

Contents

About the Authors	XVII
About the Technical Reviewer	XIX
Introduction	XXI
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	2
1.2.3 Training	3
1.3 The Learning Machine	4
1.4 Taxonomy of Machine Learning	6
1.5 Control	8
1.5.1 Kalman Filters	9
1.5.2 Adaptive Control	9
1.6 Autonomous Learning Methods	10
1.6.1 Regression	10
1.6.2 Decision Trees	13
1.6.3 Neural Networks	14
1.6.4 Support Vector Machines (SVMs)	16
1.7 Artificial Intelligence	17
1.7.1 What Is Artificial Intelligence?	17
1.7.2 Intelligent Cars	17
1.7.3 Expert Systems	18
1.8 Summary	19
2 Data for Machine Learning in MATLAB	21
2.1 Introduction to MATLAB Data Types	21
2.1.1 Matrices	21
2.1.2 Cell Arrays	22
2.1.3 Data Structures	23
2.1.4 Numerics	25
2.1.5 Images	25

CONTENTS

- 2.1.6 Datastore 26
 - 2.1.7 Tall Arrays 28
 - 2.1.8 Sparse Matrices 29
 - 2.1.9 Tables and Categoricals 30
 - 2.1.10 Large MAT-Files 32
- 2.2 Initializing a Data Structure 33
 - 2.2.1 Problem 33
 - 2.2.2 Solution 33
 - 2.2.3 How It Works 33
- 2.3 mapreduce on an Image Datastore 36
 - 2.3.1 Problem 36
 - 2.3.2 Solution 36
 - 2.3.3 How It Works 36
- 2.4 Processing Table Data 38
 - 2.4.1 Problem 38
 - 2.4.2 Solution 38
 - 2.4.3 How It Works 39
- 2.5 String Concatenation 42
 - 2.5.1 Problem 42
 - 2.5.2 Solution 42
 - 2.5.3 How It Works 42
- 2.6 Arrays of Strings 42
 - 2.6.1 Problem 42
 - 2.6.2 Solution 42
 - 2.6.3 How It Works 42
- 2.7 Substrings 43
 - 2.7.1 Problem 43
 - 2.7.2 Solution 43
 - 2.7.3 How It Works 43
- 2.8 Reading an Excel Spreadsheet into a Table 44
 - 2.8.1 Problem 44
 - 2.8.2 Solution 44
 - 2.8.3 How It Works 44
- 2.9 Accessing ChatGPT 46
 - 2.9.1 Problem 46
 - 2.9.2 Solution 46
 - 2.9.3 How It Works 46
- 2.10 Summary 48

3	MATLAB Graphics	49
3.1	2D Line Plots	49
3.1.1	Problem	49
3.1.2	Solution	49
3.1.3	How It Works	50
3.2	General 2D Graphics	52
3.2.1	Problem	52
3.2.2	Solution	52
3.2.3	How It Works	53
3.3	Custom Two-Dimensional Diagrams	54
3.3.1	Problem	54
3.3.2	Solution	54
3.3.3	How It Works	55
3.4	Three-Dimensional Box	56
3.4.1	Problem	56
3.4.2	Solution	56
3.4.3	How It Works	56
3.5	Draw a 3D Object with a Texture	59
3.5.1	Problem	59
3.5.2	Solution	59
3.5.3	How It Works	60
3.6	General 3D Graphics	61
3.6.1	Problem	61
3.6.2	Solution	61
3.6.3	How It Works	62
3.7	Building a GUI	63
3.7.1	Problem	63
3.7.2	Solution	63
3.7.3	How It Works	63
3.8	Animating a Bar Chart	68
3.8.1	Problem	68
3.8.2	Solution	69
3.8.3	How It Works	69
3.9	Drawing a Robot	73
3.9.1	Problem	73
3.9.2	Solution	73
3.9.3	How It Works	73
3.10	Importing a Model	76
3.10.1	Problem	76
3.10.2	Solution	76
3.10.3	How It Works	76
3.11	Summary	83

4	Kalman Filters	85
4.1	Gaussian Distribution	86
4.2	A State Estimator Using a Linear Kalman Filter	87
4.2.1	Problem	87
4.2.2	Solution	88
4.2.3	How It Works	89
4.3	Using the Extended Kalman Filter for State Estimation	106
4.3.1	Problem	106
4.3.2	Solution	107
4.3.3	How It Works	108
4.4	Using the UKF for State Estimation	111
4.4.1	Problem	111
4.4.2	Solution	112
4.4.3	How It Works	113
4.5	Using the UKF for Parameter Estimation	117
4.5.1	Problem	117
4.5.2	Solution	118
4.5.3	How It Works	118
4.6	Range to a Car	122
4.6.1	Problem	122
4.6.2	Solution	122
4.6.3	How It Works	122
4.7	Summary	125
5	Adaptive Control	127
5.1	Self-Tuning: Tuning an Oscillator	128
5.1.1	Problem	129
5.1.2	Solution	130
5.1.3	How It Works	130
5.2	Implement MRAC	136
5.2.1	Problem	136
5.2.2	Solution	136
5.2.3	How It Works	136
5.3	Generating a Square Wave Input	140
5.3.1	Problem	140
5.3.2	Solution	140
5.3.3	How It Works	140
5.4	Demonstrate MRAC for a Rotor	142
5.4.1	Problem	142
5.4.2	Solution	142
5.4.3	How It Works	142

5.5	Ship Steering: Implement Gain Scheduling for Steering Control of a Ship . .	145
5.5.1	Problem	145
5.5.2	Solution	145
5.5.3	How It Works	145
5.6	Spacecraft Pointing	148
5.6.1	Problem	148
5.6.2	Solution	148
5.6.3	How It Works	148
5.7	Direct Adaptive Control	153
5.7.1	Problem	153
5.7.2	Solution	153
5.7.3	How It Works	153
5.8	Summary	155
6	Fuzzy Logic	157
6.1	Building Fuzzy Logic Systems	158
6.1.1	Problem	158
6.1.2	Solution	158
6.1.3	How It Works	158
6.2	Implement Fuzzy Logic	163
6.2.1	Problem	163
6.2.2	Solution	163
6.2.3	How It Works	163
6.3	Window Wiper Fuzzy Controller	169
6.3.1	Problem	169
6.3.2	Solution	169
6.3.3	How It Works	169
6.4	Simple Discrete HVAC Fuzzy Controller	174
6.4.1	Problem	174
6.4.2	Solution	174
6.4.3	How It Works	174
6.5	Variable HVAC Fuzzy Controller	180
6.5.1	Problem	180
6.5.2	Solution	181
6.5.3	How It Works	181
6.6	Summary	189
7	Neural Aircraft Control	191
7.1	Longitudinal Motion	191
7.1.1	Problem	193
7.1.2	Solution	193
7.1.3	How It Works	193

7.2	Numerically Finding Equilibrium	198
7.2.1	Problem	198
7.2.2	Solution	199
7.2.3	How It Works	199
7.3	Numerical Simulation of the Aircraft	200
7.3.1	Problem	200
7.3.2	Solution	200
7.3.3	How It Works	201
7.4	Activation Function	202
7.4.1	Problem	202
7.4.2	Solution	203
7.4.3	How It Works	203
7.5	Neural Net for Learning Control	204
7.5.1	Problem	204
7.5.2	Solution	204
7.5.3	How It Works	204
7.6	Enumeration of All Sets of Inputs	208
7.6.1	Problem	208
7.6.2	Solution	208
7.6.3	How It Works	208
7.7	Write a Sigma-Pi Neural Net Function	210
7.7.1	Problem	210
7.7.2	Solution	210
7.7.3	How It Works	210
7.8	Implement PID Control	213
7.8.1	Problem	213
7.8.2	Solution	213
7.8.3	How It Works	213
7.9	PID Control of Pitch	218
7.9.1	Problem	218
7.9.2	Solution	218
7.9.3	How It Works	218
7.10	Neural Net for Pitch Dynamics	223
7.10.1	Problem	223
7.10.2	Solution	223
7.10.3	How It Works	224
7.11	Nonlinear Simulation	226
7.11.1	Problem	226
7.11.2	Solution	226
7.11.3	How It Works	226
7.12	Summary	228

8	Introduction to Neural Nets	229
8.1	Daylight Detector	229
8.1.1	Problem	229
8.1.2	Solution	229
8.1.3	How It Works	230
8.2	Modeling a Pendulum	231
8.2.1	Problem	231
8.2.2	Solution	232
8.2.3	How It Works	232
8.3	Single Neuron Angle Estimator	235
8.3.1	Problem	235
8.3.2	Solution	236
8.3.3	How It Works	236
8.4	Designing a Neural Net for the Pendulum	240
8.4.1	Problem	240
8.4.2	Solution	240
8.4.3	How It Works	240
8.5	XOR Example	244
8.6	Training	253
8.7	Summary	254
9	Classification of Numbers Using Neural Networks	257
9.1	Generate Test Images with Defects	257
9.1.1	Problem	257
9.1.2	Solution	258
9.1.3	How It Works	258
9.2	Create the Neural Net Functions	262
9.2.1	Problem	262
9.2.2	Solution	263
9.2.3	How It Works	263
9.3	Train a Network with One Output Node	267
9.3.1	Problem	267
9.3.2	Solution	267
9.3.3	How It Works	269
9.4	Testing the Neural Network	272
9.4.1	Problem	272
9.4.2	Solution	272
9.4.3	How It Works	273
9.5	Train a Network with Many Outputs	273
9.5.1	Problem	273
9.5.2	Solution	273
9.5.3	How It Works	274
9.6	Summary	277

10	Data Classification with Decision Trees	279
10.1	Generate Test Data	280
10.1.1	Problem	280
10.1.2	Solution	280
10.1.3	How It Works	280
10.2	Drawing Trees	283
10.2.1	Problem	283
10.2.2	Solution	283
10.2.3	How It Works	283
10.3	Implementation	287
10.3.1	Problem	287
10.3.2	Solution	287
10.3.3	How It Works	288
10.4	Creating a Tree	291
10.4.1	Problem	291
10.4.2	Solution	291
10.4.3	How It Works	291
10.5	Handmade Tree	295
10.5.1	Problem	295
10.5.2	Solution	295
10.5.3	How It Works	295
10.6	Training and Testing	298
10.6.1	Problem	298
10.6.2	Solution	298
10.6.3	How It Works	298
10.7	Summary	301
11	Pattern Recognition with Deep Learning	303
11.1	Obtain Data Online for Training a Neural Net	305
11.1.1	Problem	305
11.1.2	Solution	305
11.1.3	How It Works	305
11.2	Generating Training Images of Cats	305
11.2.1	Problem	305
11.2.2	Solution	305
11.2.3	How It Works	306
11.3	Matrix Convolution	308
11.3.1	Problem	308
11.3.2	Solution	309
11.3.3	How It Works	309
11.4	Convolution Layer	311
11.4.1	Problem	311

11.4.2	Solution	311
11.4.3	How It Works	311
11.5	Pooling to Outputs of a Layer	312
11.5.1	Problem	312
11.5.2	Solution	312
11.5.3	How It Works	313
11.6	Fully Connected Layer	314
11.6.1	Problem	314
11.6.2	Solution	314
11.6.3	How It Works	314
11.7	Determining the Probability	316
11.7.1	Problem	316
11.7.2	Solution	316
11.7.3	How It Works	317
11.8	Test the Neural Network	318
11.8.1	Problem	318
11.8.2	Solution	318
11.8.3	How It Works	318
11.9	Recognizing an Image	320
11.9.1	Problem	320
11.9.2	Solution	320
11.9.3	How It Works	320
11.10	Using AlexNet	322
11.10.1	Problem	322
11.10.2	Solution	322
11.10.3	How It Works	322
	Summary	326
12	Multiple Hypothesis Testing	327
12.1	Overview	327
12.2	Theory	329
12.2.1	Introduction	329
12.2.2	Example	331
12.2.3	Algorithm	331
12.2.4	Measurement Assignment and Tracks	333
12.2.5	Hypothesis Formation	334
12.2.6	Track Pruning	335
12.3	Billiard Ball Kalman Filter	335
12.3.1	Problem	335
12.3.2	Solution	336
12.3.3	How It Works	336
12.4	Billiard Ball MHT	342

CONTENTS

12.4.1	Problem	342
12.4.2	Solution	342
12.4.3	How It Works	342
12.5	One-Dimensional Motion	345
12.5.1	Problem	345
12.5.2	Solution	346
12.5.3	How It Works	347
12.6	One-Dimensional MHT	349
12.6.1	Problem	349
12.6.2	Solution	349
12.6.3	How It Works	349
12.7	Summary	351
13	Autonomous Driving with MHT	355
13.1	Automobile Dynamics	356
13.1.1	Problem	356
13.1.2	Solution	356
13.1.3	How It Works	356
13.2	Automobile Radar	359
13.2.1	Problem	359
13.2.2	Solution	359
13.2.3	How It Works	359
13.3	Passing Control	362
13.3.1	Problem	362
13.3.2	Solution	362
13.3.3	How It Works	362
13.4	Automobile Animation	363
13.4.1	Problem	363
13.4.2	Solution	364
13.4.3	How It Works	364
13.4.4	Solution	364
13.5	Automobile Simulation and the Kalman Filter	367
13.5.1	Problem	367
13.5.2	Solution	368
13.5.3	How It Works	368
13.6	Automobile Target Tracking	371
13.6.1	Problem	371
13.6.2	Solution	371
13.6.3	How It Works	371
13.7	Summary	374

14	Spacecraft Attitude Determination	377
14.1	Star Catalog	377
14.1.1	Problem	377
14.1.2	Solution	378
14.1.3	How It Works	378
14.2	Camera Model	381
14.2.1	Problem	381
14.2.2	Solution	381
14.2.3	How It Works	381
14.3	Celestial Sphere	383
14.3.1	Problem	383
14.3.2	Solution	383
14.3.3	How It Works	383
14.4	Attitude Simulation of Camera Views	384
14.4.1	Problem	384
14.4.2	Solution	384
14.4.3	How It Works	384
14.5	Yaw Angle Rotation	387
14.5.1	Problem	387
14.5.2	Solution	387
14.5.3	How It Works	387
14.6	Yaw Images	388
14.6.1	Problem	388
14.6.2	Solution	388
14.6.3	How It Works	388
14.7	Attitude Determination	391
14.7.1	Problem	391
14.7.2	Solution	391
14.7.3	How It Works	391
14.8	Summary	399
15	Case-Based Expert Systems	401
15.1	Building Expert Systems	404
15.1.1	Problem	404
15.1.2	Solution	404
15.1.3	How It Works	404
15.2	Running an Expert System	406
15.2.1	Problem	406
15.2.2	Solution	407
15.2.3	How It Works	407
15.3	Summary	410

CONTENTS

A	A Brief History	411
B	Software for Machine Learning	419
	Bibliography	431
	Index	435