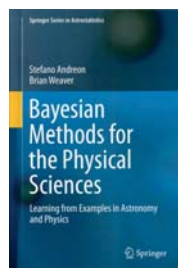


Bayesian Methods for the Physical Sciences

Learning from Examples in Astronomy and Physics

Stefano Andreon and Brian Weaver

Springer, 2015. \$109.00 (238 pp.). ISBN 978-3-319-15286-8



Most of today's experimental physicists require computational data-analysis methods that can handle an enormous volume of data and still deliver the most precise results possible given the experimental design. That necessity has led to recent textbooks that attempt to go beyond the standard pathway of "learn what you need, as you need it, from the folklore of the discipline" and that cover probabilistic reasoning, an increasingly important subject. Done right, such a textbook could be used in a Computational Data Analysis for Physicists course to be taught alongside courses on electromagnetism, quantum mechanics, and general relativity.

One of the latest additions to that genre is *Bayesian Methods for the Physical Sciences: Learning from Examples in Astronomy and Physics* by Stefano Andreon and Brian Weaver. Others included in the growing category are *Statistics, Data Mining, and Machine Learning in Astronomy: A Practical Python Guide for the Analysis of Survey Data* (Princeton University Press, 2014) by Željko Ivezić, Andrew Connolly, Jacob VanderPlas, and Alexander Gray; *Data Analysis: A Bayesian Tutorial* (2nd edition, Oxford University Press, 2006) by Devinderjit Sivia and John Skilling; and *Information Theory, Inference, and Learning Algorithms* (Cambridge University Press, 2003) by the late David MacKay. I don't think any of those books is a perfect companion for the proposed course, but I do think that Andreon and Weaver—a statistically sophisticated astronomer and a statistician working in engineering and physics, respectively—have written a book that could be a valuable component in the new Computational Data Analysis course.

In the Bayesian approach, the rules of probability are applied to beliefs about parameters. In contrast, in the frequentist approach, the rules are applied exclusively to the generation of the data. One advantage of Bayesian reasoning,

which comes at the cost of having to make additional assumptions, is the ability to perform integrals over parameters and determine their expectation values. The most significant consequence is the ability to do integrals to remove nuisance parameters. Of primary importance to both approaches is the so-called likelihood function: For a Bayesian, the function helps update beliefs; for the frequentist, it is used to construct optimal estimators.

Bayesian Methods for the Physical Sciences begins with basic probability calculus and introduces complex models and concepts as it goes along. The book has the great virtue of relating methodology to the objectives of the experimenter, and it explicitly discusses situations where that key step can be and has been done incorrectly. Most of the content is presented through real-world examples that could easily be adopted or adapted to new tasks.

My biggest complaints about the book concern what's missing. Beyond the introductory chapters, the authors rarely mention the likelihood function explicitly. Even in chapter 8, which covers a large range of important considerations in building sophisticated data models, the function appears only implicitly. I would love to have seen a clearer link between the technically subjective assumptions by the data analyst and the mathematical operations in the likelihood function.

Also missing are lessons on diagnosing when a data analysis is going off the rails and on locating and fixing the bugs. Diagnosis and testing are notoriously hard to teach, but it would be nice to see an attempt, since they are among the core skills of the data scientist. Among a few other minor complaints is the omission of an index, which would help readers locate the initial use and definition of obscure terminology.

Perhaps the best feature about *Bayesian Methods for the Physical Sciences*—and

it is an extremely important one—is its use of real-world data sets and contemporary research questions (albeit heavily weighted toward astrophysics and astronomy). The use of realistic illustrative problems instead of toy models is refreshing. In describing the models and performing calculations, the book makes heavy use of the JAGS (Just another Gibbs Sampler) statistical package and so effectively provides a strong endorsement of JAGS. Tying the book to a single package has its disadvantages, but the big advantage is that the models are unambiguous and the results reproducible—and therefore adoptable and reusable.

That a textbook on computational data analysis contains reproducible code and real data sets is something we should require for all textbooks in this new—and critical—component of the physics curriculum.

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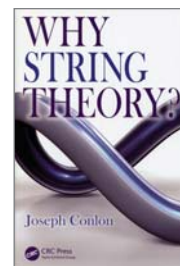
Why String Theory?

Joseph Conlon

CRC Press, 2015. \$29.95 paper (248 pp.). ISBN 978-1-4822-4247-8

String theory is among the most ambitious and elaborate theoretical frameworks ever conceived. Even the theory's most skeptical critics would not deny its mathematical elegance. But skeptics do question its relevance to our physical world. In his delightful little book *Why String Theory?*, theoretical physicist Joseph Conlon takes up that question. In laying out his arguments, he also ventures onto a road less taken by touching on the sociology of string theory, and not just its scientific merits.

Conlon's book begins with a whirlwind tour of the great advances in physics prior to string theory. The theoretical jigsaw puzzle mapped out by the giants in physics remained, near the end of the 20th century, an unfinished one with several large and crucial pieces missing. Those gaps in our understanding of nature called for a critical rethinking of



the principles that govern the universe.

String theory is a part of that critical assessment. After his introductory section, Conlon goes on to describe what string theory was and the twists and turns that shaped the theory into what it is today. Originally proposed in the 1960s as a theory of the strong interaction, string theory has evolved to become “a magnificent theoretical framework that interrelates a very wide range of topics in physics and mathematics,” according to Michael Green, one of the theory’s founding fathers. String theory describes not just the strong force and quantum gravity, but a whole lot more.

The next few chapters, devoted to the theory’s successes, are fast-paced and not overloaded with detail. Conlon does an excellent job of captivating his readers and sparking them to appreciate the marvels of modern string theory. He first discusses how the advent of the anti-de Sitter/conformal field theory (AdS/CFT) correspondence offers a new way to attack vexing problems in strongly coupled quantum field theo-

ries, such as those describing strongly correlated condensed-matter systems or the quark–gluon plasma, a novel state of matter that exists at extreme temperature or density.

The author then turns to physics and mathematics, which, as he stresses, have had a long and healthy marriage. String theory spices up that marriage by converting physical intuition into new groundbreaking areas of research in mathematics. One example is mirror symmetry, in which two different geometric spaces known as Calabi–Yau manifolds can be used to describe the same phenomenon. Through string theoretical insight, difficult computations for a Calabi–Yau manifold can be transformed into easy problems for its mirror dual. Conlon also discusses how string theory not only relates to known ideas and scenarios in particle physics and cosmology but also suggests novel ways to go beyond them.

As an active practitioner making those connections, Conlon gives a firsthand account of the research that eluci-

dates the potential experimental consequences of moduli and axion-like particles—features that arise generically in string theory when relating the 10- or 11-dimensional theory to our 4-dimensional world. String theory is, moreover, the prime candidate for a quantum theory of gravity, a status that was sealed by its microscopic account of black hole entropy. All those successes taken together have led many to believe that string theory is not only a mathematical curiosity but also highly relevant to our physical universe.

Despite its remarkable successes, string theory has a tendency to inspire some strong emotion. It is not uncommon to hear “If you cannot test string theory directly, how do you know it is right? And if you do not know it is right, and you will not know anytime soon, why do so many of you work on it?” Such questions are raised not only by critics in the scientific community but also by curious members of the general public who are excited about the fundamental laws of physics. The author care-

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fully dissects those questions and offers his honest, thoughtful responses. Instead of forcing his conclusions on the reader, he presents a set of compelling arguments for the value of string theory while acknowledging its weaknesses and open challenges. Like courtroom juries, readers are encouraged to draw their own logical conclusions.

A physicist colleague once remarked to me, "There is rarely any doubt about the existence of dinosaurs, although almost certainly no humans were alive 65 million years ago to observe the extinction." Like paleontologists finding evidence for ancient life, string theorists work to tease out subtle signals from nature even though direct experimental verifications are currently out of reach. Conlon writes with flair and wit to give a lively account of the struggles and joys of theoretical physicists seeking to uncover the inner workings of a beautiful, wide-ranging theory.

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The Physics of Ettore Majorana

Theoretical, Mathematical, and Phenomenological

Salvatore Esposito

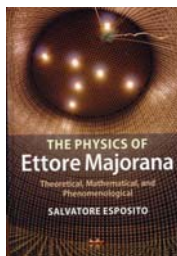
Cambridge U. Press, 2015. \$85.00
(382 pp.). ISBN 978-1-107-04402-9

When Paul Dirac proposed what we now call the Dirac equation, he apparently had gone through a dozen alternatives, which he discarded, even from his filing cabinet. To this day no one knows why he chose the simplest construction rather than the most obvious one or, indeed, any of the others that ended up filling his wastebasket. It is extraordinary that he even stumbled on his final formulation, simple and beautiful as it was, given that it was so far removed from the prevalent mathematics of his day, and also so full of physical oddities.

About a decade after the 1928 publi-

cation of the Dirac equation, the quirky Sicilian genius Ettore Majorana published a variation whose wavefunction solutions—Majorana fermions—are real. The truth is that Dirac's equation is bizarre, and plenty of alternatives existed even after Dirac's publication. The alternatives are in a way more curious. That some of them made it into the mainstream of physics—after originally being badly misinterpreted—just goes to show the inherent anarchy of the process of producing new science.

If you find this sort of thing interesting, you will love *The Physics of Ettore Majorana: Theoretical, Mathematical, and Phenomenological*, in which author Salvatore Esposito delves deep into Majorana's notebooks and published work. The book goes back to the time when relativistic quantum mechanics, quantum field theory, and particle physics were still embryonic. To read about the hits and misses, the clashes, the missed opportunities, the tensions between



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