<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Practical Aspects of a Vision System — Image Display, Input/Output, and Library Calls</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenCV</td>
<td>2</td>
</tr>
<tr>
<td>The Basic OpenCV Code</td>
<td>2</td>
</tr>
<tr>
<td>The IPLImage Data Structure</td>
<td>3</td>
</tr>
<tr>
<td>Reading and Writing Images</td>
<td>6</td>
</tr>
<tr>
<td>Image Display</td>
<td>7</td>
</tr>
<tr>
<td>An Example</td>
<td>7</td>
</tr>
<tr>
<td>Image Capture</td>
<td>10</td>
</tr>
<tr>
<td>Interfacing with the AIPCV Library</td>
<td>14</td>
</tr>
<tr>
<td>Website Files</td>
<td>18</td>
</tr>
<tr>
<td>References</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Edge-Detection Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Purpose of Edge Detection</td>
<td>21</td>
</tr>
<tr>
<td>Traditional Approaches and Theory</td>
<td>23</td>
</tr>
<tr>
<td>Models of Edges</td>
<td>24</td>
</tr>
<tr>
<td>Noise</td>
<td>26</td>
</tr>
<tr>
<td>Derivative Operators</td>
<td>30</td>
</tr>
<tr>
<td>Template-Based Edge Detection</td>
<td>36</td>
</tr>
<tr>
<td>Edge Models: The Marr-Hildreth Edge Detector</td>
<td>39</td>
</tr>
<tr>
<td>The Canny Edge Detector</td>
<td>42</td>
</tr>
<tr>
<td>The Shen-Castan (ISEF) Edge Detector</td>
<td>48</td>
</tr>
<tr>
<td>A Comparison of Two Optimal Edge Detectors</td>
<td>51</td>
</tr>
</tbody>
</table>
Color Edges 53
Source Code for the Marr-Hildreth Edge Detector 58
Source Code for the Canny Edge Detector 62
Source Code for the Shen-Castan Edge Detector 70
Website Files 80
References 82

Chapter 3  
Digital Morphology 85
Morphology Defined 85
Connectedness 86
Elements of Digital Morphology — Binary Operations 87
  Binary Dilation 88
  Implementing Binary Dilation 92
  Binary Erosion 94
  Implementation of Binary Erosion 100
  Opening and Closing 101
  MAX — A High-Level Programming Language for Morphology 107
  The “Hit-and-Miss” Transform 113
  Identifying Region Boundaries 116
  Conditional Dilation 116
  Counting Regions 119
Grey-Level Morphology 121
  Opening and Closing 123
  Smoothing 126
  Gradient 128
  Segmentation of Textures 129
  Size Distribution of Objects 130
Color Morphology 131
Website Files 132
References 135

Chapter 4  
Grey-Level Segmentation 137
Basics of Grey-Level Segmentation 137
  Using Edge Pixels 139
  Iterative Selection 140
  The Method of Grey-Level Histograms 141
  Using Entropy 142
  Fuzzy Sets 146
  Minimum Error Thresholding 148
Sample Results From Single Threshold Selection 149
## Chapter 5  **Texture and Color**  177

- Texture and Segmentation  177
- A Simple Analysis of Texture in Grey-Level Images  179
- Grey-Level Co-Occurrence  182
  - Maximum Probability  185
  - Moments  185
  - Contrast  185
  - Homogeneity  185
  - Entropy  186
- Results from the GLCM Descriptors  186
- Speeding Up the Texture Operators  186
- Edges and Texture  188
- Energy and Texture  191
- Surfaces and Texture  193
  - Vector Dispersion  193
  - Surface Curvature  195
- Fractal Dimension  198
- Color Segmentation  201
- Color Textures  205
- Website Files  205
- References  206

## Chapter 6  **Thinning**  209

- What Is a Skeleton?  209
- The Medial Axis Transform  210
- Iterative Morphological Methods  212
- The Use of Contours  221
  - Choi/Lam/Siu Algorithm  224
- Treating the Object as a Polygon  226
  - Triangulation Methods  227
## Chapter 7  Image Restoration  251

Image Degradations — The Real World  251
The Frequency Domain  253
   The Fourier Transform  254
   The Fast Fourier Transform  256
   The Inverse Fourier Transform  260
   Two-Dimensional Fourier Transforms  260
   Fourier Transforms in OpenCV  262
Creating Artificial Blur  264
The Inverse Filter  270
The Wiener Filter  271
Structured Noise  273
Motion Blur — A Special Case  276
The Homomorphic Filter — Illumination  277
   Frequency Filters in General  278
   Isolating Illumination Effects  280
Website Files  281
References  283

## Chapter 8  Classification  285

Objects, Patterns, and Statistics  285
   Features and Regions  288
   Training and Testing  292
   Variation: In-Class and Out-Class  295
Minimum Distance Classifiers  299
   Distance Metrics  300
   Distances Between Features  302
Cross Validation  304
Support Vector Machines  306
Multiple Classifiers — Ensembles  309
   Merging Multiple Methods  309
   Merging Type 1 Responses  310
Evaluation  311
Converting Between Response Types  312
Chapter 9  Symbol Recognition  321
The Problem  321
OCR on Simple Perfect Images  322
OCR on Scanned Images — Segmentation  326
Noise  327
Isolating Individual Glyphs  329
Matching Templates  333
Statistical Recognition  337
OCR on Fax Images — Printed Characters  339
Orientation — Skew Detection  340
The Use of Edges  345
Handprinted Characters  348
Properties of the Character Outline  349
Convex Deficiencies  353
Vector Templates  357
Neural Nets  363
A Simple Neural Net  364
A Backpropagation Net for Digit Recognition  368
The Use of Multiple Classifiers  372
Merging Multiple Methods  372
Results From the Multiple Classifier  375
Printed Music Recognition — A Study  375
Staff Lines  376
Segmentation  378
Music Symbol Recognition  381
Source Code for Neural Net Recognition System  383
Website Files  390
References  392

Chapter 10  Content-Based Search — Finding Images by Example  395
Searching Images  395
Maintaining Collections of Images  396
Features for Query by Example  399
Color Image Features  399
Mean Color  400
Color Quad Tree  400
Chapter 11  High-Performance Computing for Vision and Image Processing 425

Paradigms for Multiple-Processor Computation 426
  Shared Memory 426
  Message Passing 427
Execution Timing 427
  Using clock() 428
  Using QueryPerformanceCounter 430
The Message-Passing Interface System 432
  Installing MPI 432
  Using MPI 433
  Inter-Process Communication 434
Running MPI Programs 436
Real Image Computations 437
Using a Computer Network — Cluster Computing 440
A Shared Memory System — Using the PC Graphics Processor 444
GLSL 444
OpenGL Fundamentals 445
Practical Textures in OpenGL 448
Shader Programming Basics 451
Vertex and Fragment Shaders 452
Required GLSL Initializations 453
Reading and Converting the Image 454
Passing Parameters to Shader Programs 456
Putting It All Together 457
Speedup Using the GPU 459
Developing and Testing Shader Code 459
Finding the Needed Software 460
Website Files 461
References 461

Index 465