PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

MATLAB for Brain and Cognitive Scientists

Mike X Cohen

The MIT Press
Cambridge, Massachusetts
London, England

10947_000.indd 3 12/28/2016 10:32:46 AM

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

© 2017 Massachusetts Institute of Technology

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from the publisher.

This book was set in Stone Sans and Stone Serif by Toppan Best-set Premedia Limited.
Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Names: Cohen, Mike X., 1979- author.
Title: MATLAB for brain and cognitive scientists / Mike X. Cohen.
Description: Cambridge, MA : MIT Press, [2017] | Includes bibliographical references and index.
Identifiers: LCCN 2016033649 | ISBN 9780262035828 (h : alk. paper)
Subjects: LCSH: MATLAB. | Neurosciences--Data processing. | Cognitive science--Data processing.
Classification: LCC QP357.5 .C56 2017 | DDC 612.8--dc23 LC record available at https://lccn.loc.gov/2016033649

10 9 8 7 6 5 4 3 2 1

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

Contents

Preface xv

Part I: Introductions 1

1 What Is MATLAB and Why Use It? 3
1.1 "I Want to Be a Scientist; Do I Also Need to Be a Good Programmer?" 3
1.2 Octave 4
1.3 Python, Julia, C, R, SPSS, HTML, and So Forth 5
1.4 How Long Does It Take to Become a Good Programmer? 6
1.5 How to Learn How to Program 6
1.6 The Three Steps of Programming 7
1.7 How Best to Learn from This Book 8
1.8 Exercises and Their Solutions 10
1.9 Written Interviews 11
1.10 Where Is All the Code? 11
1.11 Can I Use the Code in This Book for Real Data Analyses? 11
1.12 Is This Book Right for You? 12
1.13 Are You Excited? 12

2 The Philosophy of Data Analysis 15
2.1 Keep It Simple 15
2.2 Stay Close to the Data 16
2.3 Understand Your Analyses 17
2.4 Use Simulations, but Trust Real Data 17
2.5 Beware the Paralysis of Analysis 18
2.6 Be Careful of Overfitting 19
2.7 Noise in Neuroscience Data 21
2.8 Avoid Circular Inference 22
2.9 Get Free Data 23

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

3 Do Replicable Research 25
3.1 Avoid Mistakes in Data Analysis 26
3.2 Have a "Large Enough" *N* 27
3.3 Maximize Level 1 Data Count 27
3.4 Try Different Analysis Parameters, and Trust Analytic Convergence 28
3.5 Don't Be Afraid to Report Small or Null Effects, but Be Honest About Them 29
3.6 Do Split-Half Replication 29
3.7 Independent Replications 29
3.8 Write a Clear Methods Section 30
3.9 Make Your Analysis Code or Data Available 30
4 The MATLAB Program 31
4.1 The MATLAB Program Graphical User Interface 31
4.2 Layouts and Visual Preferences 32
4.3 Color-Coordinating MATLAB 35
4.4 Where Does the Code Go? 35
4.5 MATLAB Files and Formats 37
4.6 Changing Directories Inside MATLAB 38
4.7 The MATLAB Path 38
4.8 Comments 40
4.9 Cells 41
4.10 Keyboard Shortcuts 41
4.11 Help Box and Reporting Variable Content 43
4.12 The Code Analyzer 45
4.13 Back Up Your Scripts, and Use Only One Version 46
4.14 MATLAB Etiquette 46
5 Variables 49
5.1 Creating and Destroying Variables 49
5.2 `Whos` Are My Variables? 50
5.3 Variable Naming Conventions and Tips 50
5.4 Variables for Numbers 52
5.5 Variables for Truth 54
5.6 Variables for Strings 55
5.7 Variables for Cells 56
5.8 Variables for Structures 56
5.9 The Colon Operator 57
5.10 Accessing Parts of Variables via Indexing 58
5.11 Initializing Variables 60
5.12 Soft-coding versus Hard-coding 61

10947_000.indd 6 12/28/2016 10:32:46 AM

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

5.13 Keep It Simple 62
5.14 Exercises 62
6 Functions 67
6.1 Introduction to Functions 67
6.2 Outputs as Inputs 68
6.3 Multiple Inputs, Multiple Outputs 69
6.4 Help 70
6.5 Functions Are Files 71
6.6 Writing Your Own Function 72
6.7 Functions in Functions 74
6.8 Arguments In 74
6.9 Think Global, Act Local 75
6.10 Stepping into Functions 76
6.11 When to Use Your Own Functions 79
6.12 When to Modify Existing Functions 80
6.13 Timing Functions Using the Profiler 80
6.14 Exercises 80
7 Control Statements 85
7.1 The Anatomy of a Control Statement 85
7.2 If-then 85
7.3 For-loop 91
7.4 Skipping Forward 93
7.5 While-loop 94
7.6 Try-catch 97
7.7 Switch-case 98
7.8 Pause 98
7.9 Exercises 99
8 Input-Output 103
8.1 Copy-Paste 103
8.2 Loading .mat Files 103
8.3 Saving .mat Files 107
8.4 Importing Text Files 109
8.5 Exporting Text Files 112
8.6 Importing and Exporting Microsoft Excel Files 113
8.7 Importing and Exporting Hardware-Specific Data Files 113
8.8 Interacting with Your Operating System via MATLAB 114
8.9 Exercises 114
9 Plotting 117
9.1 What You Need to Know Before You Know Anything Else 117
9.2 Plotting Lines 119

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

9.3 Bars 121
9.4 Scatter Plots 122
9.5 Histograms 123
9.6 Subplots 124
9.7 Patch 127
9.8 Images 128
9.9 Get, Set, and Handle 132
9.10 Text in Plots 135
9.11 Interacting with MATLAB Plots 137
9.12 Creating a Color Axis 138
9.13 Saving Figures as Picture Files 140
9.14 Exercises 141

Part II: Foundations 145

10 Matrix Algebra 147
10.1 Vectors 147
10.2 Vector Addition and Multiplication 150
10.3 Matrices 153
10.4 Finding Your Way around a Matrix 155
10.5 Matrix Multiplication 156
10.6 When to Use .* and ./ versus * and / ? 158
10.7 Linear Independence and Rank 159
10.8 The Matrix Inverse 160
10.9 Solving **Ax** = **b** 161
10.10 Making Symmetric Squares from Rectangles 162
10.11 Full and Sparse Matrices 163
10.12 Exercises 164
11 The Fourier Transform 167
11.1 Sine Waves 167
11.2 The Imaginary Operator and Complex Numbers 168
11.3 The Complex Dot Product 171
11.4 Time Domain and Frequency Domain 175
11.5 The Slow Fourier Transform 176
11.6 Frequencies from the Fourier Transform 177
11.7 The Fast Fourier Transform 180
11.8 Fourier Coefficients as Complex Numbers 181
11.9 DC Offsets in the Fourier Transform 182
11.10 Zero-Padding the Fourier Transform 184
11.11 The Inverse Fourier Transform 186

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

11.12 The 2D Fourier Transform 187
11.13 Exercises 188
12 Convolution 193
12.1 Time-Domain Convolution 194
12.2 The Convolution Theorem 196
12.3 Convolution Implemented in the Frequency Domain 198
12.4 Convolution in Two Dimensions 200
12.5 Exercises 201
13 Interpolation and Extrapolation 205
13.1 The MATLAB Functions `griddedInterpolant` and `scatteredInterpolant` 206
13.2 Interpolation in Two Dimensions Using `scatteredInterpolant` 208
13.3 Using `interp*` Functions 212
13.4 Zero-Padding Theorem and Zero-Padding 213
13.5 Down-sampling 214
13.6 Exercises 218
14 Signal Detection Theory 221
14.1 The Four Categories of Correspondence 221
14.2 Discrimination 222
14.3 Isosensitivity Curves (a.k.a. ROC Curves) 224
14.4 Response Bias 226
14.5 Conditional Accuracy Functions 227
14.6 Exercises 231
15 Nonparametric Statistics 233
15.1 The Idea of Permutation-Based Statistics 233
15.2 Creating an Empirical Null Hypothesis Test 234
15.3 Creating a Null Hypothesis Distribution 238
15.4 Evaluating Significance 240
15.5 Example with Real Data 241
15.6 Extreme Value–Based Correction for Multiple Comparisons 244
15.7 Meta-permutation Tests 246
15.8 Exercises 246
16 Covariance and Correlation 249
16.1 Simulating and Measuring Bivariate Covariance 249
16.2 Multivariate Covariance 252
16.3 From Covariance to Correlation 255
16.4 Pearson and Spearman Correlations 259
16.5 Statistical Significance of Correlation Coefficients 261
16.6 Geometric Interpretation of Correlation 262
16.7 Exercises 263

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

17 Principal Components Analysis 265
17.1 Eigendecomposition 265
17.2 Simple Example with 2D Random Data 267
17.3 PCA and Coordinate Transformation 271
17.4 Eigenfaces 272
17.5 Independent Components Analysis 278
17.6 Exercises 280

Part III: Analyses of Time Series 285

18 Frequency Analyses 287
18.1 Blitz Review of the Fourier Transform 287
18.2 Frequency Resolution 288
18.3 Edge Artifacts and Data Tapering 289
18.4 Many FFTs for Many Trials 291
18.5 Defining and Extracting Frequency Ranges 297
18.6 Effects of Nonstationarities 301
18.7 Spectral Coherence 302
18.8 Steady-State Evoked Potentials 305
18.9 Exercises 306
19 Time-Frequency Analysis 311
19.1 Complex Morlet Wavelets 312
19.2 Morlet Wavelet Convolution 314
19.3 From Line to Plane 314
19.4 From Single Trial to Super-trial 319
19.5 Edge Artifacts 323
19.6 STFFT 325
19.7 Baseline Normalization 327
19.8 Time-Frequency Analysis in Real EEG Data 330
19.9 Exercises 331
20 Time Series Filtering 335
20.1 Running-Mean Filter 335
20.2 Running-Median Filter 337
20.3 Edges in the Frequency Domain 339
20.4 Gaussian Narrow-Band Filtering 341
20.5 Finite Impulse Response Filter 345
20.6 The Hilbert Transform 350
20.7 Exercises 351
21 Fluctuation Analyses 355
21.1 Root Mean Square to Measure Fluctuations 355

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

21.2 Fluctuations in Time Series 355
21.3 Multichannel RMS 356
21.4 Detrended Fluctuation Analysis 358
21.5 Demeaned Fluctuation Analysis 362
21.6 Local and Global Minima and Maxima 363
21.7 Exercises 367

Part IV: Analyses of Action Potentials 369

22 Spikes in Full and Sparse Matrices 371
22.1 Spike Times as Full Matrices and as Sparse Vectors 371
22.2 Mean Spike Count in Spikes per Second 375
22.3 Peri-event Time Spike Histogram 376
22.4 Exercises 377
23 Spike Timing 379
23.1 Spike Rhythmicity 379
23.2 Spike Rhythmicity via the Frequency Domain 381
23.3 Cross-Neuron Spike-Time Correlations 383
23.4 Spike-Field Coherence 384
23.5 Frequency-Specific Spike-Field Coherence 387
23.6 Exercises 389
24 Spike Sorting 393
24.1 Spike Amplitude and Width 393
24.2 Spike Features via Principal Components Analysis 395
24.3 Spike Features via Independent Components Analysis 400
24.4 Clustering Spikes into Discrete Groups 402
24.5 Exercises 403

Part V: Analyses of Images 405

25 Magnetic Resonance Images 407
25.1 Importing and Plotting MRI Data 407
25.2 fMRI Data as a Four-Dimensional Volume 408
25.3 fMRI Statistics and Thresholding 412
25.4 Exercises 415
26 Image Segmentation 417
26.1 Threshold-Based Segmentation 417
26.2 Intensity-Based Segmentation 421
26.3 Once More, with Calcium 423
26.4 Defining Grids in Images 428

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

26.5 Fractals and Boxes 433
26.6 Exercises 436

27 Image Smoothing and Sharpening 439
27.1 Two-Dimensional Mean Filtering 439
27.2 Two-Dimensional Median Filter 441
27.3 Gaussian Kernel Smoothing 442
27.4 Image Filtering in the Frequency Domain 443
27.5 Exercises 447

Part VI: Modeling and Model Fitting 451

28 Linear Methods to Fit Models to Data 453
28.1 Least-Squares Fitting 453
28.2 Evaluating Model Fits 455
28.3 Polynomial Fitting Using `polyfit` and `polyval` 459
28.4 Example: Reaction Time and EEG Activity 462
28.5 Data Transformations Adjust Distributions 465
28.6 Exercises 467

29 Nonlinear Methods to Fit Models to Data 471
29.1 Nonlinear Model Fitting with `fminsearch` 471
29.2 Nonlinear Model Fitting: Piece-wise Regression 473
29.3 Nonlinear Model Fitting: Gaussian Function 477
29.4 Nonlinear Model Fitting: Caught in Local Minima 479
29.5 Discretizing and Binning Data 480
29.6 Exercises 482

30 Neural and Cognitive Simulations 487
30.1 Integrate-and-Fire Neurons 487
30.2 From Neuron to Networks 490
30.3 Izhikevich Neurons 492
30.4 Rescorla-Wagner 494
30.5 Exercises 500

31 Classification and Clustering 503
31.1 Neural Networks with Backpropagation Learning 503
31.2 *K*-means Clustering 508
31.3 Support Vector Machines 511
31.4 Exercises 515

Part VII: User Interfaces and Movies 519

32 Graphical User Interfaces 521
32.1 Basic GUIs 521

PROPERTY OF THE MIT PRESS
FOR PROOFREADING, INDEXING, AND PROMOTIONAL PURPOSES ONLY

32.2 Getting to Know GUIDE 522
32.3 Writing Code in GUI Functions 524
32.4 Exercises 529
33 Movies 531
33.1 Waving Lines 531
33.2 Moving Gabor Patches 534
33.3 Spinning Heads 540
33.4 Exercises 543

References 545
Index 549

List of Interviews

Chapter 13: Robert Oostenveld 215
Chapter 16: Hualou Liang 258
Chapter 17: Pascal Wallisch 276
Chapter 19: Arnaud Delorme 321
Chapter 21: Simon-Shlomo Poil 364
Chapter 24: Rodrigo Quian Quiroga 399
Chapter 26: Dylan Richard Muir 429
Chapter 30: Eugene M. Izhikevich 496
Chapter 32: Vladimir Litvak 526

10947_000.indd 13 12/28/2016 10:32:46 AM