Modern Signal Processing
MSRI Publications
Volume **46**, 2003

Introduction
A New Generation of Signal Processing

In many ways, the late 1950s marked the beginning of the digital age, and with it, the beginning of a new age for the mathematics of signal processing. High-speed analog-to-digital converters had just been invented. These devices were capable of taking analog signals like time series (think of continuous functions of time like seismograms which measure the seismic activity — the amount of bouncing — at a fixed location, or an EEG, or an EKG) and converting them to lists of numbers. These numbers were obtained by *sampling* the time series, that is, recording the value of the function at regular intervals, which at that time could be as fast as 300,000 times every second. (Current technology permits sampling at much higher rates where necessary.) Suddenly, reams and reams of data were being generated and new mathematics was needed for their analysis, manipulation and management.

So was born the discipline of Digital Signal Processing (DSP), and it is no exaggeration to say that the world has not been the same. In the mathematical sciences the DSP revolution has, among other things, helped drive the development of disciplines like algorithmic analysis (which was the impetus behind the creation of computer science departments), communication and information theory, linear algebra, computational statistics, combinatorics, and discrete mathematics. DSP tools have changed the face of the arts (electroacoustic music and image processing), health care (medical imaging and computed imaging), and, of course, both social and economic commerce (i.e., the internet). Suffice to say that the mathematics of DSP is one of the pillars supporting the amazing technological revolution that we are experiencing today.

Some fifty years later, as we turn the corner on the twenty-first century, we find ourselves facing an analogous paradigm shift in the world of signal processing. Ubiquitous networked computing has once again changed the order of magnitude of the size of datasets that are routinely interrogated and manipulated by an increasingly large and diverse set of customers. New sensing modalities are changing the form of the data that researchers need to consider, as well as making necessary techniques for integrating data from different sources in order to best understand the information they contain. This information is presented in a variety of formats, ranging from simple one-dimensional time domain signals, through the 2-D, 3-D and 4-D realms of basic imagery and video, and on to increasingly higher-dimensional data of various sorts. The growing mathematical sophistication of the signal processor's toolbox is driven by the need to collect, manage, analyze, and exploit data that are growing in complexity, size, and diversity.

This volume contains a collection of papers which gives some idea of the spectrum of mathematical tools that researchers are now bringing to bear on the new challenges of what might be called *modern signal processing*. It is the outgrowth of the Summer Graduate Program in Modern Signal Processing which we ran at the Mathematical Sciences Research Institute in June 2001.

The program was divided into two main parts: fundamentals and current research. Each morning was devoted to introductory lectures on some of the standard mathematical tools which currently comprise DSP. These included a brief tour of Fourier-based DSP (sampling theory, algorithms) group theoretic generalizations, several lectures on adaptive wavelet-based approaches, basic statistical signal processing ideas including detection and estimation theory, and information theoretic tools including source and channel coding (data compression and error correction).

Afternoons were given over to a series of invited outside lectures sampling directions of current research. Some of the papers included here are derived from those lectures, while others were solicited, and all were refereed. Applications areas touched upon here range among robotics, phylogeny, radar antennae design, imaging, sensing, and optical communication. The mathematical tools used include noncommutative harmonic analysis, differential geometry, time-frequency analysis, and mathematical statistics. This body of work gives some indication of the wide range of disciplines and methodologies that currently comprise the frontier of signal processing, as well as the wide range of working environments and application areas where signal processing is studied (academia, industry, defense laboratories, etc.).

We like to think that the breadth of mathematical research represented by this volume is at least reminiscent of the wide range of topics presented at the famous 1968 Arden Conference devoted to the FFT. That meeting brought together mathematicians and statisticians, physicists interested in astronomical and atomic calculations, M.D.s interested in spectral analysis for medical sensing, radar and sonar engineers, hardware and software developers, and it exemplifies the excitement that surrounded the birth of the digital revolution. In a June 1967 special issue of the the *IEEE Transactions on Audio and Electroacoustics* (which has turned into the *IEEE Transactions on Signal Processing*), B. Bogert closes his guest editorial with the words "What lies over the horizon in digital processing is anyone's guess, but I think it will surprise us all." We hope that the papers collected here are an indication of the beginnings of a similarly intellectually exciting and fertile era.

In closing, we'd like to thank everyone who made the summer program possible: our friends and colleagues who contributed time and lectures, as well as MSRI's friendly and professional staff who kept everything running so smoothly. Special thanks to all of those who contributed papers to this volume, and to Silvio Levy, without whose patience and technical savvy this volume would have never seen the light of day. Rockmore gratefully acknowledges the support of NSF, AFOSR, and the Santa Fe Institute over the course of the production of this volume.

Daniel N. Rockmore
Dennis M. Healy, Jr.
Hanover, NH, and College Park, MD