ENOUGH MATERIAL TO FILL A SEMESTER WITH CHAOS

Chaos in Dynamical Systems

Edward Ott
Cambridge U. P., New York, 1993. 385 pp. $69.95 hc
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Reviewed by Kurt Wiesenfeld

More and more, colleges are introducing formal courses on nonlinear science and chaos. Many students enter such courses already excited about chaos from reading popular accounts, seeing spectacular fractal images, or perhaps even generating strange attractors on their own computers. Raw enthusiasm is one thing, but deciding which aspects of nonlinear dynamics to include in a textbook is another.

Enthusiasm has its drawbacks. In his television series "America", Alistair Cooke recalled a 1930s story of an American student from the prairie who, newly arrived in England, watches the passing scenery from his railroad compartment. He sits opposite a parson absorbed in his newspaper. Amazed at the small scale landscape, the student blurts out, "You know, sir, the whole of England could be fitted into one corner of Nebraska!" The parson crisply replies, "Yes, but to what *end*, young man?"

One is often tempted to ask, "But to what end?" when faced with the more razzle-dazzle books on chaos. An instructor wants to cover what is interesting and popular but needs to emphasize those aspects of greatest practical importance. Chaos, though important, is just one aspect of nonlinear science. A monograph is one thing, but does enough substantial material exist for a textbook? I was skeptical when I picked up Edward Ott's *Chaos in Dynamical Systems*, but this book proves there is definitely enough worthwhile material on chaos to fill a semester.

The preface calls this a graduate textbook for science and engineering students, and also a researcher's reference. It hits its mark on both counts. The style is careful and pedagogical. Ott, a leading researcher in the field, treats technical aspects by emphasizing main ideas rather than resorting to formal definitions. This is not to say the material lacks technical sophistication: There is plenty of that.

Though the book lacks a compelling progression in the order of chapter topics (and at times even in the sequence of sections within a chapter), each chapter is essentially self-contained, so the reader can pick and choose. Chapter exercises are at a good level for graduate students; interestingly, relatively few involve computer work, which may appeal to the computationally impaired (a syndrome afflicting more professors than students). The price is in line with standard graduate textbooks.

The book is also worthwhile for the researcher who wants to learn about chaos on his or her own. This is not the place to learn how to implement modern tools of time-series analysis, but the reader will become well versed in the field's language and standard constructs and will gain a good foundation for tackling technical literature and seminars. A lengthy bibliography provides a guide to further reading.

The back cover claims the book will also be of value to the advanced undergraduate, but this claim overreaches. It reminds me of the overzealous publisher who tried convincing an author to drop the first word from his monograph, titled *Elementary Particle Physics*, to boost sales. Nevertheless, *Chaos in Dynamical Systems* is a welcome volume for those who keep even modest collections on nonlinear dynamics.

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Introduction to Photorefractive Nonlinear Optics

Pochi Yeh
Wiley, New York, 1993. 410 pp. $79.95 hc
ISBN 0-471-58692-7

The photorefractive effect is a means of making dynamic real-time holograms using light-induced redistribution of charges in an electro-optic material. This process has been studied in several inorganic crystals, such as $LiNbO_3$ and $BaTiO_3$, and more recently in organic crystals and polymers. Photorefractive holograms are particularly novel because the resulting modulation of the index of refraction (or the index "grating") is generally spatially offset from the bright and dark fringes that produced the hologram.

This displacement makes photorefractive holograms nonlocal and nonreciprocal, properties that are not obtained in holograms formed by local mechanisms such as photochemistry, photochromism, heating, and so on. The spatial phase shift causes the two beams (in the material generating the hologram) to couple with one another and exchange energy, an effect that is responsible for many of the most novel applications of photorefractive materials, such as image amplification, novelty filtering, self-phase conjugation and oscillation. New ways to use this fascinating effect continue to appear in the literature. In addition, because photorefractive materials may be used to produce extremely dense and reversible holographic information storage, the study of their optical properties continues to advance in importance.

In his new book, *Introduction to*

Photorefractive Nonlinear Optics, Pochi Yeh has drawn on his many years of contributions to the field to provide a well-organized, advanced textbook intended for a course in modern optics for electrical engineering and applied physics students. A general knowledge of electromagnetism, solid state physics and differential equations is assumed. The book should also find immediate acceptance with researchers entering the field of photorefractivity, because it treats in detail many of the most fascinating and most subtle beam-coupling properties that arise from the nonlocal phase shift of photorefractive holograms.

Yeh successfully builds a foundation for many applications in several introductory chapters that review electromagnetism in crystals, the coupled-mode theory in periodic media and the physical mechanisms that lead to photorefractivity. Such topics often require entire books for a full exposition (for example, *Optical Waves in Crystals* by Amnon Yariv and Yeh; Wiley, New York, 1984), but the presentation here is still lucid and reasonably complete.

To describe the variety of applications resulting from beam-coupling effects and nonreciprocality, Yeh begins with explanations of how oscillation can occur in photorefractive resonators, paying particular attention to the role of the photorefractive phase shift and the oscillation conditions. To make the strange effects that can occur with self-pumped and multiple-pumped phase conjugators physically reasonable, Yeh effectively presents three theoretical explanations based on four-wave mixing, resonator theory and hologram sharing, respectively. The storage capacity of volume holograms is calculated as the number of "uncertainty volumes" that can be placed in the wavevector phase space of a given material. This discussion could have included an example of the application of uncertainty volume to specific storage architecture.

The book pays particular attention to the nonreciprocal nature of optical elements formed from photorefractive materials. Yeh correctly realizes that to understand what is different about photorefractives used in interferometric applications, the reader must first understand the Stokes relationships for a normal lossless beam splitter. This background greatly helps the reader appreciate the subsequent descriptions of ring cavities and Michelson interferometers containing photorefractive materials, as well as the optical computing applications based on amplitude subtraction and addition, reconfigurable optical interconnection, and dynamic neural networks.

Only a few small enhancements would have improved this already excellent text. The general introduction briefly describes the early days of photorefractive nonlinear optics, but no references are listed for the early measurements until the later chapters. A list of variables and nomenclature would have assisted the researcher in translating specific results to other naming conventions. On the whole, however, this book is an important contribution to the field, worthy of the attention of anyone serious about understanding the novel properties of photorefractive materials.

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Quantum Measurement

Vladimir B. Braginsky and Farid Ya. Khalili (Edited by Kip S. Thorne)
Cambridge U. P., New York, 1992. 191 pp. $39.95 hc
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Even before humans were human, we learned to predict, with only a quick glance at a moving animal, where it would be a few seconds later. Now, not so long afterward, a small group of experimental physicists has sharpened this skill by a factor of 10^{16}—to catch not rabbits but gravitational waves.

When a gravitational wave shines on an aluminum bar or a pair of interferometer mirrors, a differential force stretches or compresses the bar or the separation between the mirrors by a fraction of an atomic diameter. One makes two or more measurements of position and then predicts the future position in the absence of the wave. If a subsequent measurement differs from the prediction, the apparatus has caught a gravitational wave.

The gravitational wave—containing frequencies below a few kilohertz and a large number of coherent quanta—can be described classically. Its interaction with the bar or interferometer is also classical, as is the subsequent motion. Only the position measurements are quantum mechanical.

The problem of measuring the position of a particle in the absence or presence of a very small force is simple, general and elegant. Although the bar or interferometer with which gravitational measurements are done is really a harmonic oscillator, for small amplitude changes the position of one end of the bar or of one mirror can be approximately described as a free particle. At a time t seconds after the initial position and velocity have been measured, the uncertainty in the predicted new position is the root mean square sum of Δx_0 and $\Delta p_0 t/m$.

Because Δp_0 is related to Δx_0 by $\Delta p_0 = \hbar/2\Delta x_0$, Δx_0 can be chosen to minimize the uncertainty of the new position. The resulting minimum uncertainty in the predicted position, the standard quantum limit, is $(\hbar t/2m)^{1/2}$. Thermal fluctuations make measurements at the SQL hard to achieve, but Vladimir Braginsky has built a tiny system that works at the SQL even at room temperature.

Although a real detector of small forces, such as a bar or pair of mirrors, is not a free particle but a harmonic oscillator, the SQL of a real detector is, within a factor of 2π, that of a free particle with the time t replaced by the oscillator period.

The surprise is that, for classical forces, the standard quantum limit can be beaten. One can get far below the SQL by measuring a combination of position and momentum that responds to the force while leaving the quantum state of the oscillator unchanged. This quantum non-demolition measurement extracts information but does not destroy the original state. One candidate for a quantum nondemolition measurement is the oscillator energy. This measurement gives no information about the oscillator phase. Another candidate is one of the oscillator's two quadrature amplitudes. This measurement, similarly, gives no information about the other quadrature amplitude. In each case, the cost of measuring one variable more and more accurately is that the measuring apparatus must throw more and more energy into the conjugate variable to increase its uncertainty. The oscillator is put into a state in which the measured variable with the small uncertainty is squeezed, while its conjugate variable is inflated. The limit is eventually set by the amount of energy available, or the robustness of the oscillator.

A more accurate title for this book, by Braginsky and Farid Khalili of Moscow State University, might have been *Quantum Measurement of Classical Forces.* The book applies all the tools of classical and quantum measurement to the measurement of small forces. The tools include time evolution operators, eigenstates, density matrices, correlation functions, noise spectral densities and hetero- and homodyne detection. By focus-