but definitely not all—scientists. Oddly, Churchland appears to adopt the "just the facts" mindset of those scientists who are impatient with the more conceptual and foundational issues in their fields.

Here is an example of the kind of issue I am talking about. There has been a vigorous debate among both psychologists and philosophers about whether mental images represent in the manner of pictures (Kosslyn) or in the manner of sentences (Pylyshyn), and the discussion of this issue has involved conceptual issues about representation that link up to long-standing philosophical literature. Although Churchland devotes an entire chapter to how the brain represents, this issue does not come up.

Churchland's impatience with foundational issues also extends to conceptual issues more closely connected to the big problems. For example, anti-innatists have argued that no phenotypic characteristic can be genetically determined, because there is always some environmental feature (even within the womb) in which the phenotypic characteristic would not develop (e.g., as demonstrated in imprinting in chicks). The innatists say that although every phenotypic characteristic is produced by a complex gene-environment interaction, in some cases when we ask where a certain phenotypic informational structure comes from, the best answer is "from the genes." This is the classic "poverty of the stimulus" argument. Churchland has a section on innateness, but instead of grappling with this conceptual issue, she confines herself to describing the complexity of the gene-environment interaction. Lastly, in her discussion of consciousness, Churchland takes theories that see experiential consciousness as a kind of brain activation and theories that see the essence of consciousness in terms of higher order cognitive states as rivals. But many philosophers have suggested that such theories may be talking about consciousness in different senses of the term: experience is one thing and experience accompanied by higher order cognition is another. One would think a philosophical treatment of the relation between these theories would at least discuss this possibility, if only to dismiss it.

*Brain-Wise* makes many excellent methodological points and has some interesting and sensible things to say about the big problems of philosophy. Unfortunately, Churchland, despite her militantly interdisciplinary views, approaches many conceptual issues in the sciences of the mind like the more antiphilosophical of scientists.

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MATHEMATICS

# A Polemic on Probability

**Andrew H. Jaffe**

What is probability? This question has long puzzled scientists (who must make inferences based on inexact data) as well as philosophers like Karl Popper and polymaths like John Maynard Keynes. In *Probability Theory: The Logic of Science*, Edwin Jaynes provides an answer and works out its repercussions for scientists confronted with data from their experiments and observations. Jaynes is a Bayesian: he holds that probabilities encode degrees of belief and do not exist except as a representation of information about the world. For some, this position means that a Bayesian view of probability is hopelessly, fatally subjective—"unscientific."


**Probability Theory**
**The Logic of Science**

*by E. T. Jaynes. G. Larry Bretthorst, Ed.*

Cambridge University Press, New York, 2003. 757 pp., $60, £45. ISBN 0-521-59271-2.


An important theme reiterated throughout the book is the distinction between frequencies, which may be objective experimental results, and probabilities, which are assigned based on experimental and theoretical information. Jaynes makes the case (correctly, I think) that rather than worrying about subjectivity, we need to think of probabilities as irrevocably conditional: they can only be assigned based on information. The probability ($P$) of some proposition ($A$) depends on background information ($I$) and is given by $P(A|I)$. Objectivity arises from the requirement that the same information $I$ will lead to the same probability assignment and thus the same inference.

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The distinction between Bayesian and orthodox interpretations of probability can be understood by considering a simple scientific result: How does one interpret the statement that the expansion rate of the universe, the Hubble constant, is $H_0 = 72 \pm 3$ kilometers per second per megaparsec? Most of us would read the expression as saying that the constant is near 72, with 3 as some sort of measurement of the uncertainty. If Bayesian methods are used, this is indeed the correct interpretation. However, if orthodox frequentist methods have been used to derive these results, they must be interpreted differently: Here they would mean that if the actual value of $H_0$ were 72, in some ensemble of repeated experiments—which may not even be possible in a cosmological context—some given fraction (68% or 95%, for example) of the results would lie in this range. Nonetheless, even scientists with an orthodox statistical education are closeted Bayesians and usually interpret these statements in the Bayesian sense (perhaps even while demanding such non-Bayesian properties as unbiasedness and optimality for our estimates). In addition, the Bayesian interpretation of probability is a model for learning: the output from one experiment (the posterior probability), can be used as input (the prior probability) in the next. The frequentist methodology does not allow this bootstrapping from previous data, except in some special cases.

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**Advocate for an unorthodox statistics.** Jaynes's approach to probability theory was both sparked and greatly influenced by the statistical and philosophical work of the geophysicist Harold Jeffreys.

Jaynes makes his case for the Bayesian interpretation by showing that the usual laws of probability are the unique extension of Aristotelian (true-false) logic to conditions of uncertainty. The upshot of this is Bayes's famous theorem: the posterior probability (the probability of a parameter given the data) is proportional to the prior probability (the probability in the absence of the data) times the likelihood (the probability of the data given the parameter). Much of the book is then devoted to considerations of the use of probability theory to test hypotheses and estimate parameters, in which Jaynes examines how we apply new data to update our understanding of the underlying theories—the most important use of probability theory.

Jaynes also spends considerable effort discussing the assignment of probabilities, using such approaches as maximum entropy and his "group invariance" techniques. These methods are far from universally applicable. Although the author implies that good experiments have data that overwhelm the prior probabilities, this is not always true in real-world problems. Nonetheless, at least Bayesian techniques are honest in explicitly acknowledging their dependence on external information. In a self-contained pair of chapters, Jaynes delves into decision theory, which deserves to be better known among scientists; unfortunately he does not pursue that topic further.

*Probability Theory* is a posthumous work, collated by Jaynes's former student Larry Bretthorst. Much of the book has been available as internet samizdat for the last decade. Although Bretthorst, in his introduction, explains his decision to leave the book in this essentially unfinished form, it would have benefited from a less reverent editor. Many of the chapters start with tantalizing ideas but then do not quite work them out in full or provide sufficiently detailed examples. For instance, Jaynes outlines the formalism of the Bayesian approach to comparing models, which is used in circumstances similar to more traditional goodness-of-fit tests to choose among theories rather than simply estimate the parameters applicable to a single theory. This is one of the most useful and least familiar applications of Bayesian theory, but the book abandons the topic without completing any truly illustrative cases. Readers desiring more worked examples might consider Devinder Sivia's *Data Analysis: A Bayesian Tutorial* (Clarendon Press, Oxford, 1996), which reflects a similar philosophy.

The book also exhibits some smaller problems, most of which are traceable to inadequate editing. For example, Jaynes provides a derivation (within a slightly idiosyncratic context) of de Finetti's famous "representation theorem." Unfortunately, when he does so he does not refer to the theorem by name, which makes references to it elsewhere in the text confusing to the uninitiated. In addition, the index is woefully inadequate, and the text contains some obvious typos and notational inconsistencies.

More than a textbook, *Probability Theory* is a polemic. Jaynes vents several decades of built-up spleen for perceived ridicule at the hands of the orthodox statistical community, and he decries the general state of research in mathematics and statistics. He devotes several entire chapters to rubbishing orthodox frequentist statistics and a few of its individual practitioners. Still, he does accord a grudging respect to some, as when he notes that "since we disagree with Feller so often on conceptual issues, we are glad to be able to agree with him on nearly all technical ones." At least one of his other (more impersonal) attacks is simply off the mark. He denigrates the use of Monte Carlo techniques, stating "whenever there is a randomized way of doing something, there is a nonrandomized way that yields better results, but requires more thinking." This is especially ironic because it is the recent advent of Monte Carlo Markov Chains as tools for exploring distributions that has been responsible for much of the ascendancy of Bayesian methods.

Overall, Jaynes's curmudgeonly outlook makes *Probability Theory* considerably more entertaining reading than the average statistics textbook. (Admittedly, the bar here is not very high.) More important, the conceptual points that underlie his attacks are often right on.

## BROWSINGS

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**Digital Art.** *Christiane Paul*. Thames and Hudson, New York, 2003. 224 pp. Paper, $14.95, C$23. ISBN 0-500-20367-9. World of Art.

Digital technologies have reshaped both the production and experience of contemporary art. In some cases—such as Dieter Huber's 1997 photograph *Clone #76* (left)—the technologies are used to produce traditional forms of art. In others, they provide a medium for the creation of new artistic practices, including virtual reality, digital installation, software art, and net art. Paul covers both approaches in her discussions of key artists and works. She also delves into viewer interaction, artificial life, social activism, telepresence, and other topics raised by the art as well as issues such as the presentation, collection, and preservation of digital works.

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