# Index

A	Approximate reasoning, see
Adaptive Neuro-Fuzzy Inference	Reasoning
	Artificial neural networks (ANNs)
	,
System (ANFIS), 214 Sugeno FIS    aggregation, 217    antecedent, 216    architecture of, 215    consequent, 217    defuzzification, 215    membership functions, 216    normalization, 216    rules, 214 Tsukamoto FIS, 217–220 Adaptive Resonance    Theory (ART), 230    applications of, 234    architecture, 230, 231    attention, 230    classification problems, 231 $F_1$ and $F_2$ (attentional	Artificial neural networks (ANNs) activation functions, 163 leaky ReLU, 167–169 ReLU functions, 166, 167 sigmoid, 163 softmax function, 165, 166 Tanh, 164 backpropagation, 159 computational graph of, 159 concepts of, 161 cost function, 160 forward propagation, 158 gradient descent process, 160 hidden layers, 158 input layer, 158 layers, 157 LSTM, 182 multi-layer
layer), 233, 234 orientation, 230	architecture, 169, 170
output layer, 232 Python implementation, 235 vigilance threshold, 231 Akaike information criteria (AIC), 149	convolutional neural networks, 170–178 recurrent neural networks, 178–182 output layer, 158

Artificial neural networks	universe of discourse 5
	universe of discourse, 5
(ANNs) (cont.)	Venn diagram, 5
perceptron, 162, 163	Clustering
weights and bias, 161	ART (see Adaptive Resonance
Auto-associative memory, 209	Theory (ART))
	categories, 224
В	C-Means (see C-Means
_	clustering approach)
Bayesian information criteria	FALCON network, 244–247
(BIC), 150-153	FINEST, 248–251
	NEFCLASS, 247, 248
•	C-Means clustering approach
C	applications of, 228
Center of gravity method/centroid	definition, 225
method, 103	euclidean distance, 226–228
Center of Sum method, 106-108	fuzzycmeans, 228
Classical sets	Python implementation,
cardinality of sets, 7	228-230
countable set, 10	Composite and non-composite
crisp (see Crisp set)	membership functions, 65
family of sets, 7, 8	Convolutional neural networks, 170
membership of elements, 7	components, 171
null/empty set, 8	convolution layer, 172, 173
operations, 10	padding, 174
complement, 12	activation function, 174
difference, 13	output layer, 175
intersection, 11	pooling layer, 174
union, 10	zero-padding, 174
powerset, 9	pixel matrix, 171
properties of, 6	Crisp set
singleton set, 8	De Morgan Laws, 18
subset, 8	idempotent law, 16
superset, 9	identity law, 16
uncountable set, 10	Involution Law, 17
· ·	•

Law of Absorption, 17	Fuzzy Inference Neural Networks
Law of Associativity, 15	(FINNs)
Law of Commutativity, 15	architectures, 208
Law of Contradiction, 18	categories, 206
Law of Distributivity, 16	concurrent, 207
Law of Excluded Middle, 18	cooperative, 206, 207
Law of Transitivity, 18	Fuzzy Inference Software (FINEST)
properties of, 14	composite unit, 250
	executable UNIX file, 250
5 5	function unit, 249
D, E	list of, 248
Dataset, 138	memory unit, 250
Defuzzification, 94	rule unit, 249
approaches, 94	Fuzzy Inference System (FIS)
center of gravity method/	comparative analysis, 127
centroid method, 103	Mamdani method (see
center of sum method, 106-108	Mamdani method)
first/last/mean of maximum	process of, 108, 109
method, 102, 103	Takagi-Sugeno-Kang, 119–124
FIS (see Fuzzy Inference System	Tsukamoto, 124-127
(FIS))	Fuzzy sets
$\lambda$ cut method, 95–100	De Morgan laws, 22
max principle/height	Idempotent Law, 21
method, 100	identity law, 21
process of, 94	involution law, 22
weighted average	Law of Associativity, 20
method, 105, 106	Law of Commutativity, 20
	Law of Distributivity, 20
_	Law of Transitivity, 22
F	members and non-members, 19
Fundamental memory set, 209	operations, 29
Fuzzy Adaptive Learning Control	complement, 31
Network (FALCON),	difference, 33
244-247	disjunctive sum, 33

Fuzzy sets (cont.)	swap mutation, 242
intersection, 31	tournament selection, 239
power, 34	uniform crossover, 241
product, 32	
union, 30	11 1 12
properties, 19	H, I, J, K
	Hetero-associative memory, 209
G	Hybrid neural networks, 200
G	
Gated recurrent units	1
(GRU), 189, 190	L
Gaussian membership	Long short-term memory (LSTM)
function, 50–52	components, 182, 183
Generalized bell membership	forget gate, 184
function, 52–54	gated recurrent units, 189, 190
Generalized modus ponens	input gate, 185
(GMP), 83–85	output gate, 186–189
Genetic algorithms, 236	reset gate, 191-198
arithmetic crossover, 241	update gate, 190
bit flip mutation, 242	
candidate solution, 236	N/I
chromosomes, 236	M
decision variables, 236	Machine learning (ML) models
flowchart	accuracy, 142
representation, 236, 237	recall/true positive rate, 142
initialization step, 238	true negative rate, 142
inversion mutation, 243	algorithms, 130
mutation, 241–243	bias and variance, 154–156
one-point crossover, 240	binary classification, 131
recombination, 239-241	classification, 132, 136
replacement, 243	confusion matrix, 140, 141
scramble mutation, 243	datasets types, 139, 140
selection, 238	experience, 133, 134
stopping, 244	F1-score, 143

house price dataset, 139	rulebase, 114
overfitting <i>vs.</i> underfitting,	sigmoid representation, 110
153, 154	steps, 109
precision, 142	TSK method, 116
regression model, 132, 133	Max pooling operation, 175
adjusted R-Squared	Membership functions
summary, 149	crisp set representations, 23
AIC model, 149	definition, 23, 35
BIC, 150-153	formal definition, 37
RMS error, 148	Gaussian function, 27
R-Squared formula, 148	gaussmf method, 26
ROC curve, 143-147	generalized bell
supervised <i>vs.</i> unsupervised	function, 28
learning, 135–137	ratings avg, 36
Titanic dataset, 137, 138	Scikit Fuzzy package, 24
Mamdani integrated FINNs, 210	sigmoidal function, 29
architecture of, 211	sigmoid function, 36
backpropagation method, 210	terminologies, 38
consequent layer, 212	α-Cut, 41
defuzzification layer, 212	bandwidth, 42
fuzzification layer, 211	boundaries, 40
input layer, 211	closed, 43
rule antecedent layer, 212	convexity, 42
Takagi Sugeno, 212–214	core, 40
Mamdani method	crossover points, 40
advantages of, 115	normality, 41
aggregation, 112	open left, 43
crisp output, 114, 115	open right, 43
disadvantages of, 116	singleton, 41
fuzzification, 111	strong α-Cut, 42
If-Then rules, 113	support, 39
output membership	symmetric set, 42
function, 112	trapezoidal function, 25
Python code, 116–120	triangular, 25

Membership functions (cont.)	Neurons
types of	AND/OR, 203
composite and non-	component of, 201
composite functions, 65	hybrid neural net, 202
definition, 44	implication-OR neuron, 204
Gaussian function, 50-52	Kwan and Cai (K&C)
generalized bell function,	neuron, 205
52-54	regular neural net, 202
polynomial membership	T-Co-Norm operation, 203
function, 57-65	T-Norm operation, 203
sigmoidal function, 54-57	
trapezoid, 48-50	D 0
triangular function, 45–48	P, Q
	Pi-shaped membership
N O	function, 63-66
N, O	Polynomial membership
Neural associative memory, 209	function, 57
Neural networks, 199	pi-shaped, 62–65
ANFIS (see Adaptive Neuro-	s-shaped, 60-62
Fuzzy Inference System (ANFIS))	z-shaped, 57–60
associative memories, 208-210	_
FINNs (see Fuzzy Inference	R
Neural Networks (FINNs))	Reasoning
hybrid neural networks, 200	aggregation operations, 85
Mamdani Integrated FINNs,	commutativity, 85
210-214	Co-Norms triangular, 89–92
neurons, 201-206	fixed identity, 86
properties, 199	monotonicity, 85
representation, 200	triangular norms, 86
Neuro Fuzzy system, 223	conjunction rule, 81
Neuro-Fuzzy Systems for	definition, 80
Classification of Data	disjunction rule, 82
(NEFCLASS), 247, 248	entailment rule. 81

formal notation, 80	Root Mean Squared (RMS), 148
GMP, 83-85	Rules, 77
negation, 82	consequent/conclusion, 77
projection rule, 82	implication and mapping, 79
tollens, 84	linguistic values, 77
Rectified linear unit (ReLU)	process of, 78
activation function	service, 79
dying problem, 169	
formula, 166, 167	C
leaky ReLU, 167–169	S
Python implementation, 167	Scramble mutation, 242
Recurrent neural networks, 178	Sigmoid activation function, 163
cell process, 179	Sigmoidal membership
diagrams, 179	function, 54-57
exploding gradient problem,	Soft computing
181	cognitive abilities, 2
structure of, 178	constituents of, 3
time series data, 178	crisp sets, 4
vanishing gradient problem,	definition, 1
181	vs. hard computing, 2
Relations	inference system, 3
anti-reflexive, 71	problem-solving approaches, 2
anti-similarity, 75	Softmax activation
anti-symmetric relation, 72	function, 166, 167
cylindrical extension, 70	S-shaped membership
definition, 66	function, 60-62
half order, 76	Sugeno Fuzzy Inference System
projection of, 69	(FIS)
properties of, 68	aggregation, 217
reflexive, 71	antecedent, 216
similarity, 75	architecture of, 215
symmetric relation, 72	consequent, 217
transitive, 73	defuzzification, 215
weak similarity, 76	membership functions, 216
•	

Sugeno Fuzzy Inference System
(FIS) (cont.)
normalization, 216
rules, 214
Supervised versus unsupervised
learning, 135–137

# **T, U, V**

Takagi-Sugeno-Kang (TSK) method, 116, 119–124 Tanh activation function, 165 Tournament method, 238 Trapezoidal membership function, 48–50 Triangular membership function, 47–50 True Negative Rate (TNR), 142 Tsukamoto FIS, 217–220 Tsukamoto method, 124–127

# **W**, **X**, **Y**

Weighted average method, 105, 106

## Ζ

Z-shaped membership function, 58–61