Chapter 1

Preface

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1.1 Introduction

Advances in sensor technology are revolutionizing the way remotely sensed data is collected, managed and analyzed. The incorporation of latest-generation sensors to airborne and satellite platforms is currently producing a nearly continual stream of high-dimensional data, and this explosion in the amount of collected information has rapidly created new processing challenges. In particular, many current and future applications of remote sensing in Earth science, space science, and soon in exploration science require real- or near real-time processing capabilities. Relevant examples include environmental studies, military applications, tracking and monitoring of hazards such as wild land and forest fires, oil spills and other types of chemical/biological contamination.

To address the computational requirements introduced by many time-critical applications, several research efforts have been recently directed towards the incorporation of high-performance computing (HPC) models in remote sensing missions. HPC is an integrated computing environment for solving large-scale computational demanding problems such as those involved in many remote sensing studies. With the aim of providing a cross-disciplinary forum that will foster collaboration and development in those areas, this book has been designed to serve as one of the first available references specifically focused on describing recent advances in the field of HPC applied to remote sensing problems. As a result, the content of the book has been organized to appeal to both remote sensing scientists and computer engineers alike. On the one hand, remote sensing scientists will gain benefit by becoming aware of the extremely high computational requirements introduced by most application areas in Earth and space observation. On the other hand, computer engineers will benefit from the wide range of parallel processing strategies discussed in the book. However, the material presented in this book will also be of great interest to researchers and practitioners working in many other scientific and engineering applications, in particular, those related with the development of systems and techniques for collecting, storing and analyzing extremely high-dimensional collections of data.

1.2 Contents

The contents of this book have been organized as follows. First, an introductory section addressing some key concepts in the field of computing applied to remote sensing, along with an extensive review of available and future developments in this area, is provided. This section also covers other application areas not necessarily related with remote sensing, such as multimedia and video processing, chemical/biological standoff detection, and medical imaging. Then, three main application-oriented sections follow, each of which illustrates a specific parallel computing paradigm. In particular, the HPC-based techniques comprised in these sections include multiprocessor (cluster-based) systems, large-scale and heterogeneous networks of computers, and specialized hardware architectures for remotely sensed data analysis and interpretation. Combined, the four sections deliver an excellent snapshot of the state-of-the-art in those areas, and offer a thoughtful perspective of the potential and emerging challenges of applying HPC paradigms to remote sensing problems:

- *Part I: General.* This part develops basic concepts about HPC in remote sensing, and provides a detailed review of existing and planned HPC systems in this area. Other areas that share common aspects with remote sensing data processing are also covered, including multimedia and video processing.
- *Part II: Multiprocessor systems.* This part includes a compendium of algorithms and techniques for HPC-based remote sensing data analysis using multiprocessor systems such as clusters and networks of computers, including massively parallel facilities.
- *Part III: Large-scale and heterogeneous distributed computing.* The focus of this part is on parallel techniques for remote sensing data analysis using large-scale distributed platforms, with special emphasis on grid computing environments and fully heterogeneous networks of workstations.
- *Part IV: Specialized architectures.* The last part of this book is devoted to systems and architectures for at-sensor and real-time collection and analysis of remote sensing data using specialized hardware and embedded systems. The part also includes specific aspects about current trends in remote sensing sensor design and operation.

1.2.1 Organization of Chapters in this Volume

The first part of the book (*general*) consists of two chapters which include basic concepts that will appeal to both students and practitioners who have not had a formal education in remote sensing and/or computer engineering. This section will also be of interest to remote sensing and general-purpose HPC specialists, who can greatly benefit from the exhaustive review of techniques and discussion on future data processing perspectives in this area. Also, general-purpose specialists will become aware of other application areas of HPC (e.g., multimedia and video processing) in which the design of techniques and parallel processing strategies to deal with extremely large computational requirements follows a similar pattern as that used to deal with remotely sensed data sets. On the other hand, the three application-oriented parts that follow (*multiprocessor systems*, *large-scale and heterogeneous distributed computing*, and *specialized architectures*) are each composed of five selected chapters that will appeal to the vast scientific community devoted to designing and developing efficient techniques for remote sensing data analysis. This includes commercial companies working on intelligence and defense applications, Earth and space administrations such as NASA or the European Space Agency (ESA) –both of them represented in the book via several contributions– and Universities with programs in remote sensing, Earth and space sciences, computer architecture and computer engineering. Also, the growing interest in some emerging areas of remote sensing such as hyperspectral imaging (which will receive special attention in this volume) should make this book a timely reference.

1.2.2 Brief Description of Chapters in this Volume

We provide below a description of the chapters contributed by different authors. It should be noted that all the techniques and methods presented in those chapters are well consolidated, and cover almost entirely the spectrum of current and future data processing techniques in remote sensing applications. We specifically avoided repetition of topics in order to complete a timely compilation of realistic and successful efforts in the field. Each chapter was contributed by a reputed expert or a group of experts in the designed specialty areas. A brief outline of each contribution follows:

- **Chapter 1. Preface**. The present chapter provides an introduction to the book and describes the main innovative contributions covered by this volume and its individual chapters.
- **Chapter 2. Computer Architectures for Remote Sensing Data Analysis: Overview and Case Study**. This chapter provides a review of the state-of-the-art in the design of HPC systems for remote sensing. The chapter also includes an application case study in which the pixel purity index (PPI), a well-known remote sensing data pro-

cessing algorithm included in Kodak's Research Systems ENVI (a very popular remote sensing-oriented commercial software package), is implemented using different types of HPC platforms such as a massively parallel multiprocessor, a heterogeneous network of distributed computers, and a specialized hardware architecture.

- **Chapter 3. Computer Architectures for Multimedia and Video Analysis**. This chapter focuses on multimedia processing as another example application with a high demanding computational power and similar aspects as those involved in many remote sensing problems. In particular, the chapter discusses new computer architectures such as graphic processing units (GPUs) and multimedia extensions in the context of real applications.

- **Chapter 4. Parallel Implementation of the ORASIS Algorithm for Remote Sensing Data Analysis**. This chapter presents a parallel version of ORASIS (the Optical Real-time Adaptive Spectral Identification System) that was recently developed as part of a U.S. Department of Defense program. The ORASIS system comprises a series of algorithms developed at the Naval Research Laboratory for the analysis of remotely sensed hyperspectral image data.

- **Chapter 5. Parallel Implementation of the Recursive Approximation of an Unsupervised Hierarchical Segmentation Algorithm**. This chapter describes a parallel implementation of a recursive approximation of the hierarchical image segmentation algorithm developed at NASA. The chapter also demonstrates the computational efficiency of the algorithm using remotely sensed data collected by Landsat Thematic Mapper (a multispectral instrument).

- **Chapter 6. Computing for Analysis and Modeling of Hyperspectral Imagery**. In this chapter, several analytical methods employed in vegetation and ecosystem studies using remote sensing instruments are developed. The chapter also summarizes the most common HPC-based approaches used to meet these analytical demands, and provides examples with computing clusters. Finally, the chapter discusses the emerging use of other HPC-based techniques for the above purpose, including data processing onboard aircraft and spacecraft platforms, and distributed Internet computing.

- **Chapter 7. Parallel Implementation of Morphological Neural Networks for Hyperspectral Image Analysis**. This chapter explores in detail the utilization of parallel neural network architectures for solving remote sensing problems. The chapter further develops a new morphological/neural parallel algorithm for the analysis of remotely sensed data, which is implemented using both massively parallel (homogeneous) clusters and fully heterogeneous networks of distributed workstations.

- **Chapter 8. Parallel Wildland Fire Monitoring and Tracking Using Remotely Sensed Data**. This chapter focuses on the use of HPC-based remote sensing techniques to address natural disasters, emphasizing the (near) real-time computational requirements introduced by time-critical applications. The chapter also develops several innovative algorithms, including morphological and target detection approaches, to monitor and track one particular type of hazard: wildland fires, using remotely sensed data.

- **Chapter 9. An Introduction to Grids for Remote Sensing Applications**. This chapter introduces grid computing technology in preparation for the chapters to follow. The chapter first reviews previous approaches to distributed computing and then introduces current web and grid service standards, along with some end-user tools for building grid applications. This is followed by a survey of current grid infrastructure and science projects relevant to remote sensing.

- **Chapter 10. Remote Sensing Grids: Architecture and Implementation**. This chapter applies the grid computing paradigm to the domain of Earth remote sensing systems by combining the concepts of remote sensing or sensor web systems with those of grid computing. In order to provide a specific example and context for discussing remote sensing grids, the design of a weather forecasting and climate science grid is presented and discussed.

- **Chapter 11. Open Grid Services for Envisat and Earth Observation Applications**. This chapter first provides an overview on some ESA Earth Observation missions, and on the software tools that ESA currently provides for facilitating data handling and analysis. Then, the chapter describes a dedicated Earth-science grid infrastructure, developed by the European Space Research Institute (ESRIN) at ESA in the context of DATAGRID, the first large European Commission-funded grid project. Different examples of remote sensing applications integrated in this system are also given.

- **Chapter 12. Design and Implementation of a Grid Computing Environment for Remote Sensing**. This chapter develops a new dynamic Earth Observation system specifically tuned to manage huge quantities of data coming from space missions. The system combines recent grid computing technologies, concepts related to problem solving environments, and other HPC-based technologies. A comparison of the system to other classic approaches is also provided.

- **Chapter 13. A Solutionware for Hyperspectral Image Processing and Analysis**. This chapter describes the concept of an integrated process for hyperspectral image analysis, based on a *solutionware* (i.e., a set of catalogued tools which allow for the rapid construction of data processing algorithms and applications). Parallel processing implementations of some of the tools in the Itanium architecture are presented, and a prototype version of a hyperspectral image processing toolbox over the grid, called Grid-HSI, is also described.

- **Chapter 14. AVIRIS and Related 21^{st} Century Imaging Spectrometers for Earth and Space Science**. This chapter uses the NASA Jet Propulsion Laboratory's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), one of the most advanced hyperspectral remote sensing instrument currently available, to review the critical characteristics of an imaging spectrometer instrument and the corresponding characteristics of the measured spectra. The wide range of scientific research as well as application objectives pursued with AVIRIS are briefly presented. Roles for the application of high performance computing methods to AVIRIS data set are discussed.

- **Chapter 15. High Performance Image processing with FPGA Reconfigurable Computing Systems**. This chapter discusses the role of reconfigurable computing using field programmable gate arrays (FPGAs) for onboard processing of remotely sensed data. The chapter also describes several case studies of remote sensing applications in which reconfigurable computing has played an important role, including cloud detection and dimensionality reduction of hyperspectral imagery.

- **Chapter 16. FPGA Design for Real-time Implementation of Constrained Energy Minimization for Hyperspectral Target Detection**. This chapter describes an FPGA implementation of the constrained energy minimization (CEM) algorithm, which has been widely used for hyperspectral detection and classification. The main feature of the FPGA design provided in this chapter is the use of the Coordinate Rotation DIgital Computer (CORDIC) algorithm to convert a Givens rotation of a vector to a set of shift-add operations, which allows for efficient implementation in specialized hardware architectures.

- **Chapter 17. Real-time Online Processing of Hyperspectral Imagery for Target Detection and Discrimination**. This chapter describes a real-time online processing technique for fast and accurate exploitation of hyperspectral imagery. The system has been specifically developed to satisfy the extremely high computational requirements of many practical remote sensing applications, such as target detection and discrimination, in which an immediate data analysis result is required for (near) real-time decision-making.

- **Chapter 18. Real-time Onboard Hyperspectral Image Processing Using Programmable Graphics Hardware**. Finally, this chapter addresses the emerging use of graphic processing units (GPUs) for onboard remote sensing data processing. Driven by the ever-growing demands of the video-game industry, GPUs have evolved from expensive application-specific units into highly parallel programmable systems. In this chapter, GPU-based implementations of remote sensing data processing algorithms are presented and discussed.

1.3 Distinguishing Features of the Book

Before concluding this preface, the editors would like to stress out several distinguishing features of this book. First and foremost, this book is the first volume which is entirely devoted to providing a perspective on the state-of-the-art of HPC techniques in the context of remote sensing problems. In order to address the need for a consolidated reference in this area, the authors have made significant efforts to invite highly recognized experts in academia, institutions and commercial companies to write relevant chapters focused on their vast expertise in this area, and share their knowledge with the community. Second, this book provides a compilation of several well-established techniques covering most aspects of the current spectrum of processing techniques in remote sensing, including supervised and unsupervised techniques for data acquisition, calibration, correction, classification, segmentation, model inversion and visualization. Further, many of the application areas addressed in this book are of great social relevance and impact, including chemical/biological standoff detection, forest fire monitoring and tracking, etc. Finally, the variety and heterogeneity of parallel computing techniques and architectures discussed in the book is not to be found in any other similar textbook.

1.4 Summary

The wide range of computer architectures (including homogeneous and heterogeneous clusters and groups of clusters, large-scale distributed platforms and grid computing environments, specialized architectures based on reconfigurable computing and commodity graphic hardware) and data processing techniques covered by this book exemplifies a subject area that has drawn together an eclectic collection of participants, but increasingly this is the nature of many endeavors at the cutting edge of science and technology.

In this regard, one of the main purposes of this book is to reflect the increasing sophistication of a field that is rapidly maturing at the intersection of many different disciplines, including not only remote sensing or computer architecture/engineering, but also signal and image processing, optics, electronics and aerospace engineering. The ultimate goal of this book is to provide readers with a peek of the cutting-edge research in the use of HPC-based techniques and practices in the context of remote sensing applications. The editors hope that this volume will serve as a useful reference for practitioners and engineers working in the above and related areas. Last but not least, the editors gratefully thank all the contributors for sharing their vast expertise with readers. Without their outstanding contributions, this book could not have been possibly completed.

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