# *Preface*

## Background and Motivation

The science of medical imaging owes much of its existence to the discovery of X rays by W.C. Röentgen over 100 years ago, in 1895. However, it was the development of practical computed tomography scanners in the early 1970s by G. Hounsfield and others that brought computers into medical imaging and clinical practice. Since then, computers have become integral components of modern medical imaging systems and hospitals, performing a variety of tasks from data acquisition and image generation to image display and analysis.

With the widespread acceptance of computed tomography came an implicit invitation to apply computers and computing to a host of other medical imaging situations. As new imaging modalities were developed, the need for computing in image generation, manipulation, display, and analysis grew by many folds. Computers are now found in virtually every medical imaging system, including radiography, ultrasound, nuclear medicine, and magnetic resonance imaging systems. The strengths of computer applications in medical imaging have been recognized to such an extent that radiology departments in many hospitals are changing over to "totally digital" departments, using computers for image archival and communication as well. The humble X-ray film that launched the field of radiology may soon vanish, thereby contributing to better management of the environment.

The increase in the number of modalities of medical imaging and in their practical use has been accompanied by an almost natural increase in the scope and complexity of the associated problems, requiring further advanced techniques for their solution. For example, physiological imaging with radioisotopes in nuclear medicine imaging comes with a host of problems such as noise due to scatter, effects of attenuation along the path of propagation of the gamma rays through the body, and severe blurring due to the collimators used. Radiation dose concerns limit the strength and amount of the isotopes that may be used, contributing to further reduction in image quality. Along with the increase in the acceptance of mammography as a screening tool has come the need to efficiently process such images using computer vision techniques. The use of high-resolution imaging devices for digital mammography and digital radiography, and the widespread adoption of picture archival and communication systems, have created the need for higher levels of lossless data compression. The use of multiple modalities of medical imaging for improved diagnosis of a particular type of disease or disorder has raised the need to combine diverse images of the same organ, or the results thereof, into a readily comprehensible visual display.

The major strength in the application of computers to medical imaging lies in the potential use of image processing and computer vision techniques for quantitative or objective analysis. (See the July 1972 and May 1979 issues of the *Proceedings of the IEEE* for historical reviews and articles on digital image processing.) Medical images are primarily visual in nature; however, visual analysis of images by human observers is usually accompanied by limitations associated with interpersonal variations, errors due to fatigue, errors due to the low rate of incidence of a certain sign of abnormality in a screening application, environmental distractions, etc. The interpretation of an image by an expert bears the weight of the experience and expertise of the analyst; however, such analysis is almost always subjective. Computer analysis of image features, if performed with the appropriate logic, has the potential to add objective strength to the interpretation of the expert. It thus becomes possible to improve the diagnostic confidence and accuracy of even an expert with many years of experience.

Developing an algorithm for medical image analysis, however, is not an easy task; quite often, it might not even be a straightforward process. The engineer or computer analyst is often bewildered by the variability of features in biomedical signals, images, and systems that is far higher than that encountered in physical systems or observations. Benign diseases often mimic the features of malignant diseases; malignancies may exhibit characteristic patterns, which, however, are not always guaranteed to appear. Handling all of the possibilities and the degrees of freedom in a biomedical system is a major challenge in most applications. Techniques proven to work well with a certain system or set of images may not work in another seemingly similar situation.

## The Problem-solving Approach

The approach I have taken in presenting the material in this book is primarily that of problem solving. Engineers are often said to be (with admiration, I believe) problem solvers. However, the development of a problem statement and gaining of a good understanding of the problem could require a significant amount of preparatory work. I have selected a logical series of problems, from the many I have encountered in my research work, for presentation in this book. Each chapter deals with a certain type of problem with biomedical images. Each chapter begins with a statement of the problem, and includes illustrations of the problem with real-life images. Image processing or analysis techniques are presented, starting with relatively simple "textbook methods", followed by more sophisticated methods directed at specific problems. Each chapter concludes with applications to significant and practical problems. The book is illustrated copiously, in due consideration of the visual nature of the subject matter.

The methods presented in the book are at a fairly high level of technical and mathematical sophistication. A good background in one-dimensional signal and system analysis [1, 2, 3] is very much required in order to follow the procedures and analyses. Familiarity with the theory of linear systems, signals, and transforms such as the Laplace and Fourier, in both continuous and discrete versions, will be assumed. We shall only briefly study a few representative medical imaging techniques. We will study in more detail the problems present with medical images after they have been acquired, and concentrate on how to solve the problems. Some preparatory reading on medical imaging equipment and techniques [3, 4, 5, 6] may be useful, but not always essential.

## The Intended Audience

The book is primarily directed at engineering students in their final year of undergraduate studies or in their (post-)graduate studies. Electrical and Computer Engineering students with a rich background in signals and systems [1, 2, 3] will be well prepared for the material in the book. Students in other engineering disciplines or in computer science, physics, mathematics, or geophysics should also be able to appreciate the material in this book. A course on digital signal processing or digital filters [7] would form a useful link, but a capable student without this topic may not face much difficulty. Additional study of a book on digital image processing [8, 9, 10, 11, 12, 13] could assist in developing a good understanding of general image processing methods, but is not required.

Practicing engineers, computer scientists, information technologists, medical physicists, and data-processing specialists working in diverse areas such as telecommunications, seismic and geophysical applications, biomedical applications, hospital information systems, remote sensing, mapping, and geomatics may find this book useful in their quest to learn advanced techniques for image analysis. They could draw inspiration from other applications of data processing or analysis, and satisfy their curiosity regarding computer applications in medicine and computer-aided medical diagnosis.

## Teaching and Learning Plans

An introduction to the nature of biomedical images is provided in Chapter 1. The easy-to-read material in this chapter gives a general overview of the imaging techniques that are commonly used to acquire biomedical images; for detailed treatment of medical imaging, refer to Macovski [5], Robb [14], Barrett and Swindell [3], Huda and Slone [6], and Cho et al. [4]. A good understanding of the basics of image data acquisition procedures is essential in order to develop appropriate methods for further treatment of the images.

Several concepts related to image quality and information content are described in Chapter 2, along with the related basics of image processing such as the Fourier transform and the modulation transfer function. The notions, techniques, and measures introduced in this chapter are extensively used in the book and in the field of biomedical image analysis; a clear understanding of this material is an important prerequisite to further study of the subject.

Most of the images acquired in practice suffer loss of quality due to artifacts and practical limitations. Several methods for the characterization and removal of artifacts and noise are presented in Chapter 3. Preprocessing of images to remove artifacts without causing distortion or loss of the desired information is an important step in the analysis of biomedical images.

Imaging and image processing techniques aimed toward the improvement of the general quality or the desired features in images are described in Chapter 4. Methods for contrast enhancement and improvement of the visibility of the details of interest are presented with illustrative examples.

The important task of detecting regions of interest is the subject of Chapter 5, the largest chapter in the book. Several approaches for the segmentation and extraction of parts of images are described, along with methods to improve initial approximations or results.

Objective analysis of biomedical images requires the extraction of numerical features that characterize the most significant properties of the regions of interest. Methods to characterize shape, texture, and oriented patterns are described in Chapters 6, 7, and 8, respectively. Specific features are required for each application, and the features that have been found to be useful in one application may not suit a new application under investigation. Regardless, a broad understanding of this subject area is essential in order to possess the arsenal of feature extraction techniques that is required when attacking a new problem.

The material in the book through Chapter 8 provides resources that are more than adequate for a one-semester course with 40 to 50 hours of lectures. Some of the advanced and specialized topics in these chapters may be omitted, depending upon the methods and pace of presentation, as well as the level of comprehension of the students.

The specialized topic of image reconstruction from projections is dealt with in Chapter 9. The mathematical details related to the derivation of tomographic images are presented, along with examples of application. This chapter may be skipped in an introductory course, but included in an advanced course.

Chapter 10 contains descriptions of methods for the restoration of images with known models of image degradation. The advanced material in this chapter may be omitted in an introductory course, but forms an important subject area for those who wish to explore the subject to its full depth.

The subject of image data compression and coding is treated in detail in Chapter 11. With due regard to the importance of quality and fidelity in the treatment of health-related information, the focus of the chapter is on lossless compression. This subject may also be considered to be an advanced topic of specialized interest, and limited to an advanced course.

Finally, the most important and significant tasks in biomedical image analysis — pattern analysis, pattern classification, and diagnostic decision — are described in Chapter 12. The mathematical details of pattern classification techniques are presented, along with procedures for their incorporation in medical diagnosis and clinical assessment. Since this subject forms the culmination of biomedical image analysis, it is recommended that parts of this chapter be included even in an introductory course.

The book includes adequate material for two one-semester courses or a full-year course on biomedical image analysis. The subject area is still a matter of research and development: instructors should endeavor to augment their courses with material selected from the latest developments published in advanced journals such as the *IEEE Transactions on Medical Imaging* as well as the proceedings of the SPIE series of conferences on medical imaging. The topics of biometrics, multimodal imaging, multisensor fusion, image-guided therapy and surgery, and advanced visualization, which are not dealt with in this book, may also be added if desired.

Each chapter includes a number of study questions and problems to facilitate preparation for tests and examinations. Several laboratory exercises are also provided at the end of each chapter, which could be used to formulate hands-on exercises with real-life and/or synthetic images. Selected data files related to some of the problems and exercises at the end of each chapter are available at the site

www.enel.ucalgary.ca/People/Ranga/enel697

It is strongly recommended that the first one or two laboratory sessions in the course be visits to a local hospital, health sciences center, or clinical laboratory to view biomedical image acquisition and analysis in a practical (clinical) setting. Images acquired from local sources (with the permissions and approvals required) could form interesting and motivating material for laboratory exercises, and should be used to supplement the data files provided. A few invited lectures and workshops by physiologists, radiologists, pathologists, and other medical professionals should also be included in the course so as to provide the students with a nonengineering perspective on the subject.

Practical experience with real-life images is a key element in understanding and appreciating biomedical image analysis. This aspect could be difficult and frustrating at times, but provides professional satisfaction and educational fun!

It is my humble hope that this book will assist students and researchers who seek to enrich their lives and those of others with the wonderful powers of biomedical image analysis. Electrical and Computer Engineering is indeed a great field in the service of humanity.

*Rangaraj Mandayam Rangayyan*
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# *About the Author*

Rangaraj (Raj) Mandayam Rangayyan was born in Mysore, Karnataka, India, on July 21, 1955. He received the Bachelor of Engineering degree in Electronics and Communication in 1976 from the University of Mysore at the People's Education Society College of Engineering, Mandya, Karnataka, India, and the Ph.D. degree in Electrical Engineering from the Indian Institute of Science, Bangalore, Karnataka, India, in 1980. He was with the University of Manitoba, Winnipeg, Manitoba, Canada, from 1981 to 1984. He joined the University of Calgary, Calgary, Alberta, Canada, in 1984.

He is, at present, a Professor with the Department of Electrical and Computer Engineering (and an Adjunct Professor of Surgery and Radiology) at the University of Calgary. His research interests are in the areas of digital signal and image processing, biomedical signal analysis, medical imaging and image analysis, and computer vision. His research projects have addressed topics such as mammographic image enhancement and analysis for computer-aided diagnosis of breast cancer; region-based image processing; knee-joint vibration signal analysis for noninvasive diagnosis of articular cartilage pathology; directional analysis of collagen fibers and blood vessels in ligaments; restoration of nuclear medicine images; analysis of textured images by cepstral filtering and sonification; and several other applications of biomedical signal and image analysis.

He has lectured extensively in many countries, including India, Canada, United States, Brazil, Argentina, Uruguay, Chile, United Kingdom, The Netherlands, France, Spain, Italy, Finland, Russia, Romania, Egypt, Malaysia, Singapore, Thailand, Hong Kong, China, and Japan. He has collaborated with many research groups in Brazil, Spain, France, and Romania.

He was an Associate Editor of the *IEEE Transactions on Biomedical Engineering* from 1989 to 1996; the Program Chair and Editor of the Proceedings of the IEEE Western Canada Exhibition and Conference on "Telecommunication for Health Care: Telemetry, Teleradiology, and Telemedicine", July 1990, Calgary, Alberta, Canada; the Canadian Regional Representative to the Administrative Committee of the IEEE Engineering in Medicine and Biology Society (EMBS), 1990 to 1993; a Member of the Scientific Program Committee and Editorial Board, International Symposium on Computerized Tomography, Novosibirsk, Siberia, Russia, August 1993; the Program Chair and Co-editor of the *Proceedings of the 15th Annual International Conference of the IEEE EMBS*, October 1993, San Diego, CA; and Program Co-chair, 20th Annual International Conference of the IEEE EMBS, Hong Kong, October 1998.

His research work was recognized with the 1997 and 2001 Research Excellence Awards of the Department of Electrical and Computer Engineering, the 1997 Research Award of the Faculty of Engineering, and by appointment as a "University Professor" in 2003, at the University of Calgary. He was awarded the Killam Resident Fellowship in 2002 by the University of Calgary in support of writing this book. He was recognized by the IEEE with the award of the Third Millennium Medal in 2000, and was elected as a Fellow of the IEEE in 2001, Fellow of the Engineering Institute of Canada in 2002, Fellow of the American Institute for Medical and Biological Engineering in 2003, and Fellow of SPIE: the International Society for Optical Engineering in 2003.

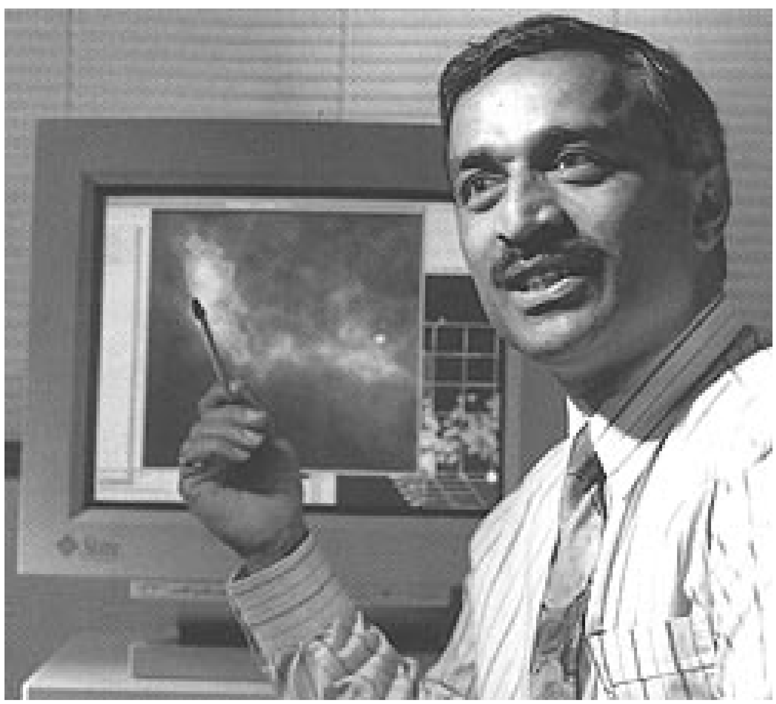

Photo by Trudie Lee.

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Writing this book on the multifaceted subject of biomedical image analysis has been challenging, yet yielding more knowledge; tiring, yet stimulating the thirst to understand and appreciate more of the subject matter; and difficult, yet satisfying when a part was brought to a certain stage of completion.

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My basic education was imparted by many influential teachers at Saint Joseph's Convent, Saint Joseph's Indian High School, and Saint Joseph's College in Mandya and Bangalore, Karnataka, India. My engineering education was provided by the People's Education Society College of Engineering, Mandya, affiliated with the University of Mysore. I was initiated into research in biomedical engineering at the Indian Institute of Science — India's premier research institute and one of the very highly acclaimed research institutions in the world. I express my gratitude to all of my teachers.

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# *Contents*