CD INSIDE

PRACTICAL ALGORITHMS FOR IMAGE ANALYSIS

SECOND EDITION

DESCRIPTION, EXAMPLES, PROGRAMS, AND PROJECTS

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CAMBRIDGE

Practical Algorithms for Image Analysis

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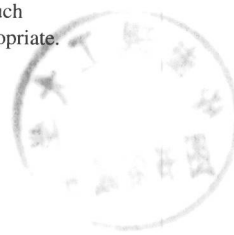

Practical Algorithms for Image Analysis

Second Edition

In classic "cookbook style," this book offers guided access for researchers and practitioners to techniques for the digital manipulation and analysis of images, ranging from the simplest steps to advanced functions. Drawing on their long experience as users and developers of image analysis algorithms and software, the authors present a description and implementation of the most suitable procedures in easy-to-use form. Each self-contained section treats a single operation, describing typical situations requiring that operation and discussing the algorithm and implementation. Sections start with a "before" and "after" pictorial example and a ready-reference listing typical applications, keywords, and related procedures.

This new edition has additional sections on Gabor filtering and on threshholding by connectivity, plus an expanded program listing and suggested projects for classroom use. And now the accompanying CD-ROM contains C programs not only as source code for carrying out the book's procedures but also as executables with a graphical user interface for Windows and Linux.

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Practical Algorithms for Image Analysis
Second Edition

Contents

1 Introduction

1.1 Introduction

In this book, we offer guided access to a collection of algorithms for the digital manipulation of images. Our goal is to facilitate the solution of practical problems, addressing users whose interest is in an informed how-to approach, whether in a technical or in a casual setting. Rather than attempting to be exhaustive, we address salient practical considerations, guiding the selection of a particular approach to commonly encountered image processing and analysis tasks, and we present an implementation of our choice of the most suitable procedures. This selection of "Practical Algorithms" reflects our own experience as long-time users and developers of algorithms and software implementations to process and analyze images in areas as diverse as magnetic domain pattern formation and document analysis.

HOW TO USE THIS BOOK

Organization of Chapters and Sections

This book contains nine chapters and an appendix. Following this introduction, in Section 1.2, an annotated section overview is presented, and, in Section 1.3, a guide to the use of the book the accompanying collection of algorithms are given. Chapters 2 through 7 present the material of the book in self-contained sections of identical format. Chapters 8 and 9, added in this new edition, respectively provide: synposes of all programs, and suggested class or term projects which draw on the material presented in the book. The appendix serves as a review of fundamental concepts to which we refer throughout the text and provides reference material to the technical literature.

Each section contains a header that illustrates the nature of the topic of interest by describing typical applications, identifying key words, and providing cross-references to related topics treated in other sections. Next, the topic of interest is introduced by a description of typical situations requiring a particular processing step or analytical operation; the effect of the operation is illustrated by a pictorial example that comprises a pair of before and after images. Possible strategies of implementation are then discussed, and a particular approach is selected for implementation. Annotated references provide an introduction to further technical literature. Appended to each section is a display of program usage for the code introduced in the section.

Single-Step Procedures

Each section treats a single primary operation (histogram evaluation, low-pass filtering, edge detection, region detection, etc.) and introduces requisite algorithms. Each of the algorithms performs a single transformation on a given input image ("inimg") to produce a modified output image ("outimg") and, in some cases, output data. Sections are self-contained to enable and encourage random access to the most suitable single-step procedure that solves the particular task of interest. Thus, a reader interested in an exposition of simple edge detection techniques would open the book to Section 3.4, while a reader interested in the methodology of Fourier filtering would proceed directly to Section 7.2.

Multistep Procedures

The analysis of images usually requires the successive application of multiple transformations. These may include simple preprocessing steps (noise removal, flat fielding, and feature detection), followed by more complex analytical steps (object shape analysis, line pattern analysis, and point pattern analysis). Multiple individual transformations must be concatenated into multi-step procedures.

To facilitate the flexible design of multi-step procedures, sections are grouped into chapters that bundle common types of analyses (global, local, and frequency domain) and common types of operations according to the images (gray scale and binary) or classes of patterns within images (lines and points) to which they are applied. Each section provides extensive cross references to enable a reader to construct a logical flow of related operations.

Chapters reflect the order in which procedures are ordinarily applied to any given image. For example, histogram analysis will precede binarization: filtering and/or flat fielding will precede object shape analysis, line coding will precede line pattern analysis, and Voronoi analysis will precede statistical analysis of point patterns. Spatial frequency analysis combines several operations in an alternative approach to the analysis of images in the spatial domain, and we choose to present it last. Within chapters, the order of sections reflects increasing levels of task complexity. This organization suggests an overall progression from simple and general to complex and specific tasks.

Code

The book is accompanied by a collection of C programs implementing the algorithms we discuss. All programs operate on existing images; the acquisition of images is not discussed here. Versions for two platforms are supplied, as shown below.

Code Platforms

PLATFORM	C COMPILER
Win32	Microsoft Visual C++, v. 6.0
LINUX kernel v. 2.6.18	GNU gcc, v. 4.1.1

Code Organization

Source code is organized in a directory structure such that modules required for building a particular program reside in a subdirectory corresponding to the book section

in which the program is first invoked. For example, **xconv** would be stored in a subdirectory referring to Section 3.1.

Corresponding LINUX Makefiles and Visual C++ Workspaces are provided to generate executables. Details relating to program compilation and installation are described in a README.TXT file contained on the code distribution disk. In some chapters, additional utilities are provided in a separate subdirectory to generate test images or to analyze output data files.

In addition, we provide three libraries:

- **LIBTIFF**, containing functions to handle input and output of image files in an uncompressed Tagged Image File (TIF) format; *LIBTIFF* 3.4, written by Sam Leffler and made available by Silicon Graphics, Inc., was modified to remove support for LZW compression;
- **LIBIMAGE**, containing **getopt()**, a command line parser, as well as a collection of higher-level graphics functions to handle drawing, filling, and character generation; portions of *LIBIMAGE* invoke *gd 1.2*, written by Tom Boutell and made available by Quest Protein Database Center, Cold Spring Harbor Labs;
- **LIBIP**, containing image analysis functions such as **poly_moments()** and **find_area_hist()** to handle common analytical tasks invoked by multiple programs.

Program Execution

Command Line Interface All programs can be executed from the command line from which a variety of arguments and options can be supplied to adjust and optimize program performance. Some programs prompt for additional input during run time. When executed without arguments, each program displays the command with arguments and options defining program usage. This usage header also is reproduced at the end of each section for programs introduced in that section. In some programs a – I option was added as a command line parameter to invert the input image before processing.

Graphical User Interface In this new edition, programs can be executed using a graphical user interface (GUI), as illustrated in the "Guided Tour" of Section 1.3. The GUI accommodates command line arguments in a separate field and displays program output, in the form of an image and/or text written to standard output, within separate windows. Output image files also are created within a specified directory while output data can be saved to text files by standard "cutting and pasting" from the corresponding display window. The GUI also provides a listing of all programs, either arranged by book chapters and sections or in alphabetical order. Details regarding the operation of the GUI are provided in a "ReadMe" file on the CD accompanying this book. Executing the GUI requires JAVA 1.5 or later (a Java Runtime Environment (JRE) is not included in the code distribution but may be obtained, for example, from SUN Microsystems). By default, programs, as provided on the accompanying CD, operate from within the GUI; for some programs, operation from the command line will require recompilation in accordance with instructions provided in the corresponding README.TXT files. When programs executed from within the GUI produce standard output, this is automatically displayed within a separate GUI window.

Notices

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We would like to thank those individuals, most notably our editor, Lauren Cowles, who have contributed to this book. This publication includes images from Corel Stock Photo Library, which are protected by the copyright laws of the United States, Canada, and elsewhere and are used under license. Images and other printed materials have been reproduced with permission from the following sources, listed in the order of first appearance and further identified in the referenced sections: [O'Gorman et al. 85] – Figs. 2.1.1, 2.2.2, 2.2.5, 5.2.4, 5.3.1, 5.6.1; [CSPL – Corel Stock Photo Library/Corel Group] – Figs. 2.2.1, 2.2.6, 2.5.1, 3.6.1, 3.7.1, 4.9.2, 5.5.1, 7.1.6, 7.1.7; [Morgan and Seul 95] – Figs. 2.3.1, 3.3.1; [Woodward and Zasadzinski 96] – Fig. 2.4.1; [The Bell Labs Technical Journal] – Fig. 2.4.6; [Costello] – Figs. 3.1.1B, 7.1.1; [Gonzalez and Woods 92] – Figs. 3.1.3, 3.1.4, 3.4.2; [Lucent Technologies – Bell Laboratories Physical Sciences Image Library] – Figs. 3.2.1, 3.2.4, 4.3.1; [Seul et al. 92] – Figs. 3.3.2, 5.3.2, 5.7.2–5; [Canny 86] – Fig. 3.5.2; [Boie et al. 86] – Figs. 3.5.3, 3.5.4; [Seul et al. 91] – Figs. 4.3.2, 4.3.3, 4.5.2, 4.5.3; [Attneave 54] – Fig. 5.4.2; [Seul and Wolfe 92B] – Fig. 5.7.1; [Seul and Wolfe 92A] – Fig. 5.7.6; [Preparata and Shamos 85] – Figs. 6.1.2., 6.1.4; [Ashcroft and Mermin 76] – Fig. 6.1.2; [Fortune 87] – Fig. 6.1.5; [Sire and Seul 95] – Figs. 6.3.1-3, 6.4.1; [Seul and Chen 93] – Fig. 7.1.8; [Goodman 68] – Figs. 7.2.1, A.3; [Bracewell 86] – Figs. A.1, A.2; [Sessions 89] – Fig. A.4; [Kruse et al. 91] – Fig. A.5.

1.2 Annotated Section Overview

Chapter 1. Introduction

SECTION TITLE	SYNOPSIS
1.1 Introduction	Describes organization of chapters and sections and code
1.2 Annotated Section Overview	Functions as table of contents (section titles) with annotation in the form of section headers (Typical Application(s), Key Words, Related Topics)
1.3 A Guided Tour	Illustrates use of code to construct multistep sequences of image processing and analysis operations

Chapter 2. Global Image Analysis

SECTION TITLE	TYPICAL APPLICATION	KEY WORDS	RELATED TOPICS[†]
2.1 Intensity Histogram: Global Features	image quality test, object location	intensity histogram, global image features	global enhancement (2.2), binarization (3.10)
2.2 Histogram Transformation: Global Enhancement	enhancement of image contrast	histogram transformations, expansion, equalization; mapping function	global features (2.1), local operations (3.1)
2.3 Combining Images	image overlays, background subtraction; XOR binary operation to control composite image	addition, subtraction; AND, OR, XOR	histogram operations (2.1), color image transformations (2.5), flat fielding (3.3), binarization (3.10), morphological and cellular processing (4.1)
2.4 Geometric Image Transformations	scaling; rotation	interpolation, resampling; image magnification and reduction; rotation	geometric image transformations (2.4), subsampling (3.6), multiresolution analysis (3.7), morphology and cellular processing (4.1), sampling (A.4)
2.5 Color Image Transformations		color, bases transformations, intensity, hue, saturation, RGB, IHS, YIQ	gray-scale analysis (Chap. 3)

[†]The numbers in parentheses indicate the section in which these topics can be found.

Chapter 3. Gray-Scale Image Analysis

SECTION TITLE	TYPICAL APPLICATION	KEY WORDS	RELATED TOPICS
3.1 Local Image Oerations: Convolution	image contrast manipulation by means of filtering, required in many of the applications discussed in subsequent sections	filter mask, kernel; smoothing, sharpening; edge and point detection; transfer function; cyclic convolution	smoothing/noise reduction (3.2), feature enhancement (3.3), edge detection (3.4), filter mask design (7.2), correlation (A.1)
3.2 Noise Reduction	reduction of extraneous image features; reduction of noise introduced by imaging system	noise removal, filtering, low-pass filter, median filter, speckle noise, smoothing, blurring	subsampling (3.6), binary noise removal (4.2), line noise reduction (5.2), frequency domain filtering (7.2)
3.3 Edge Enhancement and Flat Fielding	emphasis of localized features such as contours; elimination of inhomogeneities in scene illumination	high-pass filter, sharpening; unsharp mask, flat fielding	convolution (3.1), edge detection (3.4); shape analysis (4.4), Hough transform (4.10); frequency domain filtering (7.2)
3.4 Edge and Peak Point Detection	detection of lines and points; locate intensity peaks of extended pointlike objects; image segmentation	gradient, Laplacian; region peak detection, converging squares	edge enhancement (3.3), advanced edge detection (3.5), multiresolution analysis (3.7), template matching (3.8); binary region detection (4.3), shape analysis (4.4), Hough transform (4.10)

3.5 Advanced Edge Detection	image segmentation in the presence of noise	optimal detection, matched filter, Wiener filter	edge enhancement (3.3), edge detection (3.4), multiresolution analysis (3.7), template matching (3.8), shape analysis (4.4), Hough transform (4.10)
3.6 Subsampling	scale reduction of images to be subjected to object or feature detection	subsampling, image size reduction, resolution adjustment	geometric interpolation (2.4); noise reduction (3.2), multiresolution analysis (3.7); frequency domain filtering (7.2)
3.7 Multiresolution Analysis	object detection	scale-space processing, multiresolution analysis, multiresolution pyramids	noise reduction (3.2), edge enhancement (3.3), subsampling (3.6), template matching (3.8)
3.8 Template Matching	detection of objects of known shape in noisy environment	matched filtering, template matching, cross correlation	binary region detection (4.3), shape analysis (4.4), spectral shape analysis (4.6), Hough transform (4.10); critical point detection (5.4)
3.9 Gabor Wavelet Analysis	texture and pattern detection	texture, pattern, wavelets	multiresolution analysis (3.7), template matching (3.8), Fourier Transform (7.1), Frequency Domain Filtering (7.2)
3.10 Binarization	conversion of gray-scale to binary image	thresholding, local, global, contextual	image intensity histogram (2.1), histogram transformations (2.2), edge detection (3.4)

Chapter 4. Binary Image Analysis

SECTION TITLE	TYPICAL APPLICATION	KEY WORDS	RELATED TOPICS
4.1 Morphological and Cellular Processing	modification of region shapes in binary images	mathematical morphology, cellular logic; erosion, dilation; shrink, expand; region growing; structuring element, binary filtering	template matching (3.8), binary noise reduction (4.2), thinning (4.7), linewidth determination (4.8)
4.2 Binary Noise Removal	reduction of noise in binary images	"salt-and-pepper" noise; *k*Fill	noise reduction (3.2)
4.3 Region Detection	segmentation of images by delineation of regions and encoding of contours	region detection, segmentation, contour representation, cumulative angular bend, curvature point, region filling or coloring, connected component labeling; contour detection, polygonal representation, tangential and radial contour representation	peak detection (3.4); object shape analysis (4.4), thinning (4.7)
4.4 Shape Analysis: Geometrical Features and Moments	shape descriptors for objects, particularly those of near-circular shape, e.g., phospholipid vesicles and erythrocytes, and for domains formed in a wide variety of physical–chemical systems	global shape descriptor, curvature energy, moments, moments of inertia, moment invariants, recursive evaluation	edge and peak detection (3.4); spectral shape analysis (4.5), convex hull (4.6); polygonalization (5.3), critical point detection (5.4)

4.5 Advanced Shape Analysis: Fouries Descriptors	analysis of object shape, based either on object area or on object contour	shape analysis, spectral shape analysis, Fourier descriptors	region growing (4.3), shape descriptors (4.4)
4.6 Convex Hull of Polygons	delineation of polygonal region; association of a shape with a group of points forming the vertices of a polygon	extreme points, convex hull, shape	shape analysis (4.4), (4.5)
4.7 Thinning	thinning ("skeletonization") of elongated regions, lines, and contours	skeleton, medial axis transform	polygonalization (5.3), line fitting (5.5)
4.8 Linewidth Determination	thinning of an image with simultaneous retention of linewidth information	augmented thinning, line image reconstruction	thinning (4.7)
4.9 Global Features and Image Profiles	global analysis of collections of multiple objects	statistical features, image moments, image projection profiles, intensity signatures	global image features (2.1), multiresolution analysis (3.7), shape analysis (4.4), two-dimensional Fourier transform (7.1)
4.10 Hough Transform	detection of lines (to a lesser degree, of other shapes such as circles) in noisy images	Hough transform, line fitting	template matching (3.8); shape features (4.4); line fitting (5.5); two-dimensional Fourier transform (7.1)

Chapter 5. Analysis of Lines and Line Patterns

SECTION TITLE	TYPICAL APPLICATION	KEY WORDS	RELATED TOPICS
5.1 Chain Coding	efficient representation of line patterns such as contour maps, engineering diagrams, fingerprints, and magnetic domain patterns	directional coding, chain code	region detection (4.3), thinning (4.7)
5.2 Line Features and Noise Reduction	recording of line pattern features such as branch and end points; removal of spurious line features from thinned patterns	matched line filters, chain code, primitives chain code (PCC), thin line code (TLC)	noise reduction (3.2); binary noise removal (4.2), thinning (4.7); chain code (5.1)
5.3 Polygonalization	smoothing and parameterization of noisy contours or edges	straight-line approximation, curve representation	thinning (4.7); chain coding (5.1), critical point detection (5.4), line fitting (5.5)
5.4 Critical Point Detection	curve shape description, identification of curvature maxima along contours	critical points, dominant points, curvature, curvature plot, curvature maxima and minima, corner detection, difference of slopes (DoS), *k*-curvature	shape features (4.4); polygonalization (5.3), line fitting (5.5)