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Book Reviews

BOOK REVIEWS

The greatest challenge of this job is to find just the right reviewer for each book. Personal contacts get one only so far; I know lots of people in or near my own research area, but not so many in the larger applied mathematics community. So where do I look for reviewers? The Internet, of course! By searching the web I can find lots of names. But this approach has a drawback: the names I am most likely to find are those of very senior people, who are often too busy to write a review. Up-and-coming younger workers, who might have the time and might benefit from the exposure, are much less visible. I would like to find you.

Writing book reviews can be fun and rewarding. You spend some time with the book, get to know it well, then try to write something interesting and informative for the community. This is not a waste of time. You will surely learn something in the process. Moreover, if you write good reviews, they will be noticed.

If you (young *or* old) think that you would like to try your hand at writing reviews, please let me know (or contact one of the other members of the editorial board). Send me an email or introduce yourself at a meeting. Tell me (preferably in not too much detail) what interests you; perhaps I'll be able to find something for you.

In this issue we are pleased to offer you a timely review by Nick Trefethen of a large tome that is scheduled to appear this month, namely, *The Princeton Companion to Applied Mathematics*, edited by Nicholas J. Higham. This ambitious project is in the same spirit and style as *The Princeton Companion to Mathematics*, edited by Timothy Gowers, which appeared seven years ago. I hope you enjoy Nick's review.

In addition we have reviews of books on a wide variety of topics, including numerical linear algebra, risk and portfolio analysis, stochastic chemical kinetics, quantum mechanics, and computational complexity theory.

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Book Reviews

Edited by David S. Watkins

Featured Review: The Princeton Companion to Applied Mathematics. *Edited by Nicholas J. Higham.* Princeton University Press, Princeton, NJ, 2015. xx+988 pp., hardcover. ISBN 978-0-6911-5039-0.

What is applied mathematics? How does it relate to pure mathematics, or should we simply say, to mathematics? With the appearance of the *Princeton Companion to Applied Mathematics*, we have two magnificent data points, 1000 pages each, to help us reflect on these questions.

The first thing one feels on looking at this volume is, quite simply, pleasure. Seven years ago *The Princeton Companion to Mathematics* was published to wide acclaim, and it was clear that a similar work on applied mathematics might be a good idea. Now it has appeared. The look and feel are the same, and this is highly satisfying. Figure 1 shows maps of the two volumes, which I will have more to say about in a moment. In each case the editors divided the collection into eight parts featuring pieces of differing lengths and flavors. The formatting and the typesetting are closely matched, and the new *Companion* is a perfect companion to the earlier one.

PCM was masterminded by Timothy Gowers of the University of Cambridge, and *PCAM* has been created by Nick Higham of the University of Manchester. These must be two of the most capable editors on earth. Anyone who knows Gowers and Higham will be aware of their combination of broad mathematical vision with phenomenal attention to detail. Higham, the Richardson Professor of Applied Mathematics at Manchester and a Fellow of the Royal Society, is celebrated not just for his research in numerical analysis but also for his outreach activities, including his *Handbook of Writing for the Mathematical Sciences*, the *MATLAB Guide* (coauthored with brother Des), and his blog. Like Gowers, he is a leader who cares deeply about his field. Princeton's appointment of him as editor was the perfect choice.

Of course, it takes a village. Like *PCM* before it, *PCAM* has a board of associate editors who helped shape the volume and contributed some of the articles: Mark Dennis, Paul Glendinning, Paul Martin, Fadil Santosa, and Jared Tanner. (I am pleased to note that five of the six editors are connected with England.) It has 165 authors, experts in their topics, many of them very eminent. A key person in the back office was Sam Clark of T&T Productions Ltd, who as project manager for both *PCM* and *PCAM* was involved in all the details and deserves much of the credit for making them such a comfortable pair.

So, what can you do with a book so big that its weight is measured in kilograms? With a million words of first-rate applied mathematics?

One possibility is to read it cover to cover. I more or less did that, but I doubt you will. (I did it as much to learn about myself as to learn about applied mathematics, which brings us to our first difference between mathematics and applied mathematics. I could not have read *PCM* cover to cover.)

Publishers are invited to send books for review to Book Reviews Editor, SIAM, 3600 *Market St.,* 6th *Floor, Philadelphia, PA* 19104-2688.

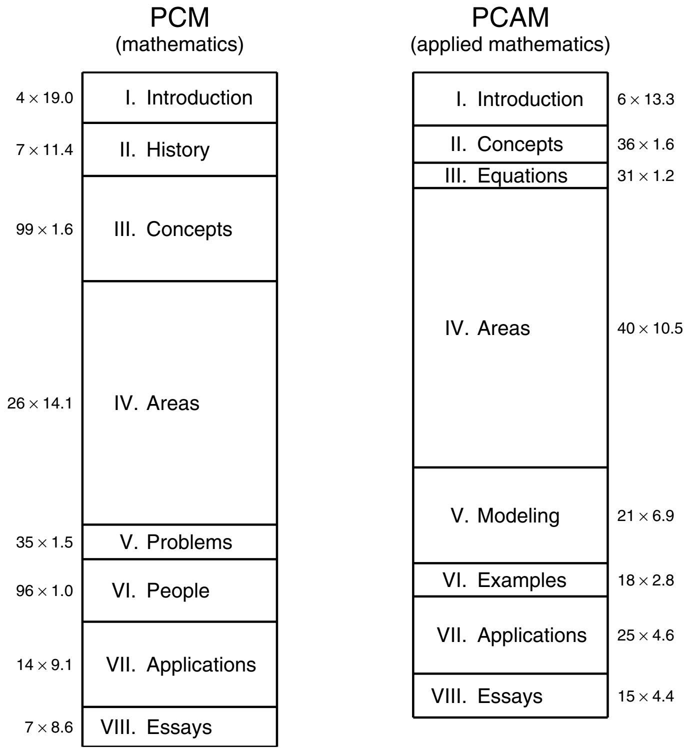

Fig. 1 *The eight parts of the two Princeton* Companions*, with shortened names. Annotations indicate numbers and average lengths of articles. For example,* PCAM *has* 18 *articles in Part VI, on Example Problems, and their average length is* 2.8 *pages.*

Another approach is to dip in and out at whim, as Higham et al. encourage.

> *Despite the careful organization, the editors expect that many readers will flick through the book to find something interesting, start reading, and by following cross-references navigate the book in an unpredictable fashion. This approach is perfectly reasonable.*

You bet it's reasonable! Your eye will be caught by Barbara Keyfitz on conservation laws, by Berry and Howls on divergent series, or by Jane Wang on insect flight. Maybe by Phil Holmes on dynamical systems, or Jack Dongarra on high-performance computing, or Andreas Griewank on automatic differentiation. The treasures go on and on.

I loved some of the accounts of things I hadn't known about. Ken Golden on the mathematics of sea ice, showing us how percolation theory applies to actual percolation—fascinating. Villani and Mouhot's article on kinetic theory—idiosyncratic and thoughtful, including a summary of 50 important papers in the field from 1912 to 2013. Donald Saari's beautifully simple explanation of why physicists believe the universe is full of dark matter. Doug Arnold's flight of a golf ball, a perfect example of how, by focusing on something small, we can see things that are big.

A third approach to this book is to use it for reference on smaller subjects or serious learning of bigger ones. I think the potential here is very great. All of us have areas we've touched upon but not immersed ourselves in properly, and some of these pieces offer outstanding opportunities for taking that next step. For example, I was grabbed by David Tong's article on classical mechanics, whose clarity is illustrated by its opening lines.

> *Classical mechanics is an ambitious subject. Its purpose is to predict the future and reconstruct the past, to determine the history of every particle in the universe.*

There are dozens of truly deep and expert survey articles in *PCAM,* such as Brian Davies on spectral theory, Stephen Wright on continuous optimization, Hairer and Lubich on the numerical solution of ODEs, David Griffiths on quantum mechanics, and Emily Shuckburgh on the dynamics of the Earth's ocean and atmosphere. Graduate students and established researchers will be profitably reading these articles for many years.

But *eight parts*?? What's going on here?

Those of us of a certain age remember when the *Encyclopedia Britannica* raised eyebrows with its 15th edition in the 1970s. Instead of the traditional flat collection of articles, they brought out 28 volumes divided into the *Propedia,* the *Macropedia*, and the *Micropedia*. Was this controversial organizational principle a success?

If you take a look at the eight parts of *PCAM,* charted in Figure 1, the presence of some of them seems self-explanatory. Of course there is going to be an Introduction to Applied Mathematics, which here consists of six articles on foundational material. (Five are by Higham, with a generally numerical viewpoint, but this lack of diversity in the opening 55 pages is unrepresentative. Overall the book is very balanced, not at all dominated by numerics.) And following *PCM's* successful model, it is satisfying to find a final Part VIII of Final Perspectives. This assortment begins with opinion pieces by Gowers and Higham themselves and moves on to Ian Stewart, David Donoho and Victoria Stodden, David Bailey and Jonathan Borwein, Heather Mendick, David Acheson, Peter Turner, Gil Strang, Rachel Levy, Ya-xiang Yuan, Maria Esteban, Jim Crowley, and Alistair Fitt. One of my favorites is Stewart's zestful essay on "How to Write a General Interest Mathematics Book."

> *I have called mathematics the Cinderella science. It does all the hard work but never gets to go to the ball.*

PCAM's organizational confusion lies in the middle 800 pages, Parts II to VII, which are devoted to Concepts, Equations, Areas, Modeling, Examples, and Applications. Though one can only admire the impulse to classify, I am afraid it is very difficult to keep these six headings straight. Why is Benford's Law an Equation and the traveling salesman problem an Example? Why does modern optics belong to Modeling and control theory to Areas of Applied Mathematics? It all feels rather arbitrary.

Naturally you get curious and wonder, were the middle six parts of the earlier *PCM* equally hard to keep straight? On inspection it turns out that no, they were not, because three of them had specially memorable themes. Part II was on history, a category that *PCAM* does not repeat. Part VI was on mathematicians, 96 one-page mini-biographies from Pythagoras to Bourbaki, which *PCAM* also does not repeat. (Too many of the best applied mathematicians had already been covered as mathematicians, I suspect, though Bourbaki, I hasten to add, was certainly not applied, quite apart from the question of existence.) And Part VII of the original *Companion* was also special, being devoted to applications ("The Influence of Mathematics"). Perplexingly, this is a category that *PCAM does* repeat, giving us effectively Applications of Applied Mathematics. (One muses about GNU's Not Unix and turtles all the way down.)

So the organization of *PCAM* is unconvincing, and Princeton could have maintained the *PCM* look and feel with five parts instead of eight, but to tell the truth, it doesn't matter. No *Britannica* reader worried much about the *Propedia* back in the 1970s, and nobody's going to lose sleep over *PCAM's* structure today. The gold is in the individual pieces, not their organization.

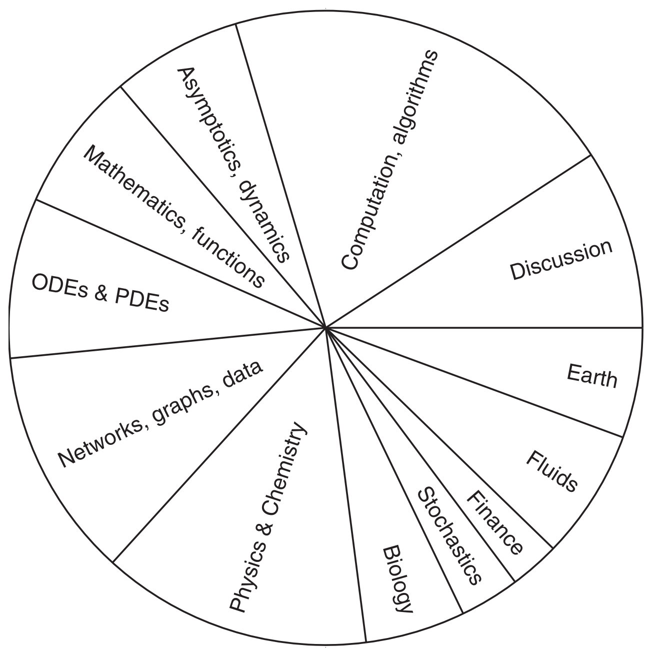

Fig. 2 *Rough breakdown of the pages of* PCAM.

Which brings us back to our opening question. What is applied mathematics? What view of the field does *PCAM* convey? To explore these matters it may be helpful to consider Figure 2, which outlines roughly where *PCAM* spends its pages.

One thing you notice is that there is a lot of physics and fluid mechanics here. These are the oldest, best established parts of applied mathematics, as important as ever, and their strength is powerfully displayed in articles on magnetohydrodynamics, quantum mechanics, optics, gravitation, and many other topics. Newer fields like finance, network theory, and biology are also well represented, although one can't help noting that whereas an article on a physics topic like kinetic theory or solid mechanics, say, will most likely be found in Areas of Applied Mathematics, a biological topic like physiology or biomechanics is more likely to appear in Modeling. It would seem that applied mathematics has terrain it has conquered and terrain it is still exploring. A century from now, will the boundaries have shifted?

It is striking that applied mathematics as displayed in *PCAM* does not define itself by its relationship to (pure?) mathematics, not at all. The book robustly stands on its own, and the proverbial Martian, if he stepped out of his flying saucer and read this volume of mathematics, would not suspect that earthlings knew any other kind.

PCAM shows us that applied mathematics is *vast* and it is *confident*. We see here a discipline engaged in every corner of the human enterprise, from cosmology to the spread of infectious diseases, from pattern formation to aircraft design, from financial portfolio optimization to the ranking of movie preferences. As Strang writes, "Our subject is extremely large!"

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Numerical Linear Algebra with Applications: Using MATLAB. *By William Ford.* Academic Press, San Diego, CA, 2015. $120.00. xxvi+628 pp., hardcover. ISBN 978-0-12-394435-1.

Numerical linear algebra is a course often offered to upper-level undergraduates or early graduate students from a variety of fields, including mathematics and computer science as well as engineering and physical science disciplines. Compared to the other available texts on this subject, this book is meant to be "an entry point" to encyclopedic treatments like Golub and Van Loan's [2] or Higham's [3] as well as to more advanced texts like Demmel's [1] or Trefethen and Bau's [4]. Ford's approach is more closely aligned with Trefethen and Bau's focus on mathematical foundations over Demmel's consideration of efficiency of algorithms and implementations.

An important distinction of this book is the inclusion of the first six chapters on (nonnumerical) linear algebra. One intended audience comprises engineers and scientists who do not have the mathematical background typically supplied by an undergraduate course in linear algebra; the first section of the book is aimed at bringing those readers up to speed before delving into numerical computations. While I appreciate the convenience of having useful background material in the same book (as opposed to referencing a separate linear algebra text), I would like the author to have done more to integrate numerical ideas into the first six chapters. Forward pointers and other references to (the exciting!) numerical ideas to come later could better motivate the material, instead of presenting the ideas more as a stand-alone primer.

The material is fairly comprehensive, spanning nearly the same set of topics as the advanced textbooks [1, 4], but the presentation is certainly gentler. Aside from the initial linear algebra refresher chapters, the book is organized like most others on the topic. It is roughly divided into the following six sections (each given more or less equal weight): introduction to (nonnumerical) linear algebra, introduction to numerical algorithms, solving linear systems (LU factorization and its variants), solving least squares problems (with QR decompositions and the SVD), computing eigenvalue decompositions, and iterative methods. Much more time and space is spent on presenting concrete examples than on in-depth topics; for example, Cholesky decomposition is presented with multiple examples including MATLAB input and output, but the reader is referred elsewhere for the proof of the backwards stability.

Perhaps the biggest gap is a lack of information about available software. Just as the mathematical foundations of linear algebra are well established, algorithms and techniques for achieving high performance in matrix computations are also mature. Software libraries for linear algebra have been evolving with computer architectures, and it's important for engineers and scientists to be aware of the general-purpose, efficient, and up-to-date software already available so they don't waste time reinventing the wheel (or more likely, failing to do so).

I think the ideal reader is a scientist or engineer who takes a class based on this book and then uses it as a reference later in his or her career. It is an accessible introduction to the fundamental matrix computations, particularly to students lacking some of the mathematical background. While a single course is not sufficient to cover the breadth of material, the reader can later revisit sections in order to brush up on the standard techniques for solving the problems of interest and find pointers to more details and information about software in the literature.

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[3] N. J. Higham, *Accuracy and Stability of Numerical Algorithms*, 2nd ed., SIAM, Philadelphia, 2002.

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Risk and Portfolio Analysis: Principles and Methods. *By Henrik Hult, Filip Lindskog, Ola Hammarlid, and Carl Johan Rehn.* Springer, New York, 2012. \$79.95. xiv+338 pp., hardcover. IBSN 978-1-4614-4102-1.

Investment and risk management problems are fundamental problems for financial institutions. A structured approach to these problems naturally leads one to the field of applied mathematics and statistics in order to translate subjective probability beliefs and attitudes toward risk and reward into actual decisions. These fields of applied mathematics and statistics form a natural basis for quantitatively analyzing the consequences of different investment and risk management decisions. Finance being largely a behavioral science, financial decisions strongly depend on subjective probabilities of the future values of financial instruments and investment choices. As such, financial decisions are often suboptimal, making it even difficult to specify a criterion for a desired trade-off between risk and potential reward in an investment situation. Applied mathematics and statistics can, however, assist in translating a probability distribution and an attitude toward risk and reward into a portfolio choice in a consistent way.

This book presents sound principles and useful methods for making investment and risk management decisions using standard principles, methods, and models. The authors combine useful practical insights with rigorous yet elementary mathematics. The material progresses systematically, and topics such as the pricing and hedging of derivative contracts, investment and hedging principles from portfolio theory, and risk measurement and multivariate models from risk management are covered appropriately.

The chapters have many real-world examples followed by several exercises to help reinforce the text and provide insight. The book is organized into two parts, as follows:

- Part I (principles) is composed of principles of portfolio analysis with a chapter on risk management.
- Part II (methods) covers risk measurement methods and multivariate models.

Chapter 1, on interest rates and financial derivatives, is very brief for a subject so broad. However, the principle of no-arbitrage for valuation of financial derivatives is well presented. Many of the investment and hedging problems that we encounter can be formulated as a minimization of a function over a set determined by the investor's risk and budget constraints and other restrictions on the type of positions that the investor can take. This and related issues are the focus of Chapters 2 to 5, which are on hedging and portfolio optimization.

Having taught risk management in a graduate program and with my experience as a practitioner, I found Chapter 6, on risk measurement principle, to be particularly well presented. The discussion on risk measurement properties is formal, yet accessible, and is followed by real-world examples. This chapter, like all of the chapters, ends with very practical examples that practitioners as well as academics will find very instructive. Chapters 7, 8, and 9 are on empirical models.

Considerations are also made on parametric family of distributions for a random variable and approaches to estimating the parameters. The book also discusses multivariate models for the joint distribution of