BOOK REVIEWS

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A Breviary of Seismic Tomography: Imaging the Interior of the Earth and the Sun

Guust Nolet

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"The Earth is a laboratory, but one that is very different from those in experimental physics, where we are taught to carefully design an experiment so that we have full control."

This quote, taken from Chap. 14 of this book, reflects one of the main challenges seismologists are faced with in their quest for imaging Earth's interior using uncontrolled seismic waves observed by a sparse and irregular network of seismometers. Professor Guust Nolet, a leading scientist in the field of global seismology, has succeeded in writing a very readable treatise on the many aspects of imaging the interior of Earth and, albeit with less emphasis, the Sun. The book covers the underlying theory of seismic wave propagation and scattering, the practical aspects of seismic observations, and, last but not least, the theory and practice of modern seismic inversion and imaging methodologies. The existing approaches to imaging Earth's interior range from normal mode analysis to reflection and transmission tomography. The emphasis in this treatise is on seismic transmission tomography, a methodology related to medical x-ray and ultrasonic tomography, ocean acoustic tomography, and cross-well tomographic imaging in exploration geophysics. Some of the specific challenges of seismic tomography are related to the fact that the interior of Earth is inhomogeneous at many scales and to the already mentioned aspect of the "uncontrolled experiment." The author addresses these challenges with the authority of more than 25 years research experience in seismic tomography.

The book is written for seismic practitioners and students. The author has chosen for a somewhat informal style, with much more emphasis on physical explanation than on mathematical rigor. This is not to say that the mathematics is compromised, but only that the author has decided to limit the treatment of the underlying mathematics to what is needed for understanding the principles of seismic tomography. Readers interested in more extensive mathematical derivations are guided to the relevant literature. The physical explanations are often chosen from everyday life: once you have read the explanation why the sky is blue and clouds are white you will never forget the essential difference between Rayleigh and Mie scattering. What I consider very valuable in this book are the many exercises for students and, in particular, the references to software repositories, which help students improving their understanding of tomography and practitioners analyzing their data.

Let me further substantiate my appreciation of this book with a brief chapter-by-chapter discussion. The introductory chapter mentions a presentation by Keiti Aki at an AGU Conference in 1974, in which arrival times of seismic waves were interpreted in terms of an image, as the starting point of modern seismic tomography. This chapter further summarizes the early successes of seismic tomography with respect to geophysical discoveries, such as images of slabs subducting into the lower mantle and evidence of major low velocity regions near the core-mantle boundary, so-called superplumes. It concludes by mentioning that further improvement of the images requires a finite-frequency approach to tomography, accounting for the fact that arrival times are sensitive to perturbations within Fresnel zones around the rays.

Chapter 2 starts with the fundamentals of acoustic and elastodynamic wave theory and derives the differential equations for ray tracing in inhomogeneous isotropic Earth. It also contains a section on the corrections that are required for ray tracing in the Sun, where the flow of the medium plays a role. I like the fact that the author does not complicate things more than needed. For example, instead of giving a formal definition of correlation distance, he mentions in a footnote that "for the purpose of this book it is sufficient to define the correlation distance as the distance over which a parameter still looks smooth." Chapter 3 introduces several approaches to ray tracing, i.e., solving the differential equations derived in Chap. 2, and discusses aspects such as convergence and stability over long distances. The author alternates theory with everyday life examples, e.g., by explaining the shortest path method as finding the shortest route between road signs in a town. Chapters 4 and 5 conclude the fundamentals of the theory for acoustic and elastodyamic body waves with a discussion of first order wave scattering (the Born approximation) and an overview of amplitude effects, such as geometrical spreading, anelastic damping, and scattering loss.

Chapter 6 discusses the various aspects of travel time observation, such as the determination of onset times, wavelet estimation, and determination of differential times via cross-correlation. It also includes a brief discussion on the sliding transition point between signal and noise and the recent developments of retrieving Green's functions from the cross-correlation of ambient noise. The interpretation of travel times is discussed in Chap. 7. After an introduction on wave front healing due to finite frequencies, it is shown that travel times are affected by heterogeneities near the ray. The sensitivity to these heterogeneities is quantified by the so-called Fréchet kernel. Chapter 8 discusses the observation and interpretation of amplitudes along similar lines as the previous two chapters, including discussions on amplitude healing and amplitude Fréchet kernels.

Chapter 9 is dedicated to normal mode analysis. Since Earth is a finite body with a stress-free surface, the solution of the wave equation yields a discrete spectrum of eigenfrequencies. For very low frequencies, below 10 mHz, these frequencies are separated well enough to be measured and analyzed, leading to an estimate of the very long wavelength features of the Earth's interior. The models obtained by transmission tomography should match these features at the low frequency end of their spectrum.

The treatment of surface waves, the most prominent arrivals on a seismogram, is complicated because surface waves do not have clearly defined wave fronts, like body waves, nor do they exhibit a discrete spectrum, like normal modes. In Chaps. 10 and 11, the author deals with this "ray-mode duality," discusses how to measure the dispersion, and develops Fréchet kernels for finite frequency surface waves.

The following chapters address the various aspects related to the tomographic inversion itself. Chapter 12 deals with the art of model *parametrization*, i.e., finding the delicate balance between not imposing too much smoothness on the model, while allowing the data misfit to be sufficiently small and at the same time avoiding too much *overparametrization*. Parameters such as the ellipticity of Earth, surface topography, crustal thickness, and instrument response cannot be estimated from the data. Chapter 13 discusses how these parameters can be included as model corrections prior to inversion, assuming of course that *a priori* information on these parameters is available. Chapter 14 discusses the actual linear inversion. It reviews the basic aspects of maximum likelihood estimation, singular value decomposition, Bayesian inversion, and information theory. An inversion result only makes sense if one knows its limitations. Therefore, a chapter is dedicated to resolution and error analysis (Chap. 15).

In the first 15 chapters, Earth and the Sun were assumed to be isotropic. Chapter 16 discusses some of the modifications that are required to take anisotropy into account. In the final chapter (Chap. 17), the author looks ahead at promising new developments in imaging and observation, such as the analysis of multiple scattering, the application of non-linear inversion, and the strive toward global coverage of seismic sensors with programs like U.S. Array. The latter program involves a dense regular array of temporary seismic stations, moving across the continent of the United States from 2005 to 2015. This program constitutes an important step in the direction of "the Earth as a carefully designed experimental physics laboratory," and will contribute to obtaining sharper and more reliable images of the interior of our planet.

Being an exploration geophysicist, I was only moderately familiar with the methodologies applied in global seismology. This very readable and inspiring book has brought my knowledge and understanding of this very interesting research field to a higher level. To my opinion, this book should be on the shelves of every seismology student and every practitioner of global seismic tomography. Moreover, it may be a very useful source for researchers in other disciplines employing tomography, such as ultrasonics, ocean acoustics, and exploration geophysics.

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Springer Handbook of Speech Processing

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Speech technology has made great strides over the past 3 decades. Automatic speech recognition (ASR), text-to-speech synthesis, voice and language recognition, speech enhancement, and auditory prostheses have all matured during this interval. The *Springer Handbook of Speech Processing* describes many of the methods and practices used to accomplish these advances. It is a highly technical tome, with most of the 53 chapters laden with equations, illustrations, and tables. The quality of writing is excellent. The prose is clear, simple to understand, and succinct. The illustrations are professionally drawn and uniform in format and appearance. The volume has the look and feel of a professional textbook, an impressive feat given that 85 authors were involved. The Handbook would be well suited as a textbook for an advanced graduate-level course in speech technology and engineering.

A typical chapter begins by briefly summarizing its contents and providing a brief historical overview. More technical (i.e., mathematical) material follows. Many chapters conclude with a discussion of commercial applications as well as a brief summary. In short, the volume strives to strike a balance between the practical and the theoretical, and it usually succeeds.

The Handbook consists of nine sections: (1) Production, Perception and Modeling of Speech, (2) Signal Processing in Speech, (3) Speech Coding, (4) Text-to-Speech Synthesis, (5) Speech Recognition, (6) Speaker Recognition, (7) Language Recognition, (8) Speech Enhancement, and (9) Multichannel Speech Processing. A complete listing of chapter titles can be found at http://www.springer.com/engineering/signals/book/978-3-540-49125-5?detailsPage=toc. A particularly useful feature is the accompanying DVD, which contains a fully searchable electronic version (PDF format) of the Handbook. Its interface allows the reader to traverse the text in a highly intuitive way, making the book a pleasure to read in electronic form.

As with any book of this length and scope, some of the chapters are more successful than others in conveying the essence of a field. Particularly detailed and useful are the chapters on pitch extraction, speech synthesis, automatic speech recognition, and environmental robustness; many of these are definitive treatments and should prove useful for years to come. Particularly helpful is the detailed discussion of experimental and computational data, which serves to clarify and enhance the theoretical sections through concrete examples.

Perhaps the volume's greatest topical weakness is its scanty treatment of speech perception and production. An additional chapter or two on the neuroscience and cognition of spoken language (and its visual analog) would have been welcome. The chapter on commercial applications of automatic speech recognition is dated due to significant changes in the industry over the past 4 years.

Another weakness of the Handbook is its focus on the past and present, and relative neglect of the future. Only a few chapters discuss future trends in a meaningful way, the most notable example being "Towards Superhuman Speech Recognition," which provides a superb description of how ASR systems may function 10–20 years hence. Also lacking is a concerted attempt by the editors to link the chapters into an overarching theoretical framework. Given the book's broad scope, this is understandable. However, many readers will wonder what ties the chapters together other than a focus on speech technology.

Many of the authors (as well as the editors) have had a professional association with Bell Laboratories at some stage of his/her career. Fortunately, this slant generally enhances the Handbook's utility based on Bell Labs' distinguished research record. However, approaches pioneered at other institutions are also well represented.

The bibliography accompanying each chapter is extensive and comprehensive. Each citation in the electronic version is linked to the appropriate reference in the text, greatly facilitating its use. Occasionally, a chapter's bibliography is overly selective, reflecting the authors' particular point of view (e.g., the chapters on speech perception and nonlinear cochlear processing).

In summary, *The Springer Handbook of Speech Processing* is a first-rate production, providing a definitive treatment of the methods and techniques used in contemporary speech technology. Although its cost is high, the Handbook's superb quality and comprehensive treatment of highly technical material should prove an attractive investment for advanced students and speech engineering professionals.

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