



MATLAB Machine Learning Recipes

A Problem-Solution Approach

—

Second Edition

—

Michael Paluszek
Stephanie Thomas



Apress®

Contents

About the Authors	XV
Introduction	XVII
1 An Overview of Machine Learning	1
1.1 Introduction	1
1.2 Elements of Machine Learning	2
1.2.1 Data	2
1.2.2 Models	3
1.2.3 Training	3
1.2.3.1 Supervised Learning	3
1.2.3.2 Unsupervised Learning	4
1.2.3.3 Semi-Supervised Learning	4
1.2.3.4 Online Learning	4
1.3 The Learning Machine	4
1.4 Taxonomy of Machine Learning	6
1.5 Control	8
1.5.1 Kalman Filters	8
1.5.2 Adaptive Control	9
1.6 Autonomous Learning Methods	9
1.6.1 Regression	10
1.6.2 Decision Trees	13
1.6.3 Neural Networks	14
1.6.4 Support Vector Machines	15
1.7 Artificial Intelligence	16
1.7.1 What is Artificial Intelligence?	16
1.7.2 Intelligent Cars	16
1.7.3 Expert Systems	17
1.8 Summary	18

2	Representation of Data for Machine Learning in MATLAB	19
2.1	Introduction to MATLAB Data Types	19
2.1.1	Matrices	19
2.1.2	Cell Arrays	20
2.1.3	Data Structures	21
2.1.4	Numerics	23
2.1.5	Images	23
2.1.6	Datastore	25
2.1.7	Tall Arrays	26
2.1.8	Sparse Matrices	27
2.1.9	Tables and Categoricals	27
2.1.10	Large MAT-Files	29
2.2	Initializing a Data Structure Using Parameters	30
2.2.1	Problem	30
2.2.2	Solution	30
2.2.3	How It Works	30
2.3	Performing MapReduce on an Image Datastore	33
2.3.1	Problem	33
2.3.2	Solution	33
2.3.3	How It Works	33
2.4	Creating a Table from a File	35
2.4.1	Problem	35
2.4.2	Solution	36
2.4.3	How It Works	36
2.5	Processing Table Data	37
2.5.1	Problem	37
2.5.2	Solution	38
2.5.3	How It Works	38
2.6	Using MATLAB Strings	41
2.6.1	String Concatenation	41
2.6.1.1	Problem	41
2.6.1.2	Solution	41
2.6.1.3	How It Works	41
2.6.2	Arrays of Strings	41
2.6.2.1	Problem	41
2.6.2.2	Solution	41
2.6.2.3	How It Works	41
2.6.3	Substrings	42
2.6.3.1	Problem	42
2.6.3.2	Solution	42
2.6.3.3	How It Works	42
2.7	Summary	43

3	MATLAB Graphics	45
3.1	2D Line Plots	45
3.1.1	Problem	45
3.1.2	Solution	45
3.1.3	How It Works	46
3.2	General 2D Graphics	48
3.2.1	Problem	48
3.2.2	Solution	48
3.2.3	How It Works	48
3.3	Custom Two-Dimensional Diagrams	50
3.3.1	Problem	50
3.3.2	Solution	50
3.3.3	How It Works	50
3.4	Three-Dimensional Box	51
3.4.1	Problem	52
3.4.2	Solution	52
3.4.3	How It Works	52
3.5	Draw a 3D Object with a Texture	54
3.5.1	Problem	54
3.5.2	Solution	54
3.5.3	How It Works	55
3.6	General 3D Graphics	56
3.6.1	Problem	56
3.6.2	Solution	56
3.6.3	How It Works	56
3.7	Building a GUI	58
3.7.1	Problem	58
3.7.2	Solution	58
3.7.3	How It Works	58
3.8	Animating a Bar Chart	63
3.8.1	Problem	64
3.8.2	Solution	64
3.8.3	How It Works	64
3.9	Drawing a Robot	67
3.9.1	Problem	67
3.9.2	Solution	67
3.9.3	How It Works	67
3.10	Summary	71

4	Kalman Filters	73
4.1	A State Estimator Using a Linear Kalman Filter	74
4.1.1	Problem	74
4.1.2	Solution	75
4.1.3	How It Works	75
4.2	Using the Extended Kalman Filter for State Estimation	92
4.2.1	Problem	92
4.2.2	Solution	93
4.2.3	How It Works	93
4.3	Using the Unscented Kalman Filter for State Estimation	97
4.3.1	Problem	97
4.3.2	Solution	97
4.3.3	How It Works	99
4.4	Using the UKF for Parameter Estimation	104
4.4.1	Problem	104
4.4.2	Solution	104
4.4.3	How It Works	104
4.5	Summary	108
5	Adaptive Control	109
5.1	Self Tuning: Modeling an Oscillator	110
5.2	Self Tuning: Tuning an Oscillator	112
5.2.1	Problem	112
5.2.2	Solution	112
5.2.3	How It Works	112
5.3	Implement Model Reference Adaptive Control	117
5.3.1	Problem	117
5.3.2	Solution	117
5.3.3	How It Works	117
5.4	Generating a Square Wave Input	121
5.4.1	Problem	121
5.4.2	Solution	121
5.4.3	How It Works	121
5.5	Demonstrate MRAC for a Rotor	123
5.5.1	Problem	123
5.5.2	Solution	123
5.5.3	How It Works	123
5.6	Ship Steering: Implement Gain Scheduling for Steering Control of a Ship	126
5.6.1	Problem	126
5.6.2	Solution	126
5.6.3	How It Works	126

5.7	Spacecraft Pointing	130
5.7.1	Problem	130
5.7.2	Solution	130
5.7.3	How It Works	131
5.8	Summary	133
6	Fuzzy Logic	135
6.1	Building Fuzzy Logic Systems	136
6.1.1	Problem	136
6.1.2	Solution	136
6.1.3	How It Works	136
6.2	Implement Fuzzy Logic	139
6.2.1	Problem	139
6.2.2	Solution	139
6.2.3	How It Works	139
6.3	Demonstrate Fuzzy Logic	142
6.3.1	Problem	142
6.3.2	Solution	142
6.3.3	How It Works	143
6.4	Summary	146
7	Data Classification with Decision Trees	147
7.1	Generate Test Data	148
7.1.1	Problem	148
7.1.2	Solution	148
7.1.3	How It Works	148
7.2	Drawing Decision Trees	151
7.2.1	Problem	151
7.2.2	Solution	151
7.2.3	How It Works	151
7.3	Implementation	155
7.3.1	Problem	155
7.3.2	Solution	155
7.3.3	How It Works	155
7.4	Creating a Decision tree	158
7.4.1	Problem	158
7.4.2	Solution	158
7.4.3	How It Works	159
7.5	Creating a Handmade Tree	162
7.5.1	Problem	162
7.5.2	Solution	162
7.5.3	How It Works	163

7.6	Training and Testing	165
7.6.1	Problem	165
7.6.2	Solution	165
7.6.3	How It Works	166
7.7	Summary	169
8	Introduction to Neural Nets	171
8.1	Daylight Detector	171
8.1.1	Problem	171
8.1.2	Solution	172
8.1.3	How It Works	172
8.2	Modeling a Pendulum	173
8.2.1	Problem	173
8.2.2	Solution	174
8.2.3	How It Works	174
8.3	Single Neuron Angle Estimator	177
8.3.1	Problem	177
8.3.2	Solution	177
8.3.3	How It Works	178
8.4	Designing a Neural Net for the Pendulum	182
8.4.1	Problem	182
8.4.2	Solution	182
8.4.3	How It Works	182
8.5	Summary	186
9	Classification of Numbers Using Neural Networks	187
9.1	Generate Test Images with Defects	188
9.1.1	Problem	188
9.1.2	Solution	188
9.1.3	How It Works	188
9.2	Create the Neural Net Functions	192
9.2.1	Problem	192
9.2.2	Solution	193
9.2.3	How It Works	193
9.3	Train a Network with One Output Node	197
9.3.1	Problem	197
9.3.2	Solution	197
9.3.3	How It Works	198
9.4	Testing the Neural Network	202
9.4.1	Problem	202
9.4.2	Solution	202
9.4.3	How It Works	203

9.5	Train a Network with Many Outputs	203
9.5.1	Problem	203
9.5.2	Solution	203
9.5.3	How It Works	204
9.6	Summary	207
10	Pattern Recognition with Deep Learning	209
10.1	Obtain Data Online for Training a Neural Net	211
10.1.1	Problem	211
10.1.2	Solution	211
10.1.3	How It Works	211
10.2	Generating Training Images of Cats	211
10.2.1	Problem	211
10.2.2	Solution	211
10.2.3	How It Works	212
10.3	Matrix Convolution	215
10.3.1	Problem	215
10.3.2	Solution	215
10.3.3	How It Works	215
10.4	Convolution Layer	217
10.4.1	Problem	217
10.4.2	Solution	217
10.4.3	How It Works	217
10.5	Pooling to Outputs of a Layer	218
10.5.1	Problem	218
10.5.2	Solution	218
10.5.3	How It Works	219
10.6	Fully Connected Layer	220
10.6.1	Problem	220
10.6.2	Solution	220
10.6.3	How It Works	220
10.7	Determining the Probability	222
10.7.1	Problem	222
10.7.2	Solution	222
10.7.3	How It Works	222
10.8	Test the Neural Network	223
10.8.1	Problem	223
10.8.2	Solution	223
10.8.3	How It Works	223

10.9	Recognizing a Number	225
10.9.1	Problem	225
10.9.2	Solution	225
10.9.3	How It Works	226
10.10	Recognizing an Image	228
10.10.1	Problem	228
10.10.2	Solution	228
10.10.3	How It Works	228
10.11	Summary	230
11	Neural Aircraft Control	231
11.1	Longitudinal Motion	232
11.1.1	Problem	233
11.1.2	Solution	233
11.1.3	How It Works	233
11.2	Numerically Finding Equilibrium	238
11.2.1	Problem	238
11.2.2	Solution	238
11.2.3	How It Works	239
11.3	Numerical Simulation of the Aircraft	240
11.3.1	Problem	240
11.3.2	Solution	240
11.3.3	How It Works	240
11.4	Activation Function	242
11.4.1	Problem	242
11.4.2	Solution	242
11.4.3	How It Works	242
11.5	Neural Net for Learning Control	243
11.5.1	Problem	243
11.5.2	Solution	243
11.5.3	How It Works	243
11.6	Enumeration of All Sets of Inputs	248
11.6.1	Problem	248
11.6.2	Solution	248
11.6.3	How It Works	248
11.7	Write a Sigma-Pi Neural Net Function	249
11.7.1	Problem	249
11.7.2	Solution	249
11.7.3	How It Works	250
11.8	Implement PID Control	251
11.8.1	Problem	251
11.8.2	Solution	251
11.8.3	How It Works	252

11.9	PID Control of Pitch	256
11.9.1	Problem	256
11.9.2	Solution	256
11.9.3	How It Works	256
11.10	Neural Net for Pitch Dynamics	258
11.10.1	Problem	258
11.10.2	Solution	258
11.10.3	How It Works	258
11.11	Nonlinear Simulation	261
11.11.1	Problem	261
11.11.2	Solution	262
11.11.3	How It Works	262
11.12	Summary	264
12	Multiple Hypothesis Testing	265
12.1	Overview	265
12.2	Theory	267
12.2.1	Introduction	267
12.2.2	Example	269
12.2.3	Algorithm	269
12.2.4	Measurement Assignment and Tracks	270
12.2.5	Hypothesis Formation	271
12.2.6	Track Pruning	272
12.3	Billiard Ball Kalman Filter	274
12.3.1	Problem	274
12.3.2	Solution	274
12.3.3	How It Works	274
12.4	Billiard Ball MHT	280
12.4.1	Problem	280
12.4.2	Solution	280
12.4.3	How It Works	280
12.5	One-Dimensional Motion	285
12.5.1	Problem	285
12.5.2	Solution	285
12.5.3	How It Works	285
12.6	One-Dimensional Motion with Track Association	287
12.6.1	Problem	287
12.6.2	Solution	287
12.6.3	How It Works	287
12.7	Summary	289

13	Autonomous Driving with Multiple Hypothesis Testing	291
13.1	Automobile Dynamics	292
13.1.1	Problem	292
13.1.2	Solution	292
13.1.3	How It Works	292
13.2	Modeling the Automobile Radar	295
13.2.1	Problem	295
13.2.2	Solution	295
13.2.3	How It Works	295
13.3	Automobile Autonomous Passing Control	297
13.3.1	Problem	297
13.3.2	Solution	297
13.3.3	How It Works	298
13.4	Automobile Animation	299
13.4.1	Problem	299
13.4.2	How It Works	299
13.4.3	Solution	299
13.5	Automobile Simulation and the Kalman Filter	303
13.5.1	Problem	303
13.5.2	Solution	303
13.5.3	How It Works	303
13.6	Automobile Target Tracking	306
13.6.1	Problem	306
13.6.2	Solution	306
13.6.3	How It Works	306
13.7	Summary	309
14	Case-Based Expert Systems	311
14.1	Building Expert Systems	312
14.1.1	Problem	312
14.1.2	Solution	312
14.1.3	How It Works	313
14.2	Running an Expert System	313
14.2.1	Problem	313
14.2.2	Solution	313
14.2.3	How It Works	313
14.3	Summary	316
A	A Brief History of Autonomous Learning	317
A.1	Introduction	317
A.2	Artificial Intelligence	317

A.3	Learning Control	320
A.4	Machine Learning	322
A.5	The Future	323
B	Software for Machine Learning	325
B.1	Autonomous Learning Software	325
B.2	Commercial MATLAB Software	326
B.2.1	MathWorks Products	326
B.2.1.1	Statistics and Machine Learning Toolbox	326
B.2.1.2	Neural Network Toolbox	327
B.2.1.3	Computer Vision System Toolbox	327
B.2.1.4	System Identification Toolbox	327
B.2.1.5	MATLAB for Deep Learning	328
B.2.2	Princeton Satellite Systems Products	328
B.2.2.1	Core Control Toolbox	328
B.2.2.2	Target Tracking	328
B.3	MATLAB Open Source Resources	329
B.3.1	DeepLearnToolbox	329
B.3.2	Deep Neural Network	329
B.3.3	MatConvNet	329
B.4	Non- MATLAB Products for Machine Learning	329
B.4.1	R	330
B.4.2	scikit-learn	330
B.4.3	LIBSVM	330
B.5	Products for Optimization	330
B.5.1	LOQO	331
B.5.2	SNOPT	331
B.5.3	GLPK	331
B.5.4	CVX	332
B.5.5	SeDuMi	332
B.5.6	YALMIP	332
B.6	Products for Expert Systems	332
B.7	MATLAB MEX files	333
B.7.1	Problem	333
B.7.2	Solution	333
B.7.3	How It Works	333
	Bibliography	337
	Index	341