, 60
 toolkit, 23, 62, 120, 232
 and unity of self, 30, 74
 Generalization, 141, 149, 309
 Genetic programming, 233–239, 256
 Genetic recombination, 236
 Genome, 24–25, 55–56
 base pairs, 137
 and behavior, 395, 401
 language, 343
 learning, 229–230, 332–333, 344–346
 size of, 57
 Gilbert, W., 122
 Giles, C. L., 139
 Giurfa, M., 355
 Gizmo graph, 285–286
 Go, 197–205
 God, 435
 Gödel, 49–50, 429, 444
 Good Old Fashioned AI (GOFAI), 206
 Goodale, M., 414
 Gorilla, 371
 Gould, C. G., and J. L., 1, 159, 182, 228, 326, 327, 328, 338, 354, 364, 371, 372
 Grammar, 307, 338–346
 animals, 370–372
 evolution, 379–380
 language acquisition, 369
 Grant, P., and R., 447
Graphplan, 213
 Graph 3-coloring, 281–286, 293–296
 Grenier, J. K., 55, 61, 62, 63, 121, 323, 324, 329
 Griffin, Donald, 158
 Grizzly bear, 335, 398
 Grünau, M. von, 410
 Gur, C. R., 421
 Hainsworth, John, 256
 Halting problem, 50, 127, 435
 Hand-coding, 207–208
 Hard problem, the, 31, 67
 Harlow, H. F., 314, 316
 Harman, Gilbert, 444
 Hartley, D., 419
 Hausa, 229
 Hauser, M. D., 314, 344, 328, 363, 364, 371, 372, 376, 377
 Haussler, D., 91, 451
 Hayek, Friedrich, 250
 Hayek Machine, 224, 232, 250–266
 agents, 253, 259, 386–387, 414–415
 Blocks World, 252–255, 332–333
 meta-agents, 260–261
 Post production systems, 262–266
 Rubik's cube, 255–256, 266
 S-expressions, 257–260
 Hazlett, T. W., 251
 Hebb's Law, 330, 452
 Heinrich, Bernd, 159, 359
 Herman, Louis, 371
 Heterophenomenological view, 386
 Heuristic, 109, 203, 214, 243
 Heutze, M. W., 55
 Hilbert, David, 33, 50
 Hill climbing, 125–126
 back-propagation, 116–118
 Blocks World, 265
 credit assignment, 119–120, 124–125
 and evolution, 109, 120, 123, 125, 332
 fitness landscape, 111
 inductive bias, 321

- learning, 118–119
Traveling Salesman Problem, 114–116
- Hillis, Daniel, 244
- Hinton, G., 86, 118, 331, 333, 334, 335, 343
- Holland, J. H., 72, 124, 246
- Honeybee, 326, 354–357, 361
- Hong, W., 70
- Hopfield, J. J., 419, 420
- Horizon effect, 188–191, 447
- Hox gene, 23, 55, 62, 120
- Hubel, D., 312
- Hutchinson, A., 326
- Indigo bunting, 314
- Inductive bias, 4, 25–26, 55, 126, 316–329. *See also* Learning
animals, 325–329
defined, 173, 304–305, 316–317
encryption, 317
evolution, 63, 305, 316–329
evolved, 323–325
genes, 329
language, 337–343, 368–369
MDL, 318–319
straight-line fit, 317
topological knowledge, 320–321
VC dimension, 317–318
word learning, 307
- Inflation, monetary, 229
- Innate drive, 394, 396–398, 400
- Input, data, 107
- Input neuron, 81
- Intelligence, 32, 157, 169, 182–183. *See also* Reasoning
- Intentionality, 71, 78, 162
- Intractability, 271–302. *See also* NP-complete problem; NP-hard problem
constraint propagation, 293–302
hardness, 271–281
polynomial time mapping, 280–286
problem classes and formulations, 287–293
- Intron, 54–56, 121–123
- Intuition, 67
- Isomorphism, 217–218
- Itch, 425
- Jackson, F. C., 7, 31, 228, 424, 453
- Jealousy, 425
- Johnson, D. S., 284, 450
- Johnson, Mark, 16, 220–223, 225–226, 229
- Junk DNA, 55–56, 137, 141
- Kandel, E. R., 64, 330
- Kanji, 373
- Kanzi, 371
- Karp, R. M., 284, 450
- Kasparov, Gary, 187, 189
- Kauffman, S. A., 445
- Keefe, A. D., 57
- Keir, R., 327
- Kepler's laws, 94
- Kernighan, B. W., 114
- Khardon, R., 210
- Kholmogorov complexity, 93
- King safety term, 188
- Kitten, 312, 314
- Kleitman, N., 419
- Koch, C., 453
- Koehler, J., 186, 214
- Kolers, P. A., 410
- Kotov, Alexander, 191, 192
- Koza, J., 233
- Krakauer, D. C., 378–379, 383
- Kramnik, Vladimir, 189
- Kruus, Erik, 256
- Kulozik, A. E., 55
- Kuniyoshi, Y., 289
- Kurzweil, R., 182–183
- Lakatos, I., 446, 448–9
- Lakoff, G., 16, 220–223, 225–227, 229
- Lambda calculus, 41
- Language, 302, 349–383
acquisition, 341–342, 367–370
animals, 368, 370–378, 380–381
awareness, 416
communication, 374–378
and consciousness, 30–31
constraint propagation, 299–300
DNA, 307
evolution, 28, 337–346, 350–351, 378–382
grammar, 307, 338–346, 369–372, 379–380
inductive bias, 337–343, 368–369
learning, 306–308, 314, 319, 337–343
metaphors, 16, 77, 204
modularity, 27, 365–367
and reasoning, 349, 372–374
reflective thought, 158
sexual selection, 244
symbols, 27–28
syntax, 11
and understanding, 211, 299–300
vocabulary, 345–346
words as labels, 365–367
- Language Instinct, The*, 299
- Lawrence, S., 139
- Layered feed-forward net of threshold neurons, 81
- Leaf, 234

- Learning, 303–347. *See also* Inductive bias; Reinforcement learning
 animals, 360–365
 causal analysis, 204
 children, 364–365, 376–377
 compression, 136
 culture, 26, 335–337
 and development, 26, 304, 308–316
 DNA, 25–27, 172–173, 304–305, 387–388
 evolution, 122–123, 126–127, 140–142, 156, 210,
 331–335, 395–396
 general, 219, 316, 342
 generalization, 309
 genetic programming, 236–238
 genome, 229–230, 332–333, 344–346
 grammar, 343–346
 hill climbing, 118–119
 language, 306–308, 314, 319, 337–343
 meta-learning, 123–125, 239, 260–261, 441
 modularity, 26–27, 173, 182–183, 229–230, 232,
 305, 329, 360–365
 and programming, 78
 to reason, 210
 semantics, 323, 325, 344–345
tabula rasa, 25, 326, 330
 words, 307, 380–382
 LeCun, Y., 92, 118
 Leiserson, C. E., 177
 Lenat, Douglas, 72, 76, 77, 208, 211, 243
 Leopold, D. A., 411
 Levit, M., 352
 Lin, S., 114
 Linear separation, 87–90
 Lin-Kernighan algorithm, 114
 Linsley, P. S., 330
 Lisp, 222, 233, 258
 Literal, 282–284
 Littman, M., 333, 334, 452
 Liver cell, 61
 Loading problem, 280, 322
 neural networks, 111, 116–118, 125
 NNLDP, 275–278
 Logical isomorphism, 217–218
 Logothetis, N. K., 411
 Long, M., 122
 Long-term memory, 63–64, 330
look instruction, 238–240
 Lookup table, 36–37
 Loop controls, 234–235
 Luzatti, C., 417
 Lying, 420–421
 Macaque, 363
 Machine, 69–71
 MacKay, D. J. C., 99, 122
 Maes, P., 72
 Main function, 413, 415
 Makalowski, W., 55
Many Faces of Go, 199
Maple, 252
 Mapping, 216, 275–276, 280–286
 Maquet, P., 419
 Marcus, G., 371
 Material balance, 188
Mathematica, 252
 Mathematics, 427–430
 Mattick, J. S., 56
 Maxwell’s equations, 79, 104
 Maynard Smith, J., 61, 123, 249, 324
 Mazzotta, J., 220
 McDermott, D. V., 207, 386, 429, 452
 McFall-Ngai, M. J., 353
 Meaning, 5, 439–440. *See also* Semantics
 Meiosis, 248
 Meister, M., 409
 Melchner, L. V., 314
 Memory, 12
 DNA, 61
 dreams, 419–420
 long-term, 63–64, 330
 reinforcement learning, 146–148
 short-term, 418–419
 Merkle, R. C., 208
 Meta-agents, 260–261
 Metabolism, 59–60
 Meta-heuristic, 243
 Meta-learning, 123, 260–261, 441
 Metaphor, 16, 77, 204, 220–230
 argument as, 221, 223
 code reuse, 220–222
 cultural variation, 229
 and modularity, 220–230
 orientational, 224–225
Metaphors We Live By, 220
 Methylation, 61
 Metzinger, T., 385
 Michal, G., 59
 Miller, G. A., 418
 Miller, M. B., 353
 Miller, M. S., 243, 247, 449
 Millikan, R., 444
 Milner, D., 414
 Mind. *See also* Thought
 algorithm generation, 176
 compact descriptions, 132–133
 as computer program, 52, 134, 437
 distributed/summary computation, 412–
 414

- evolution of, 3, 63–64, 161
modularity, 215–216
and objects, 14, 169
reasoning, 223–228
and semantics, 4
theory of, 216, 376–377
Mind and Mechanism, 386
Mineka, S., 327
Minimum description length (MDL), 93–95, 103–105, 132
and Bayesian statistics, 100–102
inductive bias, 318–319
Minsky, Marvin, 30, 38, 41, 72, 171, 221–222, 268, 386, 407–408, 413
Mitchison, G., 419, 420
Models of computation, 40–46, 318
simulation of, 37, 39–47
Modularity, 4–5, 15, 215–232
and animals, 349–350
chess, 193–196
code discovery, 27
compact program, 15–16, 157
deception, 421
decision-making, 414
development, 63
DNA, 292, 301, 315, 336
and evolution, 134, 218–220, 231–232, 240
evolutionary programming, 267–268
exploiting structure, 19–20, 177–178
and human problem-solving, 176–177, 181
intelligence, 169, 182–183
language, 27, 365–367
learning, 26–27, 173, 182–183, 229–230, 232, 305, 329, 360–365
and metaphor, 220–230
NP-hardness, 293
reasoning, 223–228
self, 405–406, 408
sources of, 230–231
Molecule, 60
signaling, 352–353
transcription factors, 53–54
Monkey, 314, 327–328, 344, 350, 368, 372, 380, 411
Moore’s law, 209, 268, 440
Moral Politics, 227
Morse code, 101, 132, 445
Motivation, 250. *See also* Wanting
Mouse, 62, 324, 331
Mueller, Martin, 199
Multiple personalities, 74
Multiprocessor, 43
Mutation, 52, 109, 126, 236–237
Myhrvold, N., 209, 446
Natural kind, 288
Natural numbers, 165–166
Nature vs. nurture, 374–378
Nau, D. S., 451
Navigation, 314
Neanderthal, 378
Neese, R. M., 327
Nelson, R. R., 327
Neumann, John von, 6, 47–52, 444
Neural circuitry, 12–13
Neural Net Loading Decision Problem (NNLDP), 275–278
Neural network, 8–12, 44, 81–93, 102
back-propagation, 117–118, 138
block-stacking, 154–155
in brain, 82–83
compact representations, 136
early stopping, 139
evolution simulation, 334
fitness, 110–111
layered feed-forward net of threshold neurons, 81
limitations of, 153–157
loading problem, 111, 116–118, 125
model of computation, power of, 44
n-input, 87–91
number order, 320
reactive, 157
reinforcement learning with, 149–158
robotics, 289–290
semantics, 85–86
sigmoidal functions, 152
simple, 86–87
size, 135
training of, 83–84, 109, 137–140, 153–154, 290
weight constraints, 136–137
Neuron, 81–82, 311
feedback, 155
quiescent/spiking, 82
Newell, A., 72
Newton’s theory of gravitation, 79, 94, 103, 119, 211–212, 434
Nolfi, Stefano, 289, 290
Nondeterministic polynomial. *See* NP-complete problem
Normal distribution, 118
Norvig, P., 184
Nowak, M. A., 28, 378–379, 383
Nowlan, S., 86, 118, 331, 333, 334, 335
NP-complete problem, 21–23, 274–276. *See also* Intractability
in AI, 210
loading problem, 125, 322
satisfiability, 281–286
TSP, 112–113

- NP-hard problem, 21, 276–280. *See also* Intractability
 compact representations, 286–287
 graph 3-coloring, 293–296
 modularity, 293
 TSP, 271–281, 284, 287–288, 292
 Numbers, topology of, 320
NumCorrect, 154, 235, 237–238, 252–256, 259, 332–333
Nuture, 335, 374–378
- Object, 14, 168–174
 compact description, 170, 172
 compression, 173–174
 natural kind, 288
 programming, 15
 Objectivity, 226
 Occam's razor, 3, 8, 12–13, 68, 125
 agents, 389
 Bayesian statistics, 99–100
 compact representation, 130, 135
 compression, 102
 evolution, 123
 heuristic, 109
 minimum description length, 93, 103–104
 neural networks, 91
 and physics, 79
 Vapnik-Chervonenkis dimension, 102–103
On the Origin of Objects, 169
 Ontogeny, 337
 Ontology, 208
 Optical character recognition, 136
 Optical illusion, 410–413
 Optimality theory, 339, 395
 Optimization, 10. *See also* Hill climbing
 and evolution, 109
 hand-coding, 208
 Traveling Salesman Problem, 112–117
 Orangutan, 364, 371
 Orgasm, 29, 397, 402
 Overfitting, 138–139
- Pain, 31, 68–69, 146, 385, 390–391, 402–404, 424–425
 Pallas, S. L., 314
 Palmer, R. G., 420
 PARADISE, 193–194
 Parental approval, 397–398
 Parrot, 364, 371
 Parse tree, 233
 Pathway, 59
 Pattern-matching, 41, 58
 DNA, 65
 meta-learning, 261
- Post production systems, 262
 Pauli, Wolfgang, 434
 Pavlov, I. P., 373
 Penrose, Roger, 7, 429
 Pepperberg, Irene, 371
 Perceptual aliasing, 291
 Periodic table, 79, 104
 Pfeifer, R., 289
 Phenol-thio-urea, 425
 Phenotype, 141–142
 Phlogiston, 434
 Phylogeny, 337
 Physicalism, 424–426, 428
 Physics, 1, 3, 279, 434
 compression, 104
 free will, 427
 measurement, 386
 minimum description length, 94
 Occam's razor, 79
 rigorous methods, 161
 Pidgin, 342
 Pigeon, 325–326
 Pinker, Steven, 299, 300, 314, 342–343
 Pirsig, R. M., 211
 Plan compilation, 186, 212–214
 Planning graph, 213
 Planning problem, 18–19
 exploiting structure, 210–211
 search, 184–186
 Plato, 14, 174, 211
 Pleitropic gene, 63, 232
 Plover, 376
 Plus (+) symbol, 233–234
 Policy iteration, 160
 Political reasoning, 227–228
 Pollan, M., 425
 Pollution, 245
 Polymerase, 54
 Polynomial, 138–139, 274–276, 280–286
 Polynomial slowdown, 46
 Post, Emil, 41, 261
 Post production systems, 41–42
 gene expression, 61
 Hayek Machine, 262–266
 and life mechanisms, 53–54, 64–65
 Premack, David, 376
 Price, V., 327
 Primitive, 257
 Principles and parameters, 338–339
 Probability, Bayesian, 95–102, 104
 evidence, 98
 medical testing, 98–99
 Problem class, 287–293
 Problem space, 181, 183, 186, 293

- Production systems. *See* Post production systems
- Program evolution, 13, 308. *See also* Evolutionary programming
- Program space, 181, 183, 186, 293
- Proofs and Refutations*, 448
- Propagation, 388–389
- Property rights, 242–247, 249, 265–266
- Proprioception, 406
- Protein, 48, 54–57, 140
- coding, 122
 - folding, 56–58
 - molecular behavior, 60
 - repressor, 61
 - toolkit genes, 62
 - transcription factors, 53–54
- Psychophysics, 216, 411
- Ptolemaic theory, 67, 79
- Putnam, H., 429
- Q-learning, 146–148
- Qualia*, 31–32, 67, 424–426. *See also* Pain; Sensation
- Quantum coherence, 46
- Quantum computer, 44–46
- Quantum mechanics, 45, 386, 427, 435
- Quartz, S., 314, 316, 330
- Quiescence search, 189
- Quiescent neuron, 82
- Quine, Willard Van Orman, 368
- Ramachandran, V. S., 216, 406, 417
- Random access machine, 42–43, 46
- Random search, 118–119
- Rat, 325–326, 363, 364
- Raven, 159, 363
- Read, L., 20, 241
- Read-write head, 36, 71–72
- Real numbers, 202–203
- Reasoning
- animals, 301, 372–374
 - evolution of, 226–227
 - and language, 349, 372–374
 - and modularity, 223–228
 - political, 227–228
 - spatial, 224
- Receptor tyrosine kinases, 60
- Recursion, 229, 363
- Blocks World, 178–183
 - as module, 293
 - recursive functions, 40, 44
 - S-expressions, 258–260
- Red Queen race, 123–124, 244
- Refenes, A.-P., 92
- Reflection, 157–160
- Reinagel, P., 409
- Reinforcement learning, 12–13, 29. *See also* Learning
- compact evaluation function, 149–154
 - defined, 146
 - evolution, 12, 146, 151
 - evolutionary programming, 161–163, 242
 - Hayek Machine, 254
 - neural networks, 155–157
 - Q-learning, 146–148
 - reaction vs. reflection, 157–159
 - value iteration, 147, 149, 153–155, 159–160
 - wanting, 391–395
- Reitman, Walter, 199
- REM sleep, 419–420
- Reproducing automaton, 47–52
- Retina, 352
- Reuse, code, 16, 63, 132–133, 156
- DNA, 171
 - game analysis, 204
 - and intention, 162
 - metaphor, 220–222
 - modularity, 231
- Reward function, 219, 224, 321
- agency, 402–403
- chess, 392
- evolution, 146, 153, 392–398
- Rewrite rules, 41–42
- Ridley, M., 244, 245, 249, 388, 396, 397, 398, 434, 449
- Rissanen, J., 93
- Ristau, Carolyn, 376
- Rivest, R. L., 177
- RNA, 54, 56, 122, 257
- Robertson, Douglas S., 409, 426–430, 433, 434, 435
- Robotics, 12, 145–146, 289–291
- Roth, D., 210
- Roth, G., 452, 453
- Roulette wheel selection, 265–266
- Rubik’s cube, 154, 255–256, 266
- Rumelhart, D., 86, 118
- RushHour*, 256
- Russell, S., 184
- Saccade, 412
- Sackheim, H. A., 421
- Sandberg, R., 331
- Satisfiability (SAT), 281–286
- Scheier, C., 289
- Scheinberg, D. L., 411
- Schell, T., 55
- Schema Theorem, 236

- Scheme, 222, 258
 Schenk, Roger, 77, 206
 Schrödinger, Erwin, 1, 2, 24
 Schrödinger's cat, 45–46
 Sea lion, 371
 Sea urchin, 60
 Search
 evolution, 324
 exhaustive, 107–108, 187, 196, 271
 exponential, 108, 119, 183–186, 272
 Hayek Machine, 253–254
 modularity, 293
 plan compilation, 212–213
 planning problems, 184–186
 quiescence, 189
 random, 118–119
 recursive, 181–182
 Searle, John, 7, 71–78, 102, 199–200, 206, 427,
 428, 429, 444
 Seay, B. M., 314
 Sejnowski, T. J., 314, 316, 330
 Self, 30, 403–408, 439
 Self-consistent (model of consciousness), 31–32,
 69, 385–386, 453
 Self-reference, paradoxes arising from, 49–50
 Self-reproducing automaton, 47–52
 Selfridge, O., 72
 Semantics, 3–5
 awareness, 438–439
 compression, 102
 curve fitting, 80–81
 development, 62
 evolution, 141
 genes, 120–121
 learning, 323, 325, 344–345
 neural networks, 85–86
 overconstrained world, 22–23
 and syntax, 11, 75–78
 understanding, 299–300
Semeai race, 201
 Sensation, 67–69, 385, 431, 435–436, 438. *See also*
 Pain; *Qualia*
Sente, 202
 Sex, 124, 248–249
 evolution, 122–123
 recombination, 124
 reproduction, 248–249
 selection, 243–244, 343–344, 396–397
 S-expression, 233–236, 252–253, 449
 define statements, 258–260
 typed, 236
 Shannon, C. E., 28, 38, 379
 Sherry, David, 363
Shibumi, 197
 Shoemaker, D. D., 330
 Shor, P. W., 45
 Short-term memory, 418–419
 Shusterman, Ronald, 371
 Siegel, J. M., 419
 Siegelmann, H. T., 39
 Signaling molecule, 352–353
 Siskind, J. M., 369, 380
 Skin cell, 61
 Skin response, 406, 421
 Skyrms, B., 434
 Slate, D. J., 191
 Slotine, J., 70
 Slug, 403
 Smell, 425
 Smith, Adam, 20
 Smith, Brian Cantwell, 169, 444
 Smith, W. D., 39
 Smolensky, P., 339
 Smolin, L., 450
 Snake, 327
Society of Mind, The, 72, 221, 407, 415
 Sokolowski, R., 444
 Solipsist approach, 71
 Source code, 13, 133–134
 Sovereign agency, 29, 386–387
 Spatial reasoning, 224
 Speed, computational, 209
Sphex, 354
 Spiking neuron, 82
 Spin glass, 445–446
 Split-brain patient, 416–417
 Squid, 353
 Squirrel, 372
 Stacker, 253
 Standard deviation, 118
 Start state, 36
 Startle response, 426
 State
 of mind, 40
 of physical system, 35–36
 Statistics, 1
 Steiglitz, K., 39
 Stem cell, 61
 Stephenson, Neal, 42
 Stereo vision, 313
 Stickgold, R., 419
 Stock, J., 352
 Stockmeyer, L., 284
 Stop state, 36
 Straight line, 80–81, 317
 STRIPS, 185
 Stroke victim, 215–216, 417–418
 Strong Artificial Intelligence, 6

- Structure and Interpretation of Computer Programs*, 222
Subrahmanian, V. S., 451
Subroutine, 4–5, 15, 53–54, 60
Subtree, 236
Sugar, 425
Sugihara, K., 298
Suicide bomber, 399, 401
Superposition of states, 45
Supertree, game, 201–202
Super-Turing behavior, 34, 39–40, 47
Sur, M., 314
Surette, M. G., 353
Sussman, G. J., 222
Sussman, J., 222
Sutton, R. S., 149, 150
Symbol, 27–28, 34
Syntax, 3, 7
and animals, 371
compact program, 9–10
error correction, 380
and semantics, 11, 75–78
Szathmary, E., 61, 249, 324
Szostak, J. W., 57, 257–258
- Tabula rasa* learning, 326, 330, 440
Tamarin, 364–365, 371
Tanenhaus, M. K., 300
Taste, 425
Tesar, B., 339
Tesauro, Gerry, 150–153, 159, 365
Thematic analysis, 192–193
Theron, C., 191
Think Like a Grandmaster, 192
Thomas, J. A., 101
Thought, 437–441. *See also* Mind
defined, 69–71
and grammar, 370
and language, 372–374
model of, 360–365
reactive/reflective, 157–160
3-satisfiability (3-SAT), 284–286
Time, 221–223
Toga, A., 220
Tooby, J., 216, 217, 303
Toolkit gene, 23, 62, 120, 232
Tooze, J., 54
Topology, 320–321
Toy universe, 39
Tragedy of the Commons, 244–246
Training
genetic programming, 233
neural networks, 83–84, 109, 137–140, 153–154
robotics, 290
- Transcription factor, 53–54
Traveling Salesman Decision Problem (TSDP), 274–275
Traveling Salesman Problem (TSP), 112–117, 123, 126, 130–131
branch-and-bound, 189
exploiting structure, 165
NP-hardness, 271–281, 284, 287–288, 292
planning problems, 185
polynomial time, 274
Trevanian, 197
Tridgell, A., 92
Trivers, R., 226, 372, 420, 421, 422
Trueswell, J. C., 300
Turing, Alan, 5–7, 33–37, 40–41, 46, 50, 69–72, 127, 435
Turing machine, 5, 36–47, 69, 435
bias, 321
Chinese Room, 71–75
components of, 36
as computer, 53
data input, 107, 126–127
halting problem, 50, 127, 435
Lambda calculus, 41
NP class, 283–284
Post production systems, 41–42, 262
random access machine, 42–43, 46
recursive functions, 40–41
super-Turing behavior, 34, 39–40, 47
universal, 37–39, 41–42, 46–47, 72, 126, 318–319
Turing test, 69–75
Two-link optimal tour, 115, 130–131
Typed S-expression, 236
- Understanding, 5, 7
and AI, 186, 206–208
causality, 173, 205
and compression, 10, 79–80, 104–105, 132
concepts, 133
constraint propagation, 298–302
exploiting structure, 292
games, 192, 196, 203
language, 211, 299–300
and memorization, 12
mind vs. computer, 22
neural networks, 84–86, 129–134
Turing test, 71–72
Universal Turing machine, 37–39, 41–42, 72, 126, 318–319
- V. cholera*, 353
V. fisheri, 353
Valiant, L., 72, 446

- Validation set, 139–140
- Valuable resource management, 204, 221–224
- Value iteration, 147, 149, 153–155, 159–160
- Vapnik, V., 93
- Vapnik-Chervonenkis dimension, 92–93, 102–103, 105, 130, 138
- compact representation, 107, 135
- effective, 138
- inductive bias, 317–318
- lower-bound theorem, 142–143
- Varian, H. P., 244
- Venn diagram, 96
- Verguts, A., 39
- Vervet monkey, 328, 344, 368, 372, 380
- Visick, K., 353
- Visual cortex, 137, 231, 238
 - fly, 62, 312
 - kitten, 312–314
- Vocabulary, 345–346
- Wall data, 290
- Walsh, C. A., 121, 324
- Waltz, David, 297–299
- Wanting, 387–403
- Warland, D., 409
- Warmuth, M., 180, 181
- Washoe, 372
- Wason selection test, 216–218, 220
- Wasp, 354
- Watson, James, 1, 47
- Weatherbee, S. D., 55, 61, 62, 63, 121, 323, 324, 329
- Weaver, L., 92
- Web crawling, 256
- Weiss, D., 371
 - What Computers Still Can't Do*, 76
 - What Is Life?*, 1
- White-crowned sparrow, 327–328
- Wiener, J., 447
- Wiesel, T., 312
- Wilcox, Bruce, 199–200, 206
- Wilczek, F., 429
- Wilkins, D., 193–196, 205, 206
- Will, 426–436
- Williams, G. C., 327
- Williams, R. J., 86, 118
- Wilson, Edward O., 399, 426, 434
- Wilson, S., 265
- Winter, S. G., 242
- Wittgenstein, Ludwig, 133, 288
- Wolfe, D., 203
- Word learning, 307, 380–382
- Worst-case result, 287
- Y2K bug, 215
- Young, H. P., 434
- Zero-Based Classifier Systems (ZCS), 246, 265
- Zhao, X., 331
- Zhu, J., 353
- Zombie, 453