Exploring complex systems through applications

When Things Grow Many: Complexity, Universality and Emergence in Nature, L. S. Schulman

When Things Grow Many: Complexity, Universality and Emergence in Nature. , L. S. Schulman, Oxford U. Press, 2022, 59.00

Robert Deegan

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her theorems and continues to pose questions in the context of general relativity today. Readers are given multiple angles from which to see how Noether's theorems can be used to probe the mathematical structure of various theories and the ways in which energy conservation is encoded in that structure.

A second theme running throughout the book is the subtleties that arise once we move beyond the familiar—and simplified—derivations of Noether's theorems. The issues discussed include the relationship between variational symmetries and other types of symmetry, especially those to which we attribute physical significance; the converse theorems; how to state the most general formulation of the theorems; and whether symmetries are more fundamental than conservation laws. In chapter 7, Harvey Brown argues that the alleged primacy of symmetries over conservation laws is because of their heuristic power and pragmatic utility rather than any physical (or even metaphysical) priority. And that brings us to a third theme, which is the wide range of contexts in which Noether's theorems find useful application. Examples in the book include general relativity, classical particle mechanics, quantum electrodynamics, algebraic quantum field theory, the theory of defects in elastic media, and the heat equation.

Because of how these and other themes recur, there are extra benefits for someone reading the volume from beginning to end. But readers who encounter a chapter that is not to their taste or for whom the mathematical demands outstrip their expertise should simply move on to the next chapter.

In 2003 Elena Castellani and I collected a set of papers on the general topic of symmetry in our edited volume *Symmetries in Physics: Philosophical Reflections*. Noether's theorems were just one theme among many discussed in our book. Almost two decades later, Read and Teh have produced a volume devoted entirely to Noether's theorems. It simultaneously serves as a comprehensive demonstration of the past 20 years of progress in philosophy of physics, an invaluable reference for physicists and philosophers alike, and a superb springboard for future research.

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How the justices of the US Supreme Court will vote on cases is an example of a complex system and one that can be predicted using the maximum-entropy method.

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L. S. Schulman
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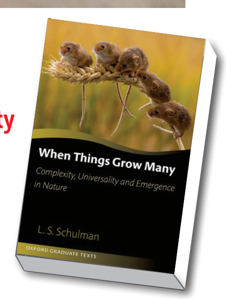

There is no universally accepted definition of a complex system, but it is often characterized as a composition of many interacting components that display emergent properties, such as self-organization, power-law distributions, and phase transitions. The complex-systems community is highly interdisciplinary, and the systems studied usually originate from disciplines outside of physics.

Because complex systems share some of the characteristics of condensed-matter systems—namely, many elementary components, multiple scales, and phase transitions—it is natural to apply statistical mechanics techniques to them. In his new textbook, *When Things Grow Many:*

Complexity, Universality and Emergence in Nature, Lawrence Schulman does just that. Beginning with an introduction to standard statistical mechanics techniques, he then explores their application to a curated set of examples from the literature on complex systems.

In the first half of the book, Schulman introduces readers to probabilistic techniques, the mean-field approximation and how it can fail because of fluctuations, bifurcations, stability analysis, critical phenomena, and master equations. He uses clearly explained examples from physics, including the ideal-gas law, ferromagnetism, and galaxy formation, and from other fields, such as epidemiology. Although those topics could occupy an entire statistical mechanics course, Schulman adeptly breezes through them while clearly highlighting their main concepts.

Schulman's inclusion of information theory and the maximum-entropy method, covered in chapter 6, is a welcome addition. To his credit, he focuses on a technique first developed by Edwin Jaynes that is not typically taught in physics curricula but deserves to be more widely known. In the 1950s Jaynes showed that the Boltzmann distribution can be derived by using information theory and the available information to find the most unbiased probability distribution. That approach treats the prediction of a system with many particles as a statistical inference problem, avoids thorny fundamental issues like ergodicity, and applies to fields well beyond physics. Schulman uses the Jaynes approach to derive the Maxwell velocity distribution and shows how it can be applied to develop a thermodynamic theory of ecosystems and even predict how US Supreme Court justices will vote.

In the second half of the book, Schulman applies statistical mechanics to a wide range of interesting topics, including traffic flow, flocking, galaxy morphology, segregation of urban neighborhoods, and synchronization. He introduces each problem well and provides entry points to the relevant literature.

One of the most challenging aspects of modeling complex systems is that their elements are often heterogeneous—in contrast to the identical atoms in condensed matter—and those elements' interactions are not necessarily short ranged and do not have the nearest-neighbor topology of atomic systems. I wish *When Things Grow Many* had more extensively covered techniques for tackling those issues, such as agent-based modeling and network theory, because easy-to-learn tools to do so are readily available.

I enjoyed reading *When Things Grow Many* and learned something new from each chapter. Schulman writes in a conversational style, and he peppers the book with jokes and opinions. Even though he intimates that he doesn't have all the answers, his fun, inviting tone will make readers want to find out if he does. Scattered throughout the book are many computational and analytical exercises, some of which are open ended. The book also contains an extensive set of appendices with brief reviews of useful topics like probability and stochastic dynamics. I expect that anyone interested in complex systems and who has the requisite knowledge of elementary calculus and linear algebra will find *When Things Grow Many* to be a rewarding read.

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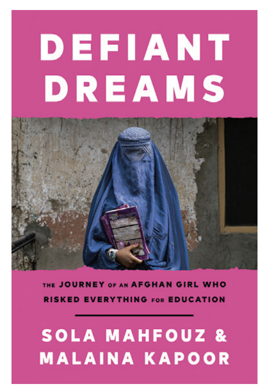
NEW BOOKS & MEDIA

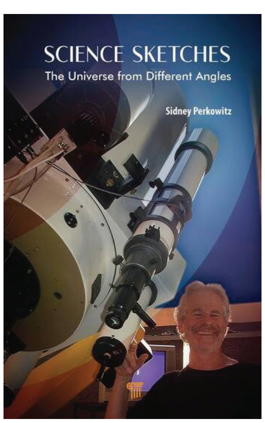
Defiant Dreams

The Journey of an Afghan Girl Who Risked Everything for Education

Sola Mahfouz and Malaina Kapoor
Ballantine Books, 2023. $28.00



It's now been two years since US-led forces withdrew from Afghanistan and the Taliban retook control of the country. This bracing new memoir by Sola Mahfouz, a pseudonymous Afghan refugee currently studying quantum computing at Tufts University, is a reminder of the stakes at play for everyday Afghan people. Born in 1996, Mahfouz lived through Taliban rule, the 2001 US-led invasion, and civil war before fleeing the country in 2016. Overcoming resistance toward women's education from both family members and the Taliban, she started studying English at home and eventually made it to the US with the help of an online conversation partner. *Defiant Dreams* is both an inspiring story and a tragic reminder of the human cost of war. —RD



Science Sketches

The Universe from Different Angles

Sidney Perkowitz
Jenny Stanford, 2022. $49.95

Science Sketches comprises 52 published articles and essays by Sidney Perkowitz, an emeritus physics professor and popular science writer. Similar to his first anthology, *Real Scientists Don't Wear Ties*, which appeared in 2019 (see Physics Today, March 2020, page 52), the material is written for general readers and falls roughly into three categories: science, technology, and culture. In addition to overviews of scientific concepts such as electromagnetic waves, black holes, and quantum gravity, Perkowitz discusses books, art, and films that present math and science concepts; biographies of scientists; and noteworthy technology and its roles in current affairs. Through his use of anecdotes, history, and nontechnical language, Perkowitz strives to present some fairly weighty scientific concepts to nonscientists. —CC PT