Book Review

Probability Theory: The Logic of Science. By Edwin T. Jaynes (Edited by G. Larry Bretthorst). Cambridge University Press, Cambridge, UK, 2003, xxix + 727 pp., $60 (hardcover). ISBN 0-521-59271-2

Serious involvement of physics with probability began in the late 18th century, first with Daniel Bernoulli, and later with Laplace who applied it to the problem of separating a signal from the noise in planetary data. As Jaynes points out elsewhere, physicists have been properly handling noise in physics for centuries, long before there were statisticians. The later work of Maxwell and Boltzmann established probabilities as an intrinsic part of physical theory, and in the 20th century probability analyses became an essential tool for the experimentalist, most of it self taught. Appearing five years after the author's death, this book is in part a plea for physicists to put probability theory as logic back into the curriculum.

Edwin Jaynes spent much of a lifetime analyzing the role of probability in science and lobbying for Bayesian methods of analysis. By Bayesian he means the following: every probability is conditional on some kind of prior information, such that the probability $P(A|H)$ represents a measure of the plausibility of a proposition A given the hypothesis H; Bayes' theorem (captured in the symmetry of the product rule for probabilities) is a fundamental property of the theory; an ability to marginalize nuisance parameters; in application there is no 'statistical' theory, but only the elementary rules of probability applied carefully and adhered to rigorously. For him probability is simply an extension of logic as espoused by Pólya, but here quantified and focused on inductive inference as practiced daily by most scientists. Thus he sails under the flag of Laplace, Keynes, and Jeffreys, to which no doubt the name Jaynes will be added in the future. In the end he appears as neither a 'frequentist' nor a 'Bayesian', but a practitioner of logical reasoning from the basic rules of probability theory; the issue of 'subjective' or 'objective' probability is eschewed in favor of human logic.

The book consists of 22 chapters divided into two parts, along with three appendixes. The ten chapters of Part I on fundamental probability theory contain a broad range of elementary applications, which is a strong point of the entire work. After two chapters on plausible reasoning and derivation of the quantitative rules for manipulating probabilities, we encounter chapters entitled: Elementary sampling theory; Elementary hypothesis testing; Queer uses for probability theory; Elementary parameter estimation; The central, Gaussian or normal distribution; Sufficiency, ancillarity, and all that; Repetitive experiments: probability and frequency; and, Physics of 'random experiments.' These chapters could form a reasonable, but intense one-semester course at the advanced undergraduate or graduate levels in any science or mathematics curriculum. Part II is devoted to advanced applications, some of which are actually essential for a thorough grounding in the subject (such as that on the entropy principle). This part addresses what is normally called 'advanced statistics', but also contains a deep analysis of, and comparison with orthodox (*i.e.*, non-Bayesian) statistical methods and technical applications. Jaynes' original plan of the work was for two volumes, the second of which was to contain numerous detailed applications such as image reconstruction, antenna design, and statistical mechanics. He never got around to finishing these chapters and only that on Communication Theory appears here. The three appendixes discourse on other approaches to probability theory, mathematical formalities and style, and convolutions and cumulants. In this reviewer's opinion the lengthy Preface alone is worth a fair piece of the price of admission, which itself is quite reasonable.

This is a bit more than a book only on probability theory, in that it reflects the author's broad scientific and cultural interests. Throughout we are exposed to his philosophy of both science and applied mathematics, the latter reflecting a strong anti-Bourbakist stance. One learns a great deal of the history of both probability and the varied fields to which applications are made, among which are biology, economics, engineering, evolutionary theory, and physics. The book, or many of its parts, needs to be read more than once to appreciate much of the deep thinking that underlies it. But that task is quite palatable, since the writing is superb and has an unusually fluid quality.

Like other first-rate minds, Jaynes insisted on doing his own thinking, and this is reflected in the numerous and delightful vignettes, asides, and insights scattered throughout. These include the annotations accompanying many of the items in the References and Bibliography (which have been separated by the editor for technical reasons). Cherished myths and folklore come under continual scrutiny and are occasionally laid bare: in the simple example of drawing balls from an urn one is reminded how the result of a current draw can affect our *knowledge* about an earlier draw, even though it can't affect that earlier result; Karl Popper's assertion that theories can never be proved true, only false, is countered by the theory that life once existed on Mars, which requires discovery of only a single fossil to prove it true, but may never be proved false; Charles Misner's claim that one cannot have full confidence in a theory until its limits of validity are known is questioned by our confidence in momentum conservation, which exists because we know of no such limits; R.A. Fisher's maxim, 'let the data speak for themselves,' is often shown to be well off the mark in those situations where prior information is crucial to a problem. Many examples are given of the follies of randomization and of the belief that probabilities are physical entities.

For a work of this size the text is exceptionally clean and free of typos, a result both of the author's attention and the careful proofing of the final manuscript by several colleagues after his death. Nevertheless, there remain a few minor bugs that probably can be attributed to the author's inability to tidy up loose ends himself. For example, Bayes' theorem is at the heart of the message, yet it is not indexed; although its form is exhibited earlier and often, it's not identified as such until Chapter 4. One wonders why it wasn't introduced in Chapter 2 in connection with the product rule. In a footnote on p.353, and again on p.630, reference is made to the "entropy concentration theorem" (References: Jaynes, 1983), which ostensibly is given in Chapter 11; but it isn't there. Either he didn't get around to inserting it, or was ambivalent about its inclusion. In the end it doesn't matter, however, for he provides plenty of evidence in other ways for the concentration of entropies corresponding to the same constraints around the entropy maximum. Finally, a note for the publisher: for those of us whose eyesight is not what it used to be, the font size used for the footnotes is way too small!

I hasten to point out that this reviewer is not a completely unbiased observer here, as is evidenced in both the Forward and the Preface. Ed Jaynes was a longtime friend and colleague whose penetrating thought influenced many of us. Therefore I have tried to provide just an overview here without arguing one way or the other for the author's views on many matters. Various partial drafts of the manuscript have been on the Internet for a number of years in any event, thereby acquainting hundreds of people with those views; but many others in all scientific fields would also be well served by making their acquaintance. It does occur to me, though, that for anyone stranded on that proverbial desert island, and more or less prepared in the way the author expects in the Preface, this may be that one book you'd like to have with you; at the very least it will keep you focused on sound reasoning about that and many other situations.

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