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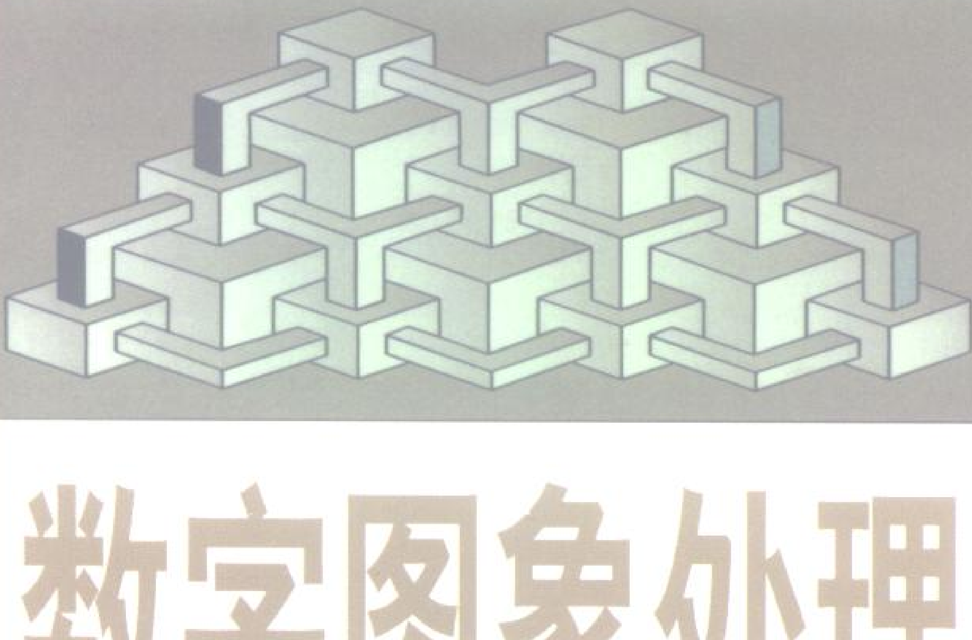
DIGITAL IMAGE PROCESSING



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KENNETH R. CASTLEMAN

清华大学出版社 · PRENTICE HALL

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出版前言

我们的大学生、研究生毕业后，面临的将是一个国际化的信息时代。他们将需要随时查阅大量的外文资料；会有更多的机会参加国际性学术交流活动；接待外国学者；走上国际会议的讲坛。作为科技工作者，他们不仅应有与国外同行进行口头和书面交流的能力，更为重要的是，他们必须具备极强的查阅外文资料获取信息的能力。有鉴于此，在国家教委所颁布的“大学英语教学大纲”中有一条规定：专业阅读应作为必修课程开设。同时，在大纲中还规定了这门课程的学时和教学要求。有些高校除开设“专业阅读”课之外，还在某些专业课拟进行英语授课。但教、学双方都苦于没有一定数量的合适的英文原版教材作为教学参考书。为满足这方面的需要，我们挑选了 7 本计算机科学方面最新版本的教材，进行影印出版。首批影印出版的 6 本书受到广大读者的热情欢迎，我们深受鼓舞，今后还将陆续推出新书。希望读者继续给予大力支持。Prentice Hall 公司和清华大学出版社这次合作将国际先进水平的教材引入我国高等学校，为师生们提供了教学用书，相信会对高校教材改革产生积极的影响。

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Preface

In the 16 years since the publication of my first book on this topic, there has been a major expansion in the utilization of digital image processing. Algorithms that could run only on mainframe computers in the 1960s and minicomputers in the 1970s migrated to the desktop in the 1980s. Personal computers transformed from something a few dedicated hobbyists built in the mid-1970s into a common home office component. The jargon of personal computers became a universal language that bridged the oceans between the United States, Europe, and Asia.

Public awareness of digital image processing has been greatly increased by video games, digital video special effects used in the entertainment industry, and articles in the popular press. Present trends indicate a continuation of the explosive growth of digital image-processing applications well into the next century.

Perhaps the most significant impact of digital image processing in the 1990s will be in the area of applications to real-world problems. This book is aimed at the reader who intends to use the technology for research or commercial purposes. It also provides a foundation for those who seek to advance the state of the art.

While the scope and scale of digital image-processing applications have changed dramatically, other aspects of the field have not. For example, many of the basic techniques that perform reliably in practice today are those that were first applied in the early days of digital imaging. While several exciting new theoretical areas have opened up, generally they build upon, rather than replace, what has served well in the past.

With the recent advances in computer technology, some of the issues treated in the earlier work are no longer of major concern. These are deemphasized in this book, while several relevant new topics have been included. New examples serve to illustrate further how the theory can be applied to the type of problems that commonly occur in industry and research.

Perhaps most significantly, a set of exercises and suggestions for projects completes each chapter. These have been selected to build the insight and understanding that are most useful to one endeavoring to apply the technology to problems of the real world. The majority of the exercises and projects emulate actual situations a professional faces working in the field of digital image processing. They are intended to give the reader a head start in gaining the insight that supplements a theoretical knowledge and can come only from the experience of solving real problems. In my own estimation, one who not only knows how to solve the problems and carry out the projects, but has actually done most of them, will be ready to take his or her place on the most productive image-processing applications team.

For about 25 years, I have had the opportunity to observe the efforts of many individuals applying digital image-processing techniques to problems offered by the real world. A few of these individuals have established an enduring track record of solid success on almost every attempt. They have consistently contributed innovative and effective solutions that creatively employ the tools of the discipline.

These highly productive individuals demonstrably hold several characteristics in common. One can venture to assume that these characteristics constitute a formula for success, to whatever extent such a thing can exist in this field.

Uniformly, these successful persons have (1) a genuine interest in—even a fascination with—the technology involved, (2) a thorough understanding of the fundamentals of this highly multidisciplinary technology, (3) a conceptual type of understanding (as opposed to rote memorization of totally abstract theory), and (4) a knack for seeing problems visually, graphically, and from more than one viewpoint. In line with this last point, they often find themselves hard pressed to explain their ideas without the aid of a graph or drawing.

This book is designed to help the reader develop the last three of these traits and perhaps enhance the first as well. The selection of materials for inclusion (and, equally important, for omission), the examples used, the references cited, and the exercises and suggestions for projects are all directed toward this goal.

In the field of digital image processing, mathematical analysis forms the stable basis upon which one can make definite predictions regarding the performance of a digital imaging system. In this treatment, however, mathematics is employed more as a faithful servant than as a ruthless master. The emphasis is on developing a conceptual understanding, and the analysis is used to support this goal.

The organization of this book generally follows that of the earlier text, simply because that particular flow of development proved to serve its purpose well. The level of mathematical complexity increases gradually through the first two parts of the book. While many readers have the background in mathematics required to begin the discussion with sampling theory and the Fourier transform, others do not.

More importantly, though, many of the most important concepts can be presented without the aid of advanced mathmatics. Thus, we are able to avoid an additional element of complexity in the interest of making the learning process less burdensome and more appealing to all readers. As a general rule, topics receive attention in relation to their importance, rather than their complexity.

The field of digital image processing has now become so rich with technology that it is impossible to cover all aspects of it in a single volume of reasonable size. Hence, we concentrate upon those techniques that prove most useful in practice and leave most of the mathematical proofs to the references. Constraints of paper and ink further make it impossible to include nearly as many examples of images as would be desirable. (See [1] for an excellent source of these.)

Part 1 presents several important concepts that do not require detailed mathematical analysis for a basic understanding of them. Part 2 addresses techniques that rely more heavily upon their mathematical underpinning and elaborates analytically upon certain concepts introduced in Part 1. Part 3 addresses applications more specifically than they are addressed in earlier chapters.

A Note to Instructors. The development of this text has been accompanied by an accumulation of example digital images and problem solutions worked out in MathCAD™ [2]. Instructors interested in obtaining these as teaching aids can contact the author via the publisher, or on the Internet (castleman@psii.persci.com or http://www.phoenix.net/~castlman/ or sci.image.processing).

A Note to Students. There are three situations that can arise during the course of study that can interfere with the learning process [3]. It is a wise reader who remains alert to their symptoms and handles them when they first occur.

The first situation is due to the nomenclature in this very multidisciplinary field. Often, ordinary words are pressed into special new usage without warning. If the concept presented in a paragraph seems unclear or leaves a blank feeling, look for the sentence that doesn't make sense. Then spot the word that doesn't fit. Look in the glossary or a dictionary for the definition that fits the context. Usually, this will resolve the entire matter. Sometimes, however, the offending word may appear one or more sentences earlier in the material. Frequent reference to the glossary and a dictionary is good insurance against any inability to fully understand and use the ideas presented.

The second situation occurs when one moves too quickly through the material. When one becomes confused, the remedy is not to restudy the confusing part, but to go back to the last part that seemed clear and restudy there. Often one will find a previously undetected confusion in the earlier area that, when resolved, will pave the way for further progress.

The third situation results when one studies theory exclusively, without any application, for too long. This can make the reader bored or even exasperated. When it occurs, the remedy is to *apply* the theory, working with actual images and image-processing equipment if possible. A balance between theory and application keeps the subject interesting. The problems and projects are included for this purpose.

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2. MathSoft, Inc., 201 Broadway, Cambridge, MA 02139.
3. L. Ron Hubbard, *Basic Study Manual*, Bridge Publications, Los Angeles, CA, 1990.

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Contents

Part One

CHAPTER 1

Images and Digital Processing

1.1 INTRODUCTION

Digital image processing—the manipulation of images by computer—is a relatively recent development in terms of humans' ancient fascination with visual stimuli. In its short history, it has been applied to practically every type of imagery, with varying degrees of success. The inherent subjective appeal of pictorial displays attracts perhaps a disproportionate amount of attention from scientist and lay person alike.

Like other multidisciplinary fields, digital image processing suffers from myths, misunderstandings, misconceptions, and misinformation. It is a broad umbrella under which fall diverse aspects of optics, electronics, mathematics, photography, and computer technology. It is plagued with imprecise and often contradictory jargon taken from many different fields. This book attempts to collect the fundamental concepts of digital image processing into a self-consistent package for a relatively easily digested introduction to the field.

Several factors indicate continued growth for the field. A major one is the perpetually declining cost of the computer equipment required. Both processing units and bulk storage devices continue to become less expensive year by year. A second factor is the increasing availability of equipment for digitizing and displaying images. There are indications that the cost of computer equipment will continue to decline.

Several new technological trends promise to further stimulate the growth of the field. Among these are parallel processing, made practical by low-cost microprocessors; inexpensive charge-coupled devices (CCDs) for digitizing; new memory technologies for large, low-cost image storage arrays; and inexpensive, high-resolution color display systems.