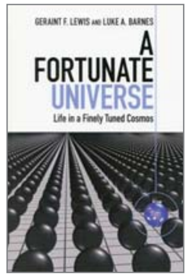
BOOKS



A Fortunate Universe

Life in a Finely Tuned Cosmos

Geraint F. Lewis and Luke A. Barnes

Cambridge U. Press, 2016. $27.99 (388 pp.). ISBN 978-1-107-15661-6

Geraint Lewis and Luke Barnes's lucid, fast-paced, and funny new book might best be summed up in their own words: "Our conclusion is that the fundamental properties of the Universe appear to be fine-tuned for life." As the authors carefully explain in *A Fortunate Universe: Life in a Finely Tuned Cosmos*, it doesn't matter whether other kinds of life are out there. It's enough that there is life here on Earth to raise the question of why the universe is the way it is, seemingly fine-tuned to allow for life. After all, in the vast parameter space of hypothetical universes, life is a tight fit. Change the fundamental constants, or the basic laws of physics, or the low-entropy, free-energy-rich initial state of the universe, and the story on Earth would have been radically different. Life has very little wiggle room.

The fine-tuning problem tends to elicit strong responses. Some physicists are casually dismissive, claiming it's a nonproblem: What else could the fundamental constants be? They are what we measure them to be, period. Others extrapolate beyond current experimentally validated theories. Multiple universes may exist in addition to ours, and in them the values of the fundamental constants might differ. If many other universes exist, it's not so surprising that in one or a few, the values will conspire to be what they are here. After all, sooner or later someone wins the lottery. We could be a rare statistical fluke in a vast landscape of potential universes. (But how can we know how rare?)

Lewis and Barnes lay it bare for anyone who wants to understand what's at stake. They find inspiration in this quote from Albert Einstein:

> I would like to state a theorem which at present cannot be based upon anything more than faith in the simplicity, i.e., intelligibility, of nature: there are no *arbitrary* constants . . . that is to say, nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally determined constants occur.

That is Einstein's dream, the ultimate triumph of theoretical physics: a metatheory that explains why the fundamental constants appear to be fine-tuned to have the values we measure them to have. No coincidences or unknowables allowed, only certainty.

Consider, though, that even if scientists were one day to be in possession of such a metatheory, one could ask why nature operates by *that* metatheory and not another that predicts different outcomes. We end up mirroring the original fine-tuning problem one step removed.

Lewis and Barnes are entirely open about the potential pitfalls of speculative theories. They argue, quite correctly, that we only find if we look, and that's what we should be doing. Their tone is optimistic and validating. Let's push current theories as far as possible and see where they lead us, they say. Fill those dustbins with fake universes.

The authors end the book with a theological discussion on the nature of God and on naturalism versus theism. That path may be a turnoff for those with little patience for religious arguments, but it is entirely justifiable given the ontological nature of the fine-tuning problem. When it comes to fundamental questions of existence—in this case, the existence of our universe and its properties—we humans are like a fish in a bowl trying to figure out the nature of the ocean. It's wiser to accept our ignorance with humility and embrace uncertainty than to claim certainty with blind arrogance and risk future embarrassment.

To make predictions with physical theories, scientists must be able to measure initial conditions of the system under examination: positions and velocities of particles, temperatures and pressures, density profiles and energy levels. But deriving the reasons why the fundamental laws of nature are what we observe them to be seems beyond the scope of what current science can do. Theories depend more on subjective experiences than most of us are willing to admit. As Werner Heisenberg once wrote, "What we observe is not Nature itself but Nature exposed to our methods of questioning." Try as we may, we can't jump out of the fishbowl.

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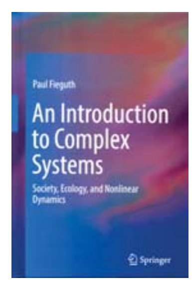
An Introduction to Complex Systems

Society, Ecology, and Nonlinear Dynamics

Paul Fieguth

Springer, 2017. $59.99 (346 pp.). ISBN 978-3-319-44605-9



Traditional coursework makes ample use of the assumptions that systems are small, linear, and governed by Gaussian statistics, and for good reason: They make for tractable math. One could therefore forgive a STEM undergraduate for the belief that one can approximate most real systems with the simple harmonic oscillator, perhaps with a bit of white noise thrown in for good measure. Unfortunately, real systems typically violate all three assumptions, with dramatic consequences. Power blackouts, financial panics, and ecosystem collapses are just a few examples of problems that can be understood only in light of the large, the nonlinear, and the non-Gaussian. The ubiquity and outsize impact of such phenomena beg for broader awareness of the mathematics and consequences of complex systems. But how is that to be achieved without stripping away the attributes that make systems complex in the first place?

In *An Introduction to Complex Systems: Society, Ecology, and Nonlinear Dynamics*, Paul Fieguth takes on that challenging task. An engineer by training, he combines a practitioner's sensibility with a hobbyist's knowledge of a grab bag of fields ranging from climate change to soil science. His book represents a new take on the pedagogy of complex systems, emphasizing concepts and consequences over calculations.

The book reads like a play in three acts. The first portion, motivated by the timely problem of global warming, introduces the reader to systems theory. With the stage thus set, Fieguth tackles the question of how to define a system in the first place. What are the system's boundaries? Is it open or closed? If open, what are its inputs and outputs, and what does thermodynamics imply about its operation? The book then deals with the representation of a system's dynamics and associated dynamical state. Are the governing equations stationary in time? In space? What do we need to measure to make meaningful statements about the system's behavior? The intent in posing those questions is not to provide one-size-fits-all answers, but to accustom the reader to thinking about the nuances of systems modeling.

The middle third of the text can be described as an atlas of complex systems, using the relatively bland linear systems as a counterpoint. Along the way, the author delves into new phenomena unlocked by each new layer of complexity; for instance, chapter 6 introduces nonlinearities in one-dimensional systems and with them the possibility of multi-stability, bifurcations, and hysteresis. Later chapters discuss higher-dimensional nonlinear systems and what the author terms "spatial systems"—those properly modeled by partial differential equations or agent-based models. Fieguth covers critical modeling issues like discretization, resolution, stability of numerical methods, and boundary-value constraints. That nod toward the fact that the science of complex systems is unavoidably computational gives the book a practical flavor that I like.

The final act covers behavior and problems common to most large complex systems. Chapter 9 shatters the illusion that bell curves dominate the statistics of real-world systems and uses examples as varied as drought lengths, city sizes, and movements of the Dow Jones Industrial Average to show that "extreme" and "improbable" are not synonymous. Next, readers are exposed to the key concept of emergent behavior, and chapter 11 provides a good introduction to the challenges of observation and inference in large complex systems. In a fitting coda, chapter 12 ties the themes together with an in-depth case study of water, from ocean acidification to groundwater availability.

Of course, one cannot treat many of the above topics without some appeal to the underlying mathematics. Fieguth strikes a good balance. He strips derivations to the bare essentials and sequesters the dry machinery of, say, eigendecomposition to an appendix. That frees him to focus on the interpretation of the problem at hand.

Occasionally, by emphasizing broad themes over nuances, Fieguth does a disservice to his readers. Take, for instance, the focus on power-law distributions, which Fieguth claims are the ubiquitous face of non-Gaussian statistics across nature and society. In fact, many reported power laws lack statistical support or a plausible generative mechanism; the author would have done better to emphasize the contrast between thin-tailed and heavy-tailed distributions in general. Conversely, at times the text pursues tangents at the expense of the main message. A cursory, few-page excursion into control theory, for example, ends up being more jarring than illuminating. But such misfires are the exception.

I can envision at least two ways Fieguth's book could be used in a classroom setting. On its own, it would be a fine primary text for an interdisciplinary course at the intermediate undergraduate level. For a more specialized course tailored to advanced physics majors, the book would naturally complement a more mathematical text in dynamical systems, chaos, or network science. For those texts I can recommend Steven Strogatz's *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering* (2014), *Chaotic Dynamics: An Introduction Based on Classical Mechanics* by Tamás Tél and Márton Gruiz (2006), and Albert-László Barabási's *Network Science* (2016). But regardless of how Fieguth's text is used, students of all stripes will find at the end of each chapter a wealth of appropriately challenging exercises ranging from the conceptual to the analytical and computational.

An Introduction to Complex Systems largely accomplishes what it sets out to do. Its application-forward approach is likely to appeal to readers in fields like environmental science and economics, in which complex systems are typically underemphasized but no less important. And if even a specialist like me can read about climate change, lake eutrophication, or any of the panoply of other case studies in this book and exclaim "I never thought about it that way!" then the book should be regarded as a success.

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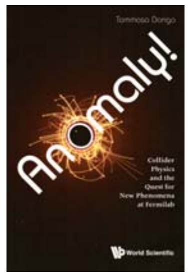
Anomaly!

Collider Physics and the Quest for New Phenomena at Fermilab

Tommaso Dorigo

World Scientific, 2016. $110.00 (304 pp.). ISBN 978-1-78634-110-5



The desire to discover something new is a powerful driver of the research process. In particle physics, the potential for discovery is especially great at the laboratories with the highest-energy particle accelerators, where particle collisions have the best chance of producing novel states and processes. The Tevatron collider at Fermilab constituted that "high-energy frontier" from 1989 until 2010; two collaborations, the Collider Detector at Fermilab (CDF) and DZero, each collected data from the collisions at the Tevatron during this period. They stopped roughly 18 months after data collection began at CERN's more powerful Large Hadron Collider.

In *Anomaly! Collider Physics and the Quest for New Phenomena at Fermilab*, Tommaso Dorigo provides an engaging and insightful perspective on the pursuit of physics discoveries at CDF. The book, written for a nonspecialist but scientifically literate audience, begins with