

## Book Reviews

**Two-Dimensional Imaging**—Ronald N. Bracewell (Englewood Cliffs, NJ: Prentice-Hall, 1994, 689 pp., \$72)

Reviewer: Alfred M. Bruckstein

Cameras and scanners are cheap, computers have plenty of memory and are incredibly fast, and multimedia CD's will soon replace books on our shelves, the experts say, and some of us are sorry to hear it. Our children learn to manipulate images on computer screens before they learn to read, while we, of the "incyberate" generation, struggle to keep up with ever more sophisticated video and digital cameras, fax machines, copiers, VCR's, and laser discs. People talk about HiRes screens and color printers with thousands of dpi's, digital HDTV, CAT's and PET's, about spy satellites reading newspaper headlines from space, and Bill Gates' race to acquire the rights for the electronic reproduction of famous paintings. The age of imaging technology has dawned!

Several disciplines dealing with "the technology of digital images" emerged over the past few decades and are taught at universities worldwide. *Image Processing* is about algorithms that filter, enhance, and restore images: this is an "image-in/image-out" technology. Coding and compression, and image reconstruction from projections are topics often incorporated in digital image processing books and courses. *Computer Graphics* deals with image synthesis: the goal is to simulate the physical image generation process and produce credible glimpses of "ghosts" residing in computers' databases, figments of the programmer's imagination or results of complicated numerical calculations. *Computer Vision*, a most frustrating discipline, addresses issues of image analysis and interpretation: the general aim is to accomplish "image-in/description-out." This endeavor leads to very difficult, often ill-posed and not well defined, inverse problems. But these issues are so interesting that recently it has become fashionable among famous mathematicians and physicists to move into this exciting new area of research. *Imaging* traditionally refers to the process of producing images from data. The data can be gathered in various ways, either by conventional cameras detecting the flux of photons falling on arrays of sensors, or by reading the echoes of waves returning from a medium whose space-varying properties we want to map.

Professor Ronald Bracewell, whose wonderful textbook on Fourier transforms should be on every engineer's bookshelf, sets out to provide in **Two-Dimensional Imaging** a solid theoretical basis for the student about to embark on the exciting adventure of dealing with images on the computer. He does this brilliantly, his writing is entertaining, his points are clever and clearly made. "Every book is autobiographical," someone remarked, and this is quite true of Professor Bracewell's recent book as well. He shares with his reader an expanded and organized story of his own frequent forays into the emerging technology of imaging. Coming from Ronald Bracewell, an outstanding astrophysicist and experienced teacher, this was bound to be, and indeed is, quite an opinionated and exciting story.

Feynman remarked in his celebrated *Lectures on Physics*, when devoting a chapter to the topic of color vision, that "the separation

of fields is merely a human convenience, and an unnatural thing." "Nature," he said, "is not interested in our separations, and many of the interesting phenomena bridge the gap between the fields." Professor Bracewell knows this and covers a truly amazing variety of topics connected to the science of digitized images with little regard for the conventional boundaries that separate the various types of image-related endeavors. In his book, image acquisition, processing, synthesis, and analysis topics mix and match, and relevant subjects, not commonly discussed in texts on digital images, such as imaging as a deconvolution process, diffraction theory of sensors and radiators, and aperture synthesis, and interferometry, are given serious consideration. At each point in the book, well-chosen and interesting examples and applications of the theoretical tools are discussed. The classical subjects of image representations in the frequency domain (via Fourier and Hartley transforms, of course!), filtering and restoration, are treated with an emphasis on analyzing the relationship between the continuous-domain theory and discrete-domain algorithms, an absolutely necessary prerequisite when dealing with images as pixel arrays.

As entirely expected, the book treats very thoroughly the Radon transform, the projection slice theorem, and computed tomography. Ronald Bracewell is credited with the invention, in the radio-astronomical context of imaging by reconstruction from projections, of the convolution backprojection algorithm used in computerized tomography. In fact, before opening his new book, I thought it would be dedicated mostly to this area of imaging science. But not so. And, in addition to the varied general topics already mentioned, we also find a chapter on synthetic-aperture radar imaging, quite suitably placed in a book with emphasis on Fourier methods (although I found this section a bit too condensed!)

As I said before, this book is very much Professor Bracewell's personal story of imaging. Readers familiar with the classical textbooks and the ongoing research in image processing, computer graphics, and machine vision will find the organization of the subject matter rather unconventional, with some odd, but definitely very interesting, subjects emphasized. And those eagerly looking to find their own papers mentioned in the book will soon realize that the references to the literature do not even attempt the "wall-to-wall coverage" of topics usually undertaken in other textbooks. Professor Bracewell quotes only occasional sources, as needed, and, very wisely, sends the students to scan current research journals in the field. As an example, the book begins with a nice discussion of the various ways a bivariate function can be represented in the computer, and a discussion of ways to project the 3D world into 2D images. This gives Professor Bracewell the opportunity to mention a beautiful paper of J. C. Maxwell on surface topography. This paper, titled "On Hills and Dales," appeared in 1870, and deals with the so-called "mountaineer's theorem," a topological index theorem stating that the number of local maxima plus the number of local minima minus the number of saddle points within an equal height contour of a generic smooth surface equals one. And, although this paper was recently "rediscovered" by the image analysis community due to its relevance to problems of recovering shape from shaded images and, in general, in analyzing image structure, it is almost never mentioned at the introductory stage of discussion on image structure in the usual texts. I fully agree with Professor Bracewell that it should. Then, the topic

of projecting the world into flat images, taken quite literally, gives Professor Bracewell the opportunity to discuss another beautiful, but rather rarely touched upon, topic: geographical map projection. Map and conformal transformations are not usually discussed in image processing and analysis textbooks, and even the computer graphics people have yet to fully discover their charm. Later on in the book, when dealing with digital representations of geometric objects, Professor Bracewell provides a nice discussion on digital straight lines: here the algorithm he proposes for straight-line generation is due to Oscar Bunemann, a name unknown (yet!) in the graphics community. Moire patterns are also discussed and cleverly used to illustrate the shortcomings of Fourier analysis in predicting perceived patterns, and analyzing nonlinear image superposition. The final section on noise images gives the author an opportunity to introduce the reader to an interesting mix of topics from autostereograms to fractals to Voronoi tessellations, in addition to the traditional subjects of Gaussian noise and autocorrelations of random scatters of points.

A minor error that will surely be rectified in the next printing of the book is found in the "Summary of Chapters" section of the Introduction: after mentioning Chapter 16, Chapter 17 is described but called Chapter 18, and a nonexistent Chapter 19, devoted to halftoning, is described in some detail. I was looking forward to read this chapter, and am sorry it was not there. Professor Bracewell probably decided to drop this chapter and include a brief discussion of halftoning in Chapter 2. Also, I would have liked to see the classic works, like Leon Battista Alberti's "On Painting," and Maxwell's "On Hills and Dales" paper, and Piero della Francesca's "De Prospectiva Pingendi" referred to by the year they first appear, not by the year these works were reprinted. It was quite strange to see them quoted as if from 1976, 1965, and 1984! Finally, I was a bit frustrated by the fact that some subjects were left out, or discussed too briefly. Shape-from-shading, a topic I first learned about from Professor Bracewell, is not

even mentioned, although quite relevant in many photogrammetric imaging applications. The subject of directional filtering—first dealt with by D. Gabor in a very nice, but largely unnoticed paper titled "Information Theory in Electron Microscopy," published in the obscure *Journal of Laboratory Investigation*, in 1965—and a very active area of research today, running under names like "adaptive image enhancement" or "edge preserving smoothing" or "anisotropic diffusion" could have been discussed too. But, these are obviously my own biases and preferences.

To summarize, this is a beautiful and unconventional book introducing the student to a wide range of topics in image analysis, synthesis, and processing. It is organized around techniques of analysis, rather than around a core of basic issues and problems. The exercises following each chapter are well chosen, stress important points, and add much insight to the theory. The textbook that Professor Bracewell has written succeeds fully in conveying the excitement of the many topics that can be gathered under the title "imaging science." I must also congratulate the author and publisher for the jacket design that displays a beautiful, and very well chosen, op-art image due to Bridget Riley. I recommend this book to all serious students entering the wonderful world of pixels and images, and to teachers interested in developing a basic course on imaging science, understood in the broadest context. And I am sure that even experienced researchers in the field will find many gems in it.

*Alfred M. Bruckstein is a Professor of Computer Science at the Technion-Israel Institute of Technology, Haifa, Israel, currently on sabbatical leave at Lucent Technologies, Bell Laboratories, Murray Hill, NJ. His research interests are computer vision, image processing and image synthesis, applied geometry, and ant-robotics.*