*Introduction to*

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# REAL-TIME IMAGING

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# Introduction to the Series

The Tutorial Texts series was begun in response to requests for copies of SPIE short course notes by those who were not able to attend a course. By policy the notes are the property of the instructors and are not available for sale. Since short course notes are intended only to guide the discussion, supplement the presentation, and relieve the lecturer of generating complicated graphics on the spot, they cannot substitute for a text. As one who has evaluated many sets of course notes for possible use in this series, I have found that material unsupported by the lecture is not very useful. The notes provide more frustration than illumination.

What the Tutorial Texts series does is to fill in the gaps, establish the continuity, and clarify the arguments that can only be glimpsed in the notes. When topics are evaluated for this series, the paramount concern in determining whether to proceed with the project is whether it effectively addresses the basic concepts of the topic. Each manuscript is reviewed at the initial stage when the material is in the form of notes and then later at the final draft. Always, the text is evaluated to ensure that it presents sufficient theory to build a basic understanding and then uses this understanding to give the reader a practical working knowledge of the topic. References are included as an essential part of each text for the reader requiring more in-depth study.

One advantage of the Tutorial Texts series is our ability to cover new fields as they are developing. In fields such as sensor fusion, morphological image processing, and digital compression techniques, the textbooks on these topics were limited or unavailable. Since 1989 the Tutorial Texts have provided an introduction to those seeking to understand these and other equally exciting technologies. We have expanded the series beyond topics covered by the short course program to encompass contributions from experts in their field who can write with authority and clarity at an introductory level. The emphasis is always on the tutorial nature of the text. It is my hope that over the next five years there will be as many additional titles with the quality and breadth of the first five years.

Donald C. O'Shea
Georgia Institute of Technology

January 1995

To

John and Christopher

# Contents

# Preface

Real-time processing for digital imaging concerns efficient, deterministic implementation of algorithms whose inputs include digital images and whose outputs are digital images, numerical features, symbolic representations, or decisions. Practically, a real-time demand occurs when one is faced with composing an algorithm that must complete an imaging task within some given time frame. Computation bottlenecks appear in many forms and, to some extent, each requires its own real-time implementation via algorithm design, software, hardware, or a combination thereof; nevertheless, there are certain fundamental algorithms at the center of digital image processing and our focus is upon the structure, computation, and application of these algorithms. Specifically, we treat linear, matrix, and nonlinear algorithms that appear across a wide range of imaging applications. Among the applications discussed are noise suppression, edge detection, matched filtering, and data compression. Specific operations covered include linear convolution, the discrete cosine transform (DCT), the fast Fourier transform (FFT), the median filter, and the morphological gradient.

The imaging algorithms discussed tend to be computationally intensive, especially when directly implemented on standard sequential hardware. Various means of providing efficient computation are discussed. For instance, fast matrix transforms result from decomposing a matrix into a cascade of more easily computable matrices. Among the various hardware paradigms treated are pipelining, dataflow, and systolic arrays. Numerous aspects of programming languages are discussed, including parameter passing, recursion, typing, and exception handling. There is also a survey of commonly used languages and ways in which these contribute or do not contribute to real-time processing. Numerous optimization techniques such as loop unrolling and loop jamming are provided for avoiding unnecessary computation at run time.

Following an account of real-time issues in the first chapter, there is a chapter introducing the basic computer architectures that will play a role in finding hardware solutions for real-time imaging tasks. The chapter contains an introductory account of sequential processing in the von Neumann architecture. This has been included to provide those who are not familiar with assembly-level programming with the basic architectural concepts and terminology that will be used subsequently. The next three chapters treat linear, matrix transform, and nonlinear imaging algorithms. Actual applications are given and computational aspects of the algorithms are discussed. The final three chapters discuss three levels at which one can address real-time processing: parallel hardware, the programming language, and code optimization.

These solutions are applied to various computations in the previously discussed imaging algorithms.Our goal has been to write a text that can be used by those who are not necessarily experts in either computer science or digital image processing, but who need to become familiar with the kinds of computation bottlenecks common in digital imaging and with some of the ways in which efficient real-time processing can be affected. References have been provided for those who wish to pursue individual topics in more detail.

We acknowledge and offer our appreciation to all who assisted in preparation of the book. These include Y. Chen, C. Cuciurean-Zapan, J. Astola, and M. Rabbani, who contributed the figures and images; J. Handley, S. Wilson, and D. Sinha, who technically reviewed the manuscript; and E. Pepper, who provided editorial assistance and who guided the manuscript through production.

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