

# 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

<b>3</b>	<b>Do Replicable Research</b>	<b>25</b>
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
<b>4</b>	<b>The MATLAB Program</b>	<b>31</b>
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
<b>5</b>	<b>Variables</b>	<b>49</b>
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

- 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

- 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  $\mathbf{Ax} = \mathbf{b}$  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

11.12	The 2D Fourier Transform	187
11.13	Exercises	188
<b>12</b>	<b>Convolution</b>	<b>193</b>
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
<b>13</b>	<b>Interpolation and Extrapolation</b>	<b>205</b>
13.1	The MATLAB Functions <code>griddedInterpolant</code> and <code>scatteredInterpolant</code>	206
13.2	Interpolation in Two Dimensions Using <code>scatteredInterpolant</code>	208
13.3	Using <code>interp*</code> Functions	212
13.4	Zero-Padding Theorem and Zero-Padding	213
13.5	Down-sampling	214
13.6	Exercises	218
<b>14</b>	<b>Signal Detection Theory</b>	<b>221</b>
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
<b>15</b>	<b>Nonparametric Statistics</b>	<b>233</b>
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
<b>16</b>	<b>Covariance and Correlation</b>	<b>249</b>
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

- 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 Analysis 355**
  - 21.1 Root Mean Square to Measure Fluctuations 355

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
<b>Part IV: Analyses of Action Potentials</b>		<b>369</b>
<b>22</b>	<b>Spikes in Full and Sparse Matrices</b>	<b>371</b>
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
<b>23</b>	<b>Spike Timing</b>	<b>379</b>
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
<b>24</b>	<b>Spike Sorting</b>	<b>393</b>
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
<b>Part V: Analyses of Images</b>		<b>405</b>
<b>25</b>	<b>Magnetic Resonance Images</b>	<b>407</b>
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
<b>26</b>	<b>Image Segmentation</b>	<b>417</b>
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

26.5	Fractals and Boxes	433
26.6	Exercises	436
<b>27</b>	<b>Image Smoothing and Sharpening</b>	<b>439</b>
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
<b>Part VI: Modeling and Model Fitting</b>		<b>451</b>
<b>28</b>	<b>Linear Methods to Fit Models to Data</b>	<b>453</b>
28.1	Least-Squares Fitting	453
28.2	Evaluating Model Fits	455
28.3	Polynomial Fitting Using <code>polyfit</code> and <code>polyval</code>	459
28.4	Example: Reaction Time and EEG Activity	462
28.5	Data Transformations Adjust Distributions	465
28.6	Exercises	467
<b>29</b>	<b>Nonlinear Methods to Fit Models to Data</b>	<b>471</b>
29.1	Nonlinear Model Fitting with <code>fminsearch</code>	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
<b>30</b>	<b>Neural and Cognitive Simulations</b>	<b>487</b>
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
<b>31</b>	<b>Classification and Clustering</b>	<b>503</b>
31.1	Neural Networks with Backpropagation Learning	503
31.2	K-means Clustering	508
31.3	Support Vector Machines	511
31.4	Exercises	515
<b>Part VII: User Interfaces and Movies</b>		<b>519</b>
<b>32</b>	<b>Graphical User Interfaces</b>	<b>521</b>
32.1	Basic GUIs	521



32.2 Getting to Know GUIDE	522
32.3 Writing Code in GUI Functions	524
32.4 Exercises	529
<b>33 Movies</b>	<b>531</b>
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