SHAPE CLASSIFICATION AND ANALYSIS

THEORY AND PRACTICE

SECOND EDITION

Luciano da Fontoura Costa
Roberto Marcondes Cesar, Jr.

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To the memory of my grandmother Clorinda, my brightest teacher.
To my wife, Soraya, my ray of sunlight.

To the memory of my grandmother Nair, who showed me how great is being alive.
To my continuously growing family and, especially, to Adriana and Tainá.

Preface - Second Edition

THE SECOND EDITION of *Shape Analysis and Classification: Theory and Practice* incorporates important enhancements from the last reprint version. The book has been graphically reformulated and we hope the reader will like the new design (fonts, equations, figures, and references). We have implemented a number of corrections and improvements, many of which suggested by readers of the first edition, to whom we are very grateful. New material has been added, in particular new sections on topics like graph and complex networks, dimensionality reduction as well as a new chapter on structural pattern recognition and shape representation using graphs. The reference list has been updated generally.

The book now includes a new type of Box called *Additional Resources* indicating useful resources on the World Wide Web (WWW) such as software, databases and videos. In particular, some open-source software projects related to the subjects covered in this book have been initiated since its first edition was issued. Links to these open-source projects are now provided throughout the book (also available from `http://ccsl.ime.usp.br/`). The user is invited to know, use and help to develop all these projects! The second edition of the book has a new URL: `http://www.vision.ime.usp.br/~cesar/shape/`. In addition, slides that may be useful in courses and talks based on the book are now available at: `http://www.vision.ime.usp.br/~cesar/shape/slides`.

In addition to all friends that helped us in the first edition, we are grateful to those colleagues, students and readers that provided important input regarding the book. Additionally to the people already mentioned in the preface of the first edition, we are grateful to: Alejandro Frery, Alexandre Crivellaro, Alexandre Noma, Ana Beatriz, Anselmo Kumazawa, Arnaldo Lara, Carlos H. Morimoto, Celina Takemura, David Martins Junior, Emerson Tozette, Fabrício Lopes, Fátima N. Sombra, Flávia Ost, Giovane Cesar, Heitor Nicoliello, Herbert Jelinek, Isabelle Bloch, Jeferson Silva, Jesus Mena, Jishu Ashimine, João Eduardo Ferreira, João Soares, Jorge Leandro, José Mario Martinez, Junior Barrera, Junior Barrera, Luis Augusto Consularo, Luis Gustavo Nonato, Luiz Henrique de Figueiredo, Luiz Velho, Marcel Claro, Marcel Jackowski, Marcelo Hashimoto, Marcos Moreti, Michael Cree, Nina S. T. Hirata, Paulo José da Silva e Silva, Pete Lestrel, Reinhard Klette, Roberto Andreani, Roberto Hirata Jr., Rogério Féris, Ronaldo F. Hashimoto, Routo Terada, Silvia Pinto, Teófilo Campos, Thiago Paixão, and Yossi Zana, as well as to the many students of undergrad and grad courses taught by the authors. In particular, the second edition would not be possible without the valuable work of David da Silva Pires. David, thank you very, very much.

As always, our friends at Taylor & Francis have provided a fundamental support to our work, and we are especially grateful to Amber Donley and Nora Konopka. We would also like to acknowledge the support provided by the following research funding agencies: FAPESP, CNPq, CAPES, FINEP, COFECUB and NSF.

We have worked hard to provide an improved text about the exciting areas of shape analysis and classification. We hope you will enjoy reading and using this new edition.

Preface - First Edition

MOST HUMAN ACTIVITIES—including the reading of this text—and interactions with the environment are performed by visual means, more specifically through the capture of electromagnetic waves and subsequent processing by the human visual system. Given the redundancy underlying most that is visual in nature, evolution has produced visual systems that pay great attention to abrupt variations along the objects, such as their boundaries delimiting uniform regions. Indeed, it was very likely the varied geometry of the outlines of uniform objects in the world that led to the human concept of *shape* and the evolution of visual processing abilities dedicated, or at least related, to the capture, processing, analysis and classification of shapes. Besides, it should be observed that many other natural processes also involve geometric objects, normally interacting through fields and waves. For instance, most biochemical reactions involve the matching between two or more molecules, a process that is governed by their respective shapes and force fields. Similarly, interactions between living beings also involve shape geometry and interactions. For example, the mouth of a whale must be particularly effective for collecting plankton and the wings of birds have to be effective for flying. In brief, the importance of shapes is not only essential to humans, but seems to provide a basic principle underlying most natural processes [Costa et al., 1999].

While the importance of the visual information is now fully acknowledged, defining a scientific area on its own, it was only recently that computer vision came to establish itself as an off-the-shelf tool for both researchers and practitioners. That is to say, it has been the continuous advances in computer technology, including higher processing speed, storage capabilities, better acquisition devices (e.g., cameras and scanners), along with more powerful concepts and algorithms and a progressive cost reduction, that paved the way to the dissemination of imaging techniques through a large number of practical applications in the most diverse areas. Indeed, it is the opinion of the authors of this book that we are undergoing an unprecedented *technological opportunity* for the effective application of image and shape analysis resources to many areas. Yet, while this tendency has been duly reflected in an ever-increasing number of books on imaging, shape processing and analysis, biological and computer vision and pattern recognition, it is felt that only a few (if any) existing textbooks provide an introductory, modern, relatively comprehensive and integrated coverage of shape representation, analysis *and* recognition, which are closely intertwined. In light of the above reasons, we cannot avoid the commonplace of observing that the current book will fill the gap not only between the areas of shape analysis and classification, including one of the most comprehensive lists of practical shape features, but also between theory and practice. While concentrating on 2D shapes, the current book also provides the basis for the treatment of higher dimensional objects.

This book is aimed at serving as a largely self-contained introductory textbook on shape analysis and recognition, including several of the most modern and promising tendencies such as scale-space, analyzing wavelets, fractals, computa-

tional geometry and so on. An important trend that has characterized the evolution of shape analysis is its inter- and multidisciplinary nature, involving an increasing variety of concepts from both mathematics and computer science, including differential geometry, Fourier analysis, signal processing, probability and multivariate calculus, to name a few. This implies that students and researchers alike often experience difficulties while trying to understand many approaches to shape analysis. On the other hand, it is worthy emphasizing that shape analysis is such an important task in so many areas, from biology to material sciences, that it would be highly desirable that experts in all those different areas could understand and apply the techniques explored in this book. As a matter of fact, even those practitioners intending simply to use imaging software should also be acquainted with the basic concepts and techniques in image and shape analysis, in order not only to properly apply the several tools usually bundled into such software, but also interpret the respectively obtained results. As the authors had in mind to create a didactic book that would be accessible to a broad range of readers, a comprehensive and mostly self-contained introduction/review of the involved basic mathematical concepts has been especially prepared and included. In addition, whenever possible the mathematical detail is always preceded by the respective conceptual characterization and discussion and several examples have been included in order to help the assimilation of the presented concepts and techniques. Several special boxes have also been included in the book, being organized according to the following types:

Examples: step-by-step examples of the introduced concepts and methods. Such examples can also be treated as exercises, in the sense that the reader should try to solve the presented problems before following up their respective solutions;

Algorithms: high-level algorithms that can be straightforwardly implemented in most programming languages, such as C, Java, Delphi®, Pascal and MATLAB® scripts;

Notes: additional information on relatively secondary or more advanced topics;

"To Probe Further" Pointers: references to more advanced complementary scientific literature, so that the reader can probe further on the state-of-the-art of each specific topic.

In order to increase its readability, this book has been generously illustrated with graphics and images. In addition, a ***WWW homepage*** (see the box at the end of this preface) has been created as a complement, which will be continuously updated with additional examples, data, programs, errata and URL pointers to related areas. Given the introductory and multidisciplinary nature of the present book, as well as space limitations, several important related works and bibliographical references have certainly been overlooked, for which we apologize in advance. In addition, please observe that although great care has been taken in preparing this book, the authors can accept no responsibility for the direct or indirect consequences of the use of algorithms or any other information in this book.

The book starts by discussing the main operations often involved in shape analysis. Chapter 2 provides a self-contained review of the main mathematical concepts that are fundamental to proper understanding of shape analysis and recognition. Since shape analysis by computers involves acquiring and processing digital images of the objects of interest, an overview of the most typical image processing techniques is provided in Chapter 3. It should be observed that while most students and practitioners from other fields will find Chapters 2 and 3 helpful, computer vision and pattern recognition experts may prefer to directly proceed to Chapter 4, which discusses and formalizes the main concepts in 2D shapes. Chapter 5 covers some of the main techniques for shape representation by digital means (i.e., computers), while Chapters 6 and 7 present several important techniques for extracting information from shapes, the latter concentrating on multiscale techniques, including curvature and wavelets. Chapter 8 presents the main techniques for classifying shapes, with emphasis on the more traditional and sound statistical approaches. Finally, some brief considerations about the future perspectives in shape processing and analysis are presented in Chapter 8.

We would like to express our gratitude to a number of people and institutions. First, we thank Prof. Philip Laplante for the kind invitation to contribute to the *CRC Image Processing Series*. Whatever the merits of the present book, Phil deserves the full credit for the initiative. Also fundamental was the kind support of all CRC staff, especially Ms. Elizabeth Spangenberger, Nora Konopka, Michele Berman, Sara Seltzer and Suzanne Lassandro. We thank Prof. Héctor Terenzi (USP) and Prof. Hernan Chaimovich (USP), through the *Pró-Reitorias* of the University of São Paulo, who made the whole project possible by kindly providing financial support. In addition, many of the reported results and techniques have been developed by the authors under sponsorship of several Brazilian funding agencies, including FAPESP, CNPq, CAPES and CCInt, having also involved several students. We also thank all those researchers who so kindly read and commented on preliminary versions of the chapters in this book, including Andréa G. Campos, Carlos P. Dionísio, Cristian Montagnoli, Jorge J. G. Leandro, Prof. Maria Cristina F. de Oliveira, Prof. Nelson D. A. Mascarenhas, Luiz A. Consularo, Luiz G. Rios, Renato Carmo, Rogério S. Feris and Vital Cruvinel Ferreira. Students who have also contributed in the production of some of the data and results presented in this book are Alexandre Crivellaro, Andréa G. Campos, Franklin C. Flores, Heraldo Madeira, Luiz A. Consularo, Marcel Brun, Nina T. Hirata, Regina C. Coelho, Roberto Hirata and Teófilo Campos. Important discussions and suggestions have been provided by many colleagues, especially Carlos Hitoshi, Damien Barache, Herbert Jelinek, Isabelle Bloch, J.-P. Antoine, João Kogler, Junior Barrera, Pierre Vandergheynst and Roberto Lotufo. A good deal of the diagrams in this book were drawn by Samuel Alvarez and additional technical support was provided by Adenilza Alves, Alexandre Silva, Cláudia Tofanelli, Edna Torres, Marcos Gonçalves and Rita de Cássia, to whom we also extend our acknowledgements. Luciano Costa is especially grateful to his wife, Soraya, for her understanding and help with the revision of this book.

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The reader should not miss the book's homepage, containing a series of additional related information, including related pointers, data files, and errata, to be found at the following address:

`http://www.ime.usp.br/~cesar/shape_crc/`

The authors also appreciate receiving comments through e-mail, which should be addressed to `luciano@if.sc.usp.br` or `cesar@ime.usp.br`.

List of Figures

1.1 3D cat and corresponding 2D silhouette . . . 3
1.2 Some typical and easily recognizable 2D shapes . . . 4
1.3 Set of plant leaves belonging to four classes . . . 6
1.4 Feature space . . . 7
1.5 Two morphological classes of prototypical cat ganglion cells . . . 8
1.6 Typical shape tasks . . . 10
1.7 Shape acquisition . . . 11
1.8 Shape detection . . . 12
1.9 Image denoising . . . 13
1.10 Shape operations . . . 14
1.11 Shape evolution . . . 15
1.12 Boundary-based and region-based shape representations . . . 16
1.13 Difference between boundary-based and region-based shape representations . . . 16
1.14 Shape measures . . . 18
1.15 Shape description using Fourier . . . 18
1.16 Polygonal representation . . . 19
1.17 Neural shape and a dendrogram . . . 20
1.18 Shape compression . . . 21
1.19 Unsupervised classification . . . 22
1.20 Supervised classification . . . 23
1.21 Shape similarity . . . 24
1.22 Shape matching . . . 24

2.1 Graphical representations of functions . . . 30
2.2 Graphical representations of the functions $f(x)$ and $g(t)$ . . . 30
2.3 Free variable transformations . . . 32
2.4 Shift behavior for $y = g(at)$ . . . 33
2.5 The affine mapping function . . . 33
2.6 The exponential function . . . 34
2.7 The sinc function . . . 35
2.8 The sigmoid function . . . 36
2.9 Graphical construction for function composition . . . 37
2.10 Graphical interpretation of the parameter σ . . . 38
2.11 Normalized Gaussian functions . . . 38
2.12 The first and second derivatives of the Gaussian function . . . 39
2.13 The step (or heavyside) function . . . 39
2.14 The signum function . . . 40
2.15 A possible box function . . . 40
2.16 The remainder function . . . 41
2.17 The Dirac delta function . . . 42

2.18 The sampling function is an infinite sum of Dirac deltas 42
2.19 The floor function 43
2.20 The ceil function 43
2.21 The trunc function 44
2.22 The round function 44
2.23 A generic complex number z in the Argand plane 45
2.24 The complex conjugation of a complex number 46
2.25 The complex exponential function with unit radius defines a helix . . . 47
2.26 The magnitude and phase functions 47
2.27 The mapping of vertical and horizontal lines by $g(z) = \exp(z)$ 48
2.28 The mapping of a rectangle by $g(z) = \exp(z)$ 49
2.29 The mapping of an orthogonal grid 49
2.30 A conformal mapping 50
2.31 Graphical representation of the vector $v = (1, 2, 3)$ 53
2.32 The vector $\vec{v}$ represented with respect to both considered bases 60
2.33 Rotations of the coordinate system 62
2.34 Graphical illustration of the triangular inequality 64
2.35 The projection L of vector $\vec{p}$ over vector $\vec{q}$ 67
2.36 The transformation T, taking a rectangle into a polygon 72
2.37 The orthogonal transformation 73
2.38 Examples of vector products 75
2.39 The original points (squares) and the obtained cubic polynomial 80
2.40 The trajectory of the parametric curve 87
2.41 Epitrochoids 88
2.42 Hypotrochoids 89
2.43 The parametric representation of a generic straight line L 89
2.44 The arc length between the points $\vec{r}(t_0)$ and $\vec{r}(t)$ 90
2.45 Two nearby points along the trajectory of a generic parametric curve . . 91
2.46 Unit tangent field for the curve in Figure 2.45 92
2.47 The speed, acceleration, and their components at the point indicated by $\vec{p}(t)$ 93
2.48 Unitary normal field for the curve in Figure 2.45 93
2.49 Change of curvature sign 95
2.50 Osculating circle and radius of curvature at a point t 96
2.51 Graphical representation of the function $z = g(x, y) = x^2 + 2y^2$ 97
2.52 The vector field variation $\vec{\Delta}_{\vec{q}}$ 102
2.53 Two functions $g(t)$ and $h(t)$ to be convolved 106
2.54 Illustration of the basic operations involved in the convolution 107
2.55 The convolution $(g * h)(\tau)$ for $\tau = 1$ 108
2.56 The complete convolution $(g * h)(t)$ 108
2.57 The correlation $(g \circ h)(t)$. 108
2.58 The correlation between two time limited functions 109
2.59 The two discrete functions $g(i)$ and $h(i)$ to be correlated 111
2.60 Graphical development of the discrete correlation $(g \circ h)(k)$ 111

2.61 The discrete signals $g(t)$ and $h(t)$ . . . 114
2.62 Venn diagram illustrating the events A, B, and their intersection . . . 116
2.63 Venn diagram illustration of the above example . . . 117
2.64 A Gaussian density function characterizing the random variable X . . . 119
2.65 The relative frequency histogram . . . 128
2.66 The observation of a larger number of samples . . . 129
2.67 The relative frequency histogram of observations of a random variable X . . . 129
2.68 The graphical representation of the observed random values . . . 132
2.69 A nonlinear relationship between the weight and diameter . . . 133
2.70 Two images and their respective circular autocorrelations . . . 135
2.71 The two main orientations of the observed data . . . 138
2.72 Several instances of the function $\cos(2\pi ft)$ . . . 141
2.73 The non-periodic original function $g(t)$ and its periodic version $h(t)$, for $a = 1$ . . . 143
2.74 Reconstruction of the rectangular function by including an increasing number of components . . . 144
2.75 The real and imaginary parts of $G(f)$ . . . 148
2.76 The power spectrum of the function $g(t)$ . . . 149
2.77 The purely real Fourier transform of the function $g(t)$ and its respective power spectrum . . . 150
2.78 The function $g(t) = \exp\{-|t|\}$ and its respective Fourier transform . . . 152
2.79 The scaled version of the function $g(t) = \exp\{-|t|\}$ and its respective Fourier transform . . . 152
2.80 The sampling function and its respective Fourier transform . . . 156
2.81 The function $g(t)$ and its Fourier transform $G(f)$ . . . 157
2.82 Two possible low-pass filtering functions . . . 159
2.83 The function $h(t)$ to be low-pass filtered . . . 160
2.84 The complemented Gaussian function for $\sigma = 0.25$ . . . 160
2.85 The function $h(t)$ to be high-pass filtered . . . 161
2.86 The first derivative filter function . . . 162
2.87 The function $h(t)$ to be high-pass filtered by the first derivative filter . . . 162
2.88 The function $h(t)$ to be band-pass filtered . . . 163
2.89 Example of a sampled function g_i to be Fourier transformed . . . 164
2.90 The DFT output function $H(f)$ is always discrete and periodic of period $1/\Delta t$ . . . 164
2.91 The DFT input function h_i is always discrete and periodic . . . 165
2.92 The sampled Fourier kernel function $w_{k,i} = \exp\left\{-\frac{j2\pi ik}{N}\right\}$ for $N = 8$ and $i = 1$ . . . 167
2.93 Sampled function to be Fourier transformed . . . 169
2.94 The graphical representation of the 4×4 Fourier matrix elements . . . 170
2.95 A continuous signal $\tilde{g}(t)$ has to be time-limited . . . 171
2.96 A hypothetic continuous signal $\tilde{g}(t)$ . . . 172
2.97 The windowed version of $\tilde{g}(t)$ . . . 172

2.98 The sampled function $g(t) = \tilde{g}(t)\,\phi(t)\,\Psi_{\Delta t}(t)$ . . . 173
2.99 The DFT output function $H(k\,\Delta f)$ . . . 174
2.100 DFT obtained by windowing with a truncated Gaussian function . . . 174
2.101 DFT algorithms require the input function $h(t)$ to be defined from 0 to $N-1$ . . . 175
2.102 The input and output functions for a typical DFT algorithm . . . 176
2.103 A graph containing 8 nodes and 10 edges . . . 181
2.104 Clustering and complex networks . . . 189

3.1 Discretization of a square shape . . . 193
3.2 Image sampling . . . 196
3.3 Image pyramid . . . 197
3.4 (a) Gray-level image, (b) binary image obtained by a human, and (c) binary image obtained by an automatic algorithm . . . 199
3.5 The square-box quantization scheme (SBQ) . . . 200
3.6 The grid-intersect quantization scheme (GIQ) . . . 201
3.7 Object boundary quantization scheme (OBQ) . . . 201
3.8 The 4-neighborhood and the 8-neighborhood of a pixel . . . 202
3.9 Connected components based on neighborhood . . . 204
3.10 Color image representation scheme . . . 205
3.11 Gray-level image representation . . . 206
3.12 Example of a video sequence . . . 207
3.13 Video sequence and respective difference images . . . 208
3.14 Simple image processing . . . 210
3.15 The main initial steps in shape analysis and classification . . . 211
3.16 Image histogram . . . 214
3.17 Digital image histogram . . . 215
3.18 The average filtering basic structure . . . 219
3.19 A circularly symmetric 2D Gaussian . . . 221
3.20 Gaussian filtering with increasing scales . . . 222
3.21 Modulus of a 2D Fourier transform . . . 226
3.22 Frequency domain 2D filter . . . 227
3.23 Frequency domain 2D Gaussian filter . . . 228
3.24 Example of the basic operation in median filtering . . . 229
3.25 Digital image and respective segmentation . . . 229
3.26 Digital image and respective edge detection . . . 230
3.27 The shape boundary concept . . . 231
3.28 The concept of edge detection through image differentiation . . . 232
3.29 The Roberts operator . . . 234
3.30 Fourier-based edge enhancement . . . 238
3.31 LoG-based detected edges . . . 240
3.32 Objects segmentation . . . 241
3.33 Digital image and corresponding histogram . . . 243
3.34 Automatically set thresholds . . . 245

3.35 Region-filling algorithm 248
3.36 Morphological dilation effects 249
3.37 Structuring element, with the origin indicated 250
3.38 Image dilation 251
3.39 Binary image of retina vessels and results after 1, 2 and 3 dilations . . . 252
3.40 Image erosion 253
3.41 Practical application of image erosion 254
3.42 Morphological closing 255

4.1 Two examples of possible "shapes" not satisfying the definition adopted in this book 261
4.2 Examples of planar continuous shapes 263
4.3 A polygonal path and a continuous path 263
4.4 A set S and examples of interior, exterior and boundary points 265
4.5 Representation of a shape as a graph 266
4.6 Some of the principal types of shapes 267
4.7 A shape S is mapped by the transformation T into its image $Q = T(S)$. 267
4.8 Morphic transformation 268
4.9 Discontinuous morphic transformation 269
4.10 Feature vector 270
4.11 The S shape mapped into the feature space 271
4.12 A set of similar shapes and their respective characterizations in the feature space 272
4.13 Basic interactions in pattern recognition 273
4.14 A family of shapes defined by two parameters 277
4.15 Several instances of the family of shapes defined in Figure 4.14 278
4.16 Landmark points for two shapes 279
4.17 A shape S including three landmarks and its representation in terms of $2n$-vector, $2n$-set, planar-by-vector and planar-by complex representations 281
4.18 Set operations: union, intersection, difference, and complementation . . 282
4.19 Shape arithmetics 283
4.20 A shape S and its position-normalized version 285
4.21 Several shapes and their mean and normalized sizes 289
4.22 The mean and centroid sizes for 500 distorted versions of shapes 290
4.23 The two shapes S and Q to be compared 291
4.24 The mean and RMS distances between a reference shape 292
4.25 A taxonomy of some morphic transformations 293
4.26 The two scalar fields defining the transformation that rotates a shape by 30° clockwise 294
4.27 A small portion of the original shape S is mapped into the vector $\vec{\Delta}_{\vec{q}}$ . . 295
4.28 A shape and its transformation by the vector field 296
4.29 The local relative magnification and phase difference (in Radians) of the transformation in terms of θ 297

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