Human beings are predominantly visual creatures, and our computing environments reflect this. We have the World Wide Web, filled with images of every possible type and provenance, and our own computers are crammed with images from the operating system, downloaded from elsewhere, or taken with our digital cameras. Then there are the vast applications that use digital images: remote sensing and satellite imaging, astronomy, medical imaging, microscopy, industrial inspection . . .

This book is an introduction to digital image processing, from a strictly elementary perspective. We have selected only those topics that can be introduced with simple mathematics; however, these topics provide a very broad introduction to the discipline.

This book is based on some very successful image-processing subjects that have been taught for the past few years at Victoria University in Melbourne, Australia. The topics chosen, and their method of presentation, are the result of many hours of talking to and learning from the hundreds of students who have taken these subjects.

There are a great many books on the subject of image processing, and this book differs from all of them in several important respects:

Not too much mathematics. Some mathematics is necessary for the explanation and discussion of image-processing algorithms. But this book attempts to keep the mathematics at a level commensurate with elementary undergraduate computer science.

The level of mathematics required is about one year's study at a tertiary level, including calculus and linear algebra.

A discrete approach. Since digital images are discrete entities, we have adopted an approach using mainly discrete mathematics. Although calculus is required for the development of some image-processing topics, we attempt to connect the calculus-based (continuous) theory with its discrete implementation.

A strong connection between theory and practice. Since we have used a mainly discrete approach to explain the material, it becomes much easier to extend the theory into practice. This becomes particularly
significant when we develop our own MATLAB functions for implementing specific image-processing algorithms.

**MATLAB-based environment.** There are image-processing books that are based on programming languages, generally C or Java. The problem is that to use such software, a specialized image-processing library must be used, and, at least for C, there is no standard for this. A problem with the Java image-processing libraries is that they are not really suitable for beginning students.

This book is based entirely on MATLAB and its Image Processing Toolbox. This provides a complete environment for image processing that is easy to use, easy to explain, and easy to extend.

**Plenty of examples.** All the example images in this text are accompanied by MATLAB commands. Thus, if you work carefully through the book, you can create the images as given in the text.

**Exercises.** Chapters finish with a selection of exercises that enable the student to consolidate and extend the material. Some of the exercises are pencil-and-paper, designed for better understanding of the material, and others are MATLAB based to explore the algorithms and methods of that chapter.

**Detailed exercise solutions.** Key exercise solutions are provided that include functions, M-file codes, and resulting images, so that instructors can show students how to easily bridge the gap between theory and MATLAB implementation.

**What Is in the Book**
The first three chapters set the scene for much of the rest of the book, exploring the nature and use of digital images and how they can be manipulated, such as acquisition, storage, display, etc. Chapter 1 provides a brief introduction to the field of image processing and attempts to give some idea as to its scope and areas of practice. We also define some common terms and provide practice exercises in some MATLAB basic functions. Chapter 2 shows how MATLAB handles images as matrices and how the manipulation of these matrices forms the background of all of subsequent work. Chapter 3 investigates aspects of image display and looks at resolution and quantization, and discusses how they affect the appearance of the image. Note that an appropriate image display method is critical for observation in digital image processing, e.g., image data types with uint8 and double have different definitions in an identical MATLAB display function.

Chapter 4 looks at some of the simplest, yet most powerful and widely used, image-processing algorithms. These are the point operations, where the value of a pixel (a single dot in a digital image) is changed according to a single function of its value.

Chapter 5 introduces spatial filtering. Spatial filtering can be used for a vast range of image-processing operations, from removing unnecessary detail to sharpening edges and removing noise. Furthermore, the
remarkable power of MATLAB in spatial filtering is easily experienced, even for students who have no previous programming experience with MATLAB.

Chapter 6 looks at the geometry of an image—its size and orientation. Resizing an image may be necessary for inclusion in a Web page or printed text; we may need to reduce it to fit, or enlarge it. Displaying an image with a different orientation is another typical issue in digital image processing. It is often necessary to modify coordinates of image pixels and have them rounded on the discrete plane. As such, interpolation techniques are also introduced to offset distortions caused by this rounding operation.

Chapter 7 introduces the Fourier transform. This is possibly the single most important transform for image processing. To get a feel for how the Fourier transform works and what information it provides, we need to spend some time exploring its mathematical foundations. This chapter has heavy emphasis on the mathematical theory of Fourier transform and requires some knowledge of complex numbers. In keeping with our philosophy, we use discrete mathematics only. We first demonstrate the scaling property of the Fourier transform on MATLAB, as it is the key step to understanding the difference between spatial and frequency domain. Then we show how images can be processed with great efficiency using the Fourier transform and how various operations can be performed using only the Fourier transform.

Chapter 8 discusses the restoration of an image from different forms of degradation. Among these is the problem of noise, or errors in an image. Such errors are a natural consequence of electronic transmission of image signals, and although error correction of the signal can go a long way to ensure that the image arrives "clean," we may still receive images with noise. We also look at the removal of blur effects in an image.

Chapter 9 addresses the problems of thresholding and of finding edges in an image. Edges are a vital aspect of object recognition: we can classify the size, shape, and type of an object by an analysis of its edges. As well, edges form a vital aspect of human visual interpretation, and thus the sharpening of edges is often an important part of image enhancement. An implementation of a representative algorithm (Hough transform) is also demonstrated in detail. Here, the students can experience how MATLAB systematically and effectively realizes useful image process algorithms and hence their applications.

Chapter 10 introduces morphology or mathematical morphology, which is an area of image processing very much wedded to set theory. Historically, morphology developed from the need for granulometry, or the measurement of grains in ore samples. It is now a very powerful method for investigating shapes and sizes of objects. Morphology is generally defined in terms of binary images (which is what we do here) and then can be extended to grayscale images. With the latter, we can also perform edge detection and some noise reduction.

Chapter 11 investigates the topology of digital images. This is concerned with the neighborhoods of pixels and how the exploration of
different neighborhoods leads to an understanding of the structure of image objects.

We continue the investigation of shapes in Chapter 12, but from a more spatial viewpoint; we look at traversing the edges of an object and how the traversal can be turned into descriptors of the size and shape of the object.

Chapter 13 looks at color. Color is one of most important aspects of human interpretation. We look at the definition of color from physical and digital perspectives and examine how a color image can be processed using the techniques we have developed so far.

Chapter 14 discusses some basic aspects of image compression. Image files tend to be large, and their compression can be a matter of some concern, especially if there are many of them. We distinguish two types of compression: lossless, where there is no loss of information, and lossy, where higher compression rates can be obtained at the cost of losing some information.

Chapter 15 introduces wavelets, which have become a very hot topic in image processing. In some places they are replacing the use of the Fourier transform. Our treatment is introductory only. We show how wavelets and waves differ, how wavelets can be defined, how they can be applied to images, and the effects that can be obtained. In particular, we look at image compression and show how wavelets can be used to obtain very high rates of lossy compression with no apparent loss of image quality.

Chapter 16 is intended to be a bit more lighthearted than the others. Here we look at some special effects used on images. These are often provided with image-editing programs—if you have a digital camera, chances are the accompanying software will allow this. Our treatment attempts to provide an understanding of the nature of these algorithms.

Appendix A provides a brief introduction to MATLAB and MATLAB programming, and Appendix B introduces the fast Fourier transform.

What This Book Is Not
This book is not an introduction to either MATLAB or its Image Processing Toolbox. We have used only a small fraction of the many commands and functions available; we used only those useful for an elementary text such as this. There are an enormous number of books on MATLAB available; a fine general introduction is the text by Hanselman and Littlefield [10]. To really come to grips with the Image Processing Toolbox, you can either use its excellent manual or browse through the comprehensive online documentation.
How to Use This Book
This book can be used for two separate streams of image processing: one very elementary, another a little more advanced. A first course consists of the following:

- Chapter 1
- Chapter 2, except for Section 2.5
- Chapter 3, except for Section 3.6
- Chapter 4
- Chapter 5
- Chapter 7
- Chapter 8
- Chapter 9, except for Sections 9.4, 9.5, and 9.9
- Chapter 10, except for Sections 10.8 and 10.9
- Chapter 13
- Chapter 14, Sections 14.2 and 14.3 only

A second course fills in the gaps:

- Section 2.5
- Section 3.6
- Section 6
- Sections 9.4, 9.5, and 9.9
- Sections 10.8 and 10.9
- Chapter 11
- Chapter 12
- Section 14.4
- Chapter 15

As taught at Victoria University of Technology, for the first course we concentrate on introducing students to the principles and practices of image processing, and we don’t worry about the implementation of the algorithms. In the second course, we spend time discussing programming issues and encourage the students to write their own programs and edit programs already written. Both courses have been very popular since their inception.

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A Note on the Images
Some of the images used in this book are the author’s and may be used freely and without restriction. They are:

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