

Contents

<i>Prolegomenon</i>	xiii
<i>How to Use This Book</i>	xv
<i>About MATLAB</i>	xviii

PART I Basic Computations and Visualization

1	MATLAB Introduction	3
1.1	Vectors and Matrices	3
1.2	Logic, Loops and Iterations	9
1.3	Iteration: The Newton–Raphson Method	13
1.4	Function Calls, Input/Output Interactions and Debugging	18
1.5	Plotting and Importing/Exporting Data	23
2	Linear Systems	31
2.1	Direct Solution Methods for $Ax = b$	31
2.2	Iterative Solution Methods for $Ax = b$	35
2.3	Gradient (Steepest) Descent for $Ax = b$	39
2.4	Eigenvalues, Eigenvectors and Solvability	44
2.5	Eigenvalues and Eigenvectors for Face Recognition	49
2.6	Nonlinear Systems	56
3	Curve Fitting	61
3.1	Least-Square Fitting Methods	61
3.2	Polynomial Fits and Splines	65
3.3	Data Fitting with MATLAB	69
4	Numerical Differentiation and Integration	77
4.1	Numerical Differentiation	77
4.2	Numerical Integration	83
4.3	Implementation of Differentiation and Integration	87

5	Basic Optimization	93
5.1	Unconstrained Optimization (Derivative-Free Methods)	93
5.2	Unconstrained Optimization (Derivative Methods)	99
5.3	Linear Programming	105
5.4	Simplex Method	110
5.5	Genetic Algorithms	113
6	Visualization	119
6.1	Customizing Plots and Basic 2D Plotting	119
6.2	More 2D and 3D Plotting	125
6.3	Movies and Animations	131
PART II Differential and Partial Differential Equations		
7	Initial and Boundary Value Problems of Differential Equations	137
7.1	Initial Value Problems: Euler, Runge–Kutta and Adams Methods	137
7.2	Error Analysis for Time-Stepping Routines	144
7.3	Advanced Time-Stepping Algorithms	149
7.4	Boundary Value Problems: The Shooting Method	153
7.5	Implementation of Shooting and Convergence Studies	160
7.6	Boundary Value Problems: Direct Solve and Relaxation	164
7.7	Implementing MATLAB for Boundary Value Problems	167
7.8	Linear Operators and Computing Spectra	172
8	Finite Difference Methods	180
8.1	Finite Difference Discretization	180
8.2	Advanced Iterative Solution Methods for $Ax = b$	186
8.3	Fast Poisson Solvers: The Fourier Transform	186
8.4	Comparison of Solution Techniques for $Ax = b$: Rules of Thumb	190
8.5	Overcoming Computational Difficulties	195
9	Time and Space Stepping Schemes: Method of Lines	200
9.1	Basic Time-Stepping Schemes	200
9.2	Time-Stepping Schemes: Explicit and Implicit Methods	205
9.3	Stability Analysis	209

9.4	Comparison of Time-Stepping Schemes	213
9.5	Operator Splitting Techniques	216
9.6	Optimizing Computational Performance: Rules of Thumb	219

10 Spectral Methods **225**

10.1	Fast Fourier Transforms and Cosine/Sine Transform	225
10.2	Chebyshev Polynomials and Transform	229
10.3	Spectral Method Implementation	233
10.4	Pseudo-Spectral Techniques with Filtering	235
10.5	Boundary Conditions and the Chebyshev Transform	240
10.6	Implementing the Chebyshev Transform	244
10.7	Computing Spectra: The Floquet–Fourier–Hill Method	249

11 Finite Element Methods **256**

11.1	Finite Element Basis	256
11.2	Discretizing with Finite Elements and Boundaries	261
11.3	MATLAB for Partial Differential Equations	266
11.4	MATLAB Partial Differential Equations Toolbox	271

PART III Computational Methods for Data Analysis

12 Statistical Methods and Their Applications **279**

12.1	Basic Probability Concepts	279
12.2	Random Variables and Statistical Concepts	286
12.3	Hypothesis Testing and Statistical Significance	294

13 Time–Frequency Analysis: Fourier Transforms and Wavelets **301**

13.1	Basics of Fourier Series and the Fourier Transform	301
13.2	FFT Application: Radar Detection and Filtering	308
13.3	FFT Application: Radar Detection and Averaging	316
13.4	Time–Frequency Analysis: Windowed Fourier Transforms	322
13.5	Time–Frequency Analysis and Wavelets	328
13.6	Multi-Resolution Analysis and the Wavelet Basis	335
13.7	Spectrograms and the Gábor Transform in MATLAB	340
13.8	MATLAB Filter Design and Wavelet Toolboxes	346

14	Image Processing and Analysis	358
14.1	Basic Concepts and Analysis of Images	358
14.2	Linear Filtering for Image Denoising	364
14.3	Diffusion and Image Processing	369
15	Linear Algebra and Singular Value Decomposition	376
15.1	Basics of the Singular Value Decomposition (SVD)	376
15.2	The SVD in Broader Context	381
15.3	Introduction to Principal Component Analysis (PCA)	387
15.4	Principal Components, Diagonalization and SVD	391
15.5	Principal Components and Proper Orthogonal Modes	395
15.6	Robust PCA	403
16	Independent Component Analysis	412
16.1	The Concept of Independent Components	412
16.2	Image Separation Problem	419
16.3	Image Separation and MATLAB	424
17	Image Recognition: Basics of Machine Learning	431
17.1	Recognizing Dogs and Cats	431
17.2	The SVD and Linear Discrimination Analysis	436
17.3	Implementing Cat/Dog Recognition in MATLAB	445
18	Basics of Compressed Sensing	449
18.1	Beyond Least-Square Fitting: The L^1 Norm	449
18.2	Signal Reconstruction and Circumventing Nyquist	456
18.3	Data (Image) Reconstruction from Sparse Sampling	464
19	Dimensionality Reduction for Partial Differential Equations	472
19.1	Modal Expansion Techniques for PDEs	472
19.2	PDE Dynamics in the Right (Best) Basis	478
19.3	Global Normal Forms of Bifurcation Structures in PDEs	482
19.4	The POD Method and Symmetries/Invariances	492
19.5	POD Using Robust PCA	499

20	Dynamic Mode Decomposition	506
20.1	Theory of Dynamic Mode Decomposition (DMD)	506
20.2	Dynamics of DMD Versus POD	510
20.3	Applications of DMD	515
21	Data Assimilation Methods	521
21.1	Theory of Data Assimilation	521
21.2	Data Assimilation, Sampling and Kalman Filtering	526
21.3	Data Assimilation for the Lorenz Equation	529
22	Equation-Free Modeling	537
22.1	Multi-Scale Physics: An Equation-Free Approach	537
22.2	Lifting and Restricting in Equation-Free Computing	542
22.3	Equation-Free Space–Time Dynamics	547
23	Complex Dynamical Systems: Combining Dimensionality Reduction, Compressive Sensing and Machine Learning	551
23.1	Combining Data Methods for Complex Systems	551
23.2	Implementing a Dynamical Systems Library	556
23.3	Flow Around a Cylinder: A Prototypical Example	564
 PART IV Scientific Applications		
24	Applications of Differential Equations and Boundary Value Problems	573
24.1	Neuroscience and the Hodgkin–Huxley Model	573
24.2	Celestial Mechanics and the Three-Body Problem	577
24.3	Atmospheric Motion and the Lorenz Equations	581
24.4	Quantum Mechanics	585
24.5	Electromagnetic Waveguides	588
25	Applications of Partial Differential Equations	590
25.1	The Wave Equation	590
25.2	Mode-Locked Lasers	593
25.3	Bose–Einstein Condensates	600

25.4	Advection–Diffusion and Atmospheric Dynamics	604
25.5	Introduction to Reaction–Diffusion Systems	611
25.6	Steady State Flow Over an Airfoil	616
<hr/>		
26	Applications of Data Analysis	620
26.1	Analyzing Music Scores and the Gábor Transform	620
26.2	Image Denoising through Filtering and Diffusion	622
26.3	Oscillating Mass and Dimensionality Reduction	625
26.4	Music Genre Identification	626
	<i>References</i>	629
	<i>Index of MATLAB Commands</i>	634
	<i>Index</i>	636