BOOK REVIEWS

Ondelettes

Wavelets and Operators. YVES MEYER. Cambridge University Press, New York, 1993. xvi, 223 pp., illus. $49.95 or £27.95. Cambridge Studies in Advanced Mathematics, 37. Translated from the French edition (Paris, 1990) by D. H. Salinger.

Wavelets. Algorithms and Applications. YVES MEYER. Society for Industrial and Applied Mathematics, Philadelphia, 1993. xii, 133 pp., illus. Paper, $19.50; to SIAM members, $15.60. Translated from the French by Robert D. Ryan.

Before we even heard of wavelets, we had realized that if only there existed some very special functions, for which we had drawn up a wish list, then we could tackle a whole variety of statistical problems that had not been successfully tamed before. And then wavelets came along, and they did all we had hoped for.

When we first heard about wavelets and all the miracles that were claimed for their use in signal analysis, we were very curious. But when we learned what it was all about, we felt cheated: we had known this technique all along, and what is more, for speech analysis it didn't really work.

Very early on in the development of wavelet theory, I wrote my own wavelet transform software, and it is now one of my best diagnostic tools: when I get some unknown signal, I often run it through a wavelet transform to see what kind of things to expect and where, and then I can fine-tune my approach.

These three quotations, collected in the last two years (obviously from three different people), reflect diverse points of view. Where lies the truth?

Wavelet theory is now a little over ten years old but has much older roots. For the benefit of readers not familiar with the concept, it may be useful to say a few words about what wavelets are.

Analysts like to decompose functions into elementary building blocks. Three familiar examples are: (i) Fourier series, in which arbitrary periodic functions are represented as a sum of simple sines and cosines with harmonic frequencies; (ii) polynomial decompositions, in which the function is written as its average, plus a linear trend, plus a quadratic correction, and so on; and (iii) finite element decompositions, in which the function is viewed as a huge mosaic of small, localized pieces. The goal in decomposing functions is generally to understand better what is going on: by looking at pieces with only a few simple features it is easier, for instance, to compute how things will change in time, or determine how the different features of the original complicated object interconnect. Depending on one's goals, one type of decomposition will be better than another. Wavelets are the elementary building blocks in yet another type of decomposition, often called the wavelet transform. A variety of different wavelet transforms exist, but in every case the wavelets are derived from a few basic templates (well-localized functions with some oscillations) by taking differently scaled versions and putting them in many different positions; in one-dimensional situations one template is sufficient. A complete family of building blocks with which one can build most anything typically contains few large-scale and very many fine-scale wavelets. (Because the latter are narrower, more of them are needed to cover a given expanse; typically, the number of wavelets of a given size is inversely proportional to their width.) The advantage of being able to decompose a complex object into different types of wavelets is that it enables one to see broad features on a wide scale while studying the fine structure in greater detail, one small patch at a time. This mathematical microscope facility is especially useful in the study of two-dimensional television images, or many types of signals with short-lived transients, or the singularities of a function and how they form or propagate. For functions with long-range coherent oscillations, wavelets make much less sense intuitively and indeed perform much less well. Other mathematical tools, closer to the Fourier transform but better adapted for parsing, have been developed recently for such oscillating signals, but that is another story.

Wavelets provide unconditional bases for a large variety of function spaces. To understand what this means, we must first understand how one can check whether one function is "close" to another. One way, laughingly referred to as the "window norm," is to hold up the two superposed graphs against a strong light and see how closely they coincide. The distance between functions would then be the maximum vertical distance between their graphs. But for finding fast, small-amplitude oscillations superposed on a more slowly varying carrier, the closeness of the data to the smooth carrier is of little interest. A different measure of distance between functions would reveal that two functions (or data sets) are close only if they have comparable-amplitude oscillations at different frequencies, with the input of the different frequency ranges weighed in a specially prescribed way. A different norm, or a different topology on the function world, would thereby be defined. Different function spaces are obtained depending on one's interests. The decomposition scheme used may be well adapted to a function space, or not. The Fourier transform, for instance, is very well adapted to settings in which one wants to give different weights to different frequency components when comparing two functions: Whether one function is close to another can be determined by simply taking the sizes of the differences of their Fourier coefficients, slapping on the appropriate weights, and adding it all—if the result is small, the functions were close. Voilà! Easy, especially if the Fourier coefficients were already in hand, having been obtained for a different purpose. If, however, one wants to compare functions with singularities, or to know what happens at a specific point, the Fourier transform works much less well. But wavelets still do the trick. For an amazing number of different spaces or different ways of measuring how close two functions are, all one needs to know is the sizes of the differences of their wavelet coefficients. This is the property alluded to in the first quotation above, from David Donoho of the statistics department at Stanford University.

Our understanding of this mathematical versatility of wavelets derives from a tradition in harmonic analysis going back to Littlewood-Paley theory and, more recently, the beautiful and deep body of work known as Calderón-Zygmund theory. But this understanding would not have had much impact on applications if there did not exist fast and easily programmable algorithms for carrying out a wavelet decomposition. Fast algorithms for different types of wavelet transforms, developed over the last ten years, are used in many wavelet applications. The most elegant one corresponds to a multiresolution analysis, in which the function to be analyzed is viewed as the result of successive approximations, and each layer of detail necessary for going from one stage to the next is given by a linear combination of wavelets at the appropriate scale. Surprisingly, the corresponding algorithm was already known to electrical engineers as a "subband filtering scheme with two channels and leading to exact reconstruction." For applications to speech coding, electrical engineers had in fact developed more intricate versions that performed better, as implied in the second quotation above, from Thomas Barnwell of the electrical engineering department at the Georgia Institute of Technology. But even though many of the wavelet applications now under study would not have been possible without the subband decomposition algorithm, the algorithm by itself does not wavelets make: Without the underlying mathematical theory there would be no reason to suspect that it could lead to a powerful tool for understanding and working with the mathematical structure of large classes of functions. For instance, the time-frequency decomposition insights gained by the author of the third quotation, John Sadowsky of the Applied Physics Laboratory at Johns Hopkins University, stem from our understanding of wavelets as function-analytic tools rather than from the algorithm.

Yves Meyer is one of the pillars of the development of wavelet theory. He was an acclaimed harmonic analyst long before the term "wavelet transform" was invented. One day, chatting with the person ahead of him in the line for the photocopy machine at the Ecole Polytechnique near Paris, he heard of the work of Alex Grossmann and Jean Morlet, a mathematical physicist and a geophysicist who were analyzing data and functions by means of wavelet transforms and discovering many interesting properties; the stir their work made among physicists led to the popularity of wavelets outside the field of mathematical harmonic analysis. (Incidentally, Grossmann and Morlet also coined the term: In geophysics calling an oscillating well-localized function a "wavelet" is a well-established custom. To contrast their new technique with existing methods, Grossmann and Morlet called their functions "wavelets of constant shape." But outside geophysics the qualifier was no longer needed and was quickly dropped, to the annoyance of geophysicists.) Upon hearing of this work, Meyer immediately realized that it was similar to the Calderón decomposition formula, a basic tool in Calderón-Zygmund theory. He became interested in the different point of view adopted by Grossmann and Morlet and wanted to provide a mathematical proof for what was implicitly assumed by many then working with wavelets—namely, that, just as for the windowed Fourier transform, one had to use redundant families, because an orthonormal basis of smooth and well-localized wavelets did not exist. This was a theorem for the windowed Fourier transform, but for wavelets it turned out to be a misconception, as Meyer showed in the summer of 1985 by constructing an orthonormal wavelet basis of rapidly decaying and infinitely smooth functions. (It later turned out that Jan Olof Stromberg had, three years earlier, constructed a different smooth wavelet basis with good decay, but its importance had not been realized at the time.) The existence of such smooth and well-localized wavelet bases was an inspiring discovery, but the explicit construction seemed to hinge upon some miraculous cancellations. A little over a year later, Meyer was contacted by Stéphane Mallat, who felt there had to be a connection with multiscale models in vision theory; together, Meyer and Mallat developed the multiresolution framework for wavelet bases, which not only explained away all the miracles of the year before but was the basis for the fast algorithms that would make many applications possible. Meyer has also developed many other aspects of wavelet theory, tying it into the Calderón-Zygmund fabric, using wavelets and inspiring his students to use them to provide easier proofs for existing theorems, and proving new theorems. His name has become as familiar to a large community of applied mathematicians and other scientists interested in wavelets as it was before in the smaller field of harmonic analysis.

The first book under review here was an instant classic when it came out in French. I know at least one mathematician who actually studied French so as to be able to read *Ondelettes et Opérateurs*; many more have been eagerly awaiting the publication of *Wavelets and Operators*. The translation covers the first volume of the three-volume French work (the other two volumes are the "et opérateurs" part, dealing with Calderón-Zygmund operators in their most recent and broadest incarnation and related developments). The book starts with an introductory chapter about Fourier series and integrals, pointing to wavelet precursors in the mathematical literature, and then proceeds to a discussion of multiresolution analysis (chapter 2) and the corresponding orthonormal wavelet bases in one and more dimensions (chapter 3). Chapter 4 contains a short discussion of nonorthogonal and redundant wavelet families in $L^2(\mathbb{R})$ (frames). The last two chapters contain a (sometimes terse) discussion of the many functional spaces where wavelets provide an unconditional basis. I recommend this book to every mathematically minded reader interested in wavelets; it is beautifully written, and the English translation is excellent, staying close to the original without feeling awkward. I found very few typos, and I like the typography better than that of the original—theorems are indicated in boldface now and so are easier to spot when leafing through the book. The reference list has been extended slightly and some references to works that had not yet been published when the French edition came out have been updated. The addition of an index is very useful.

Wavelets: Algorithms and Applications is meant for a much larger audience. The book grew out of a series of lectures presented to a varied group of scientists at the Spanish Institute in Madrid in 1991. Chapters 1 through 7 cover signal analysis, mathematics and vision, the use of subband filtering schemes to build wavelets, and different types of time-frequency analysis, with relevant historical background material. (One chapter discusses "Malvar's wavelets," which are not really wavelets at all but rather a new and much better version of the windowed Fourier transform that is due to Ronald Coifman and Meyer. Because a construction having some of its properties—though not the most interesting, the split-and-merge algorithm—had already

Vignettes: Mother and Child

Juveniles are innocent, are they not? Before answering, one really must watch a weanling monkey groom its mother's chest for several minutes, put her to sleep, and access "unapproved" time on the nipple.

—*Michael A. Pereira* and *Lynn A. Fairbanks*, in *Juvenile Primates: Life History, Development, and Behavior* (Oxford University Press)

Most mammals, and certainly chimpanzees, know their mothers, but there is no sign that they can generalize to mothers as a class, referring not only to "my mother" but also to "Pete's mother." That would be an elementary level; it would take a very much higher stage of reference before a hominid could say: "Watch out for Pete's mother; she'll stick her thumb in your eye."

—*William Howells*, in *Getting Here: The Story of Human Evolution* (Compass Press) been proposed by Henrique Malvar, Meyer, with typical modesty, named these functions Malvar's wavelets.) The last four chapters discuss some applications of wavelets to image analysis, fractals, turbulence, and astronomy, mentioning work in progress and referring the reader to the literature. In many respects the book is a personal view of the field, and others would no doubt have tackled the undertaking quite differently; this actually adds to the book's interest. There are still mathematical formulas on almost every page, so that I would not recommend the book to mathophobes, but I believe it is accessible to any scientifically minded reader with rudimentary knowledge of Fourier analysis; furthermore, the seasoned mathematician will find discussions of many interesting nonmathematical topics, so that the book is by no means superfluous for readers of the other book under review here. The translation is slightly less close to the original lecture notes, but that can be considered a plus, since a very close translation would not have captured the casual style of the notes. Some of the material has been revised and updated by the translator, Robert D. Ryan, in collaboration with Meyer. I noticed a few typos, and I guess Ryan is not a musician, since on page 6 of the English translation the reader is still told that "ré mineur" is a musical note. But these are minor blemishes, and I recommend the book as a delightful introduction to wavelets.

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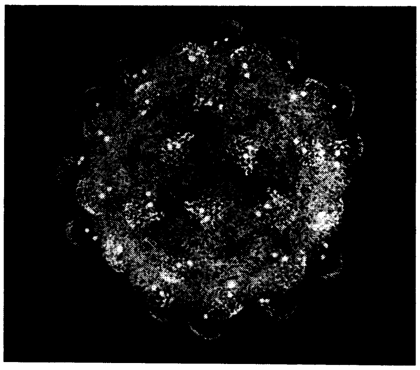
Cell-Mediated Immunity

Viruses and the Cellular Immune Response. D. BRIAN THOMAS, Ed. Dekker, New York, 1993. xviii, 524 pp., illus. $185.

In the past few years fundamental information concerning the recognition of viral antigens by receptors on $CD4^+$ and $CD8^+$ T lymphocytes has become available. Although much remains to be learned, as exemplified by our ignorance of the basic immunopathogenesis underlying HIV-1 infection, we now have a solid scientific basis for modeling cellular immune responses to virus infections, especially for viruses that induce diseases in mice.

With this book D. Brian Thomas has attempted to unify the current literature on cellular immunity to viruses, which he thinks is "fragmented," with cellular immunologists and virologists focusing on different aspects of the problem. I concur that most virologists are concerned with molecular aspects of antigenicity and viral replication and often consider neutralizing antibody to be the primary (if not the sole) determinant of immune protection. Likewise, as Thomas states, some cellular immunologists have concentrated on using virus systems to address basic questions of antigen processing and positive and negative selection of the T cell repertoire. Other immunologists, however, including some of the contributors to this book, have explored in fine detail the interactions between the infecting virus and the immune system of the host.



"Computer graphic representation of the crystal structure of [foot and mouth disease virus] serotype O1. The majority of the protein structure was clearly resolved by X-ray crystallographic techniques. However the G-H loop of VP1 (amino acids 136–159) was too disordered to produce meaningful electron density. The spaces potentially occupied by these 'invisible' regions are represented by clouds of dots." [From Francis and Rowlands's chapter in *Viruses and the Cellular Immune Response*; courtesy of David Stuart, University of Oxford]

The first few chapters provide an overview of some of the complexities of immune responses in the virus-infected host and of developing concepts of the processing of viral antigens for T cell receptor recognition. Following are useful reviews of the roles of dendritic cells and of the roles of cytokines in infectious diseases. The bulk of the book consists of detailed reviews of individual viruses, focusing on cell-mediated immunity. These provide a good beginning for the reader interested in learning about specific cellular immune responses. Particularly interesting are the chapters on the complex interactions of adenoviruses, cytomegalovirus (CMV), and Epstein-Barr virus (EBV) with the T cell responses of the infected host. It is clear that we need to learn more about how T cells control the polyclonal stimulation of B cells by EBV and why CMV causes fatal pneumonias in some transplant recipients and retinitis in AIDS patients. There are three chapters devoted to HIV-1, including a thorough review by Venet, Gomard, and Lévy of human T cell responses. The book concludes with a brief and insightful review by Allison of current vaccine development efforts incorporating concepts of $CD4^+$ and $CD8^+$ T cell responses as well as protective antibodies.

Not covered are class I–restricted $CD8^+$ cytolytic T lymphocyte responses to influenza A viruses and lymphocytic choriomeningitis virus, which have been fruitful for the study of cellular immune responses and immunopathology, and vaccinia virus, which was successfully used to eliminate smallpox. It might have been more appropriate to devote space to these important viruses and to omit coverage of some of the less-studied viruses.

Recent breakthroughs in the understanding of T cell receptor recognition of major histocompatibility complex (MHC)–peptide complexes by crystallography and the characterization of natural peptides that serve as epitopes for T cell receptors have been based on studies of virus-specific T cell clones and virus-infected cells. Although some of these accomplishments are carefully reflected in this book, others (for example, the definition of natural peptide epitopes on virus-infected cells) are not. In addition, the inclusion of color figures of some of the structures (for example, the MHC-peptide binding site, the influenza hemagglutinin molecule), would have helped the reader to better understand structure-function relationships. Despite these flaws, this is a useful reference book for anyone interested in learning more about cellular immune responses to viruses.

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Life and Computers

Artificial Intelligence and Molecular Biology. LAWRENCE HUNTER, Ed. AAAI, Menlo Park, CA, and MIT Press, Cambridge, MA, 1993. x, 470 pp., illus. Paper, $39.95 or £35.95.

Artificial intelligence (AI) comprises activities ranging from straightforward applied programming to the development of general theories of problem solving. Molecular biology is perhaps less broad, but is arguably equally ambitious as a discipline. In considering a book entitled *Artificial Intelligence and Molecular Biology* it is worth asking just what aspects of these two fields are covered, and for whom. Lawrence Hunter's collection of papers is surprisingly eclectic, both