

## Index

- Activation function of neuron, 41
- Actor–critic:
  - interpretation of policy iteration, 165
- Attention, 2, 20
  - executive, 21
  - explore–exploit strategy, 214
  - perceptive, 21
- Back-propagation algorithm, 31
- Bayes rule, 79
- Bayesian filter, 9, 77, 90, 176
  - approximation of, 94
  - block diagram of, 93
  - measurement equation, 87
  - measurement update, 92
  - optimality, 93
  - posterior distribution, 91
  - predictive distribution, 91
  - principle of duality, 121
  - state-space model, 92
  - system equation, 87
  - time update, 93
  - transition-state distribution, 91
- Bayesian framework of vision, 121
- Bayesian inference, 39, 80
  - probabilistic modeling, 80
  - statistical analysis, 81
- Bispectrum, 75
- Cognitive dynamic systems, 1
  - actuator, 3
  - perceptor, 3
- Cognitive dynamic wireless systems, 3
  - cognitive radar, 3
  - cognitive radio, 4
- Cognitive radar: case study, 192
  - simulation results, 196
  - target falling in space, 192
- Cognitive radar: multiscale memory, 211
  - cyclic directed information flow, 213
  - explore–exploit strategy, 214
  - features-of-features strategy, 213
- Cognitive radar: perception–action cycle, 169
  - approximation in measurement space, 187
  - cost-to-go function, 182
    - mean-square error, 182
    - mutual information approach, 183
    - Shannon’s entropy, 183
  - cubature Kalman filtering, 176
  - cyclic direct information flow, 184
  - dynamic optimization, 190
  - executive dynamics, 185
  - feedback information, 180
  - imperfect state information, 186
  - optimal control using ADP, 186
  - perceptual dynamics, 184
  - transition from perception to action, 180
  - waveform library, 191
- Cognitive radar: single-level memory, 199
  - chattering, 209
  - communication among subsystems, 201
  - communication between:
    - environmental scene actuator and executive memory, 203
    - environmental scene analyzer and perceptual memory, 202
  - cyclic directed information flow, 200
  - system-model library, 200
  - unexpected disturbances, 206
- Cognitive radar networks, 285
  - self-organizing, 287
  - weather forecasting, 285
- Cognitive radio, 230
  - advanced television systems, 237
  - attention, 234
  - digital television, 237
  - directed information flow, 232
  - IEEE 802.22 standard, 244
  - intelligence, 235
  - learning and memory, 234
  - multitaper method, 240
  - perception–action cycle, 232
  - predictive modeling, 235
  - radio scene actuator, 232
  - radio scene analyzer, 238
  - shadowing, 238
  - signal fading, 238
  - spectrum holes, 231, 237

- spectrum sensing, 239
- spectrum under utilization, 231
- transceiver, 232
- users,
  - primary (legacy), 232
  - secondary, 232
- white spaces, 237
- wireless microphones, 238
- Cognitive radio: case study, 242
- wideband ATSC-DTV, 242
- Cognitive radio networks, 235
  - cooperative, 244, 268
  - double-layer network dynamics, 288
  - dynamic spectrum management, 125
  - emergent behavior, 270
  - noncooperative, 244
  - orthogonal frequency division multiplexing, 244, 251
  - security, 290
  - transient behavior, 259
  - transmit-power control, 248
  - variational inequality, 259, 281
- Complexity, 271, 281
- Cramèr representation of stochastic process, 58
- Cubature Kalman filters, 97, 177
  - cubature rule, third degree, 97, 123, 189
  - properties, 104
  - radial rule, 100
  - relationship with unscented Kalman filter, 97
  - spherical rule, 99
  - spherical–radial rule, 100
- Curse of dimensionality, 109, 190
- Cyclostationarity, 64, 241
  - cyclic power spectrum, 62
  - Fourier framework for, 64
  - Fourier spectral coherences, 65
- Dynamic programming, 125
  - Bellman's dynamic programming algorithm, 130
  - Bellman's equation:
    - expectation form, 132
    - standard form, 132
  - Bellman operator, 164
    - for target policy, 153
    - off-policy,  $\lambda$ -weighted version, 154
  - Bellman's optimality criterion, 129
  - cost-to-go function, 129
  - credit-assignment problem, 125
  - imperfect state information problem, 137
  - Markov decision processes, 126
  - planning horizon, 130
  - policy iteration, 132
    - algorithm, 134
    - summary, 135
  - $Q$ -factor, 132
    - definition, 133
    - state, defined, 127
  - value iteration, 135
    - algorithm, 136
    - summary, 137
- Dynamic spectrum management, 265
  - centralized, 265
  - graph-coloring problem, 281
  - decentralized, 265
  - Hebbian learning, 267
  - self-organized, 265
- Emergent behavior of cognitive radio networks, 270
- Encoder–decoder, *see* replicator
- Energy detection, 240
- Euler approximation, 194
- Extended Kalman filter, 95, 116
  - algorithmic summary, 96
  - decoupled, 117
  - supervised training of RMLP, 114
- Feedback channel, 272
- Feedback information, 8, 180
- Femtocell networks, 275
- Fore-active radar, 168
- Fast Fourier transform, 277
- Fastest Fourier transform in the west, 277
- Fredholm integral of the first kind, 74
- Fundamental equation of spectral analysis, 74
- Fundamental integration across time in cognition, 15
- Game theory, 245, 246, 280
  - coalitional games, 269
  - mixed strategy, 246
  - Nash equilibrium, 246
- Generalized Fourier transform of nonstationary process, 58
- Generalized spectral density, 59
- Graph-coloring problem, 265, 281
- Hadamard's condition for well-posedness, 39
- Harmonic  $F$ -test for line components, 67
- Hebbian learning, 35
  - generalized, 36
- Hypothesis testing, 84, 240
- Information overload, 20, 40
- Information theory, 245, 248
  - information capacity formula, 250, 280
  - iterative water-filling controller, 252
  - normalized interference gain, 250
  - signal-to-noise ratio gap, 250
  - transmit power control, 248
  - two-user noncooperative example, 249
  - water-filling, 248
- Impulsive noise, 276
- Intelligence, 2, 21, 206
  - efficiency of processing information, 22
- Interleaving, 240

- Kalman filter, 5,
  - cubature, 97, 177
  - extended, 95
  - prediction–correction, 116
  - unscented, 105
- Likelihood, 82
- Likelihood function, 91, 122
- Likelihood principle, 58, 60
- Loève’s spectral coherences, first and second, 61
  - computational instrument, 62
- Markov chain, 88
- Markov property, 91, 127
- Maximum a–posterior probability (MAP)
  - rule, 83
- Maximum likelihood estimation, 122
- Memory, 17
  - associative, 29
  - executive, 18
  - hierarchical, 23
  - perceptual, 17
  - roles in cognition, 19
  - working memory, 20, 40
- Monomials, 99, 123
- Moore’s approach to complex stochastic processes, 75
- Multitaper method (MTM), 47
  - adaptive modification, 49
  - attributes, 47
  - bias–resolution tradeoff, 47
  - degrees of freedom, 47
  - dynamic spectrum, 60
  - generalized spectral density, 59
  - harmonic  $F$ -test for line components, 67
  - MTV-SVD processor, 54
  - regularization, 47, 74
  - robustness, 240
  - singular value decomposition (SVD), 53
  - Slepian tapers (sequences), 48
  - space–time processing, 52
  - theory, 48
  - time–frequency analysis, Loève’s nonstationary approach, 58
  - time–frequency magnitude-squared coherence, 61
- Mutual information, 228
- Nash equilibrium, 246, 280
- Neural networks, 24
  - back propagation algorithm, 31
  - benefits, 25
  - generalized Hebbian learning, 36
  - Hebbian learning, 35
  - multilayer perceptron, 27
  - neuron, model of, 27
  - recurrent multilayer perceptron, 34, 112
  - replicator, 30
  - unsupervised learning, 41
- Nonstationary processes, 57
- Optimization,
  - constrained, 253
  - convex, 216, 255
  - robust, 257
  - stochastic, 256
  - utility function, 256
- Particle filters, 95, 123
- Perception, two different views, 39
- Perception–action cycle, 14
  - radar, 169
  - radio, 232
- Periodogram, 46
- Power spectrum, 43
- Power spectrum estimation, 44
  - ill-posedness, 73
  - nonparametric methods, 46
  - parametric methods, 44
- Principle of information preservation, 8
- Probability theory, 78
  - axioms of, 78
  - central limit theorem, 122
- $Q$ -factor, 132
- Qualcomm competition on wireless microphones, 200, 278
- Recurrent multilayer perceptron, 34
- Regularization,
  - multitaper method, 47, 74, 240
  - sparse coding, 219, 229
- Reinforcement learning, 141
  - approximate form of dynamic programming, 141
  - $Q$ -learning, 141
    - behavior policy, 141
    - summarizing remarks, 143
  - temporal difference (TD) learning, 144
    - eligibility traces, 146
    - $\lambda$ -return, 149
    - multistep TD learning, 145
    - relationship with dynamic programming, 148
    - value function, 149
- Sarsa, 165
- Reinforcement learning (modern), 150
  - GQ ( $\lambda$ ) algorithm, 151, 156
    - Bellman operator, 154
    - comparison to other algorithms, 152
    - eligibility traces, 159
    - gradient operator, 156
    - objective function, 153
    - predictive learning, 152
    - practical considerations, 161
    - root mean-square of Bellman error, 155

- root mean-square of projected Bellman error, 155
  - summary of algorithm, 160
  - Sutton trick, *see* weight-doubling trick
  - weight-doubling trick, 158
- Greedy-GQ algorithm, 163
- Robbins–Monro stochastic approximation, 166
- Robustness
  - multitaper method, 240
  - transmit-power control, 256
- Root mean-square error, 196
  - Ensemble-averages root mean-square error, 196
- Schwarz’s inequality, 226
- Self-organized dynamic spectrum management, 265
- Self-organized learning, 36
- Sequential state estimation, 88
- Singular value decomposition, 53
- Slepian tapers (sequences), 74
- Sparse coding, 215
  - mathematical basis of sparseness, 216
  - overcomplete representation, 216
  - predictive sparse decomposition, 220
  - sparse encoding symmetric machine, 217
- Space–time processing, 52
- Spectral coherences of nonstationary processes, 60
- Spectrum sensing, 240
- State-space models, 87
  - linear, 5, 206
  - hierarchy of, 89
  - nonlinear, 87
- Sufficient statistic, 83
- Time-frequency analysis, 58
- Traditional active radar, 168
  - ambiguity function, 172
  - baseband model, 170
  - complex envelope, 171
  - matched filters, 171
- Unscented Kalman filter, 105
  - sigma points, 105
  - relationship to cubature Kalman filter
- Unsupervised learning, 41
- Variational inequality, 259, 281
- Wigner–Ville distribution, 61
- Wireless, microphones, 200
- Working memory, 20, 40