The Physics of Foraging: An Introduction to Random Searches and Biological Encounters

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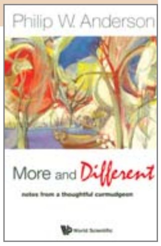
Essays on the edge

More and Different

Notes from a Thoughtful Curmudgeon

Philip W. Anderson
World Scientific, Hackensack, NJ, 2011. $38.00 paper (243 pp.).
ISBN 978-981-4350-13-6



Reviewed by N. David Mermin

When asked to review Philip Anderson's new book, I had expected the opportunity to fire a few curmudgeonly shots at the greatest curmudgeon to grace our profession over the past two-thirds of a century. But I was wrong. In *More and Different: Notes from a Thoughtful Curmudgeon*, Anderson has put together an entertaining and instructive collection of highly readable reviews, columns, talks, and unpublished essays on science and the scientists he has known. He is rarely inappropriately provocative, and he is a pleasure to read.

One of Anderson's recurrent themes is his refutation of naive reductionism going back at least 40 years to his famous 1972 essay in *Science*, "More is different," which unfortunately is not included here. Reductionism overlooks emergence. In a section entitled "Emergence as the God principle"—a well-deserved swipe at Leon Lederman—Anderson eloquently defines emergence as "obedient to the laws of the more primitive level, but not conceptually consequent from that level" (page 90). Nobody contemplating the Lagrangian of the electromagnetic and matter fields would have guessed that broken gauge symmetry was the key to the phenomenon of superconductivity. Even with the clue provided by the laboratory of Heike Kamerlingh Onnes, it took 32 years after the creation of quantum mechanics to discover the explanation, which is consistent with, but not implied by, the quantum laws.

N. David Mermin, a retired professor of physics at Cornell University in Ithaca, New York, last wrote in Physics Today about P. W. Anderson 30 years ago; in "E pluribus boojum: The physicist as neologist" (April 1981, page 46) Anderson rescues "boojum" from the dustbin of rejected scientific terms.

We also learn about interpersonal relations at Bell Labs during its heroic years. We are given Anderson's definitely non-postmodernist views on the science wars. We hear his altogether admirable opinions on the politicization of science. We get a history of the theory of superconductivity as seen from the frontlines. We get his opinions—almost all respectful, but often with an edge—about John Bardeen, Hans Bethe, Leon Cooper, Richard Feynman, Murray Gell-Mann, Stephen Hawking, Brian Josephson, Lev Landau, Bernd Matthias, Ilya Prigogine, J. Robert Schrieffer, William Shockley, and Eugene Wigner, among others. I could easily have listed more if the book came with an index.

The only part of the collection I did not find a delight to read are Anderson's attempts to convey to the general reader the scientific content of some of his own contributions. He is aware of the problem: "I have elsewhere disavowed any ability [to explain technical scientific matters to laymen], and the reader—especially the true layman—will surely agree." I would add that even a physicist from a different subfield will find some of his explanations a little terse. Just a touch of strictly pedagogical reductionism might have helped.

I blame most shortcomings of the book on the publisher. We are not told where or, more importantly, when most of the more than 60 essays were published or written, which often requires the reader to deduce from internal evidence the state of the issues at the time of Anderson's critical discussion. Sometimes an essay contains references to other articles in the unidentified collection from which that essay was taken. And because many of the themes that interest Anderson are taken up in several essays over, one assumes, a span of many years, I found the absence of an index a frequent source of frustration.

I conclude with just a few of the many wonderful obiter dicta, which give *More and Different* a special charm:

> "When we are all done, it will turn out that there is no exotic form of 'dark matter', merely a comedy of errors in a field where it is practically de rigueur to underestimate one's limits of error" (page 107).

> "Of course I am not religious—I don't in fact see how any scientist who thinks at all deeply can be so" (page 133). And, "We atheists can . . . argue that, with the modern revolution in attitudes toward homosexuals, we have become the only group that may not reveal itself in normal social discourse" (page 177).

> "Consciousness [is] one of the major deep problems, already apparent in the 20th century, which may take most of the 21st century to solve" (page 113). And "the greatest puzzle of all [is] the emergence of consciousness" (page 138). (When I complained to a very distinguished colleague that his Theory of Everything had nothing to say about consciousness, he replied, "Consciousness is an illusion.")

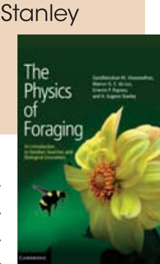
> "If there weren't any solids we'd have no way to measure space—so by breaking the symmetry of space we have in a sense created space as a new entity" (page 144). (I was once charged in the pages of Physics Today with postmodernism for making similar remarks about time.)

> And, most engagingly, "All I can say to the younger theorists is: don't trust anyone over 45, except maybe me, and I'm not so sure about me" (p. 159).

The Physics of Foraging

An Introduction to Random Searches and Biological Encounters

Gandhimohan M. Viswanathan, Marcos G. E. da Luz, Ernesto P. Raposo, and H. Eugene Stanley
Cambridge U. Press, New York, 2011. $50.00 (164 pp.).
ISBN 978-1-107-00679-9



In 1996 H. Eugene "Gene" Stanley, his graduate student Gandhimohan Viswanathan, and collaborators at Boston University and the British Antarctic Survey published a paper partly inspired by Yossi Klafter and Michael Shlesinger's stimulating suggestion that animal foraging might be modeled by non-Brownian, superdiffusive, random walks. The paper reported that a set of flight times of the wandering albatross followed a power-law distribution $t^{-\mu}$, with $\mu \approx 2$, and proposed several tentative explanations including that albatrosses forage in fractally structured natural environments, including the turbulent atmosphere and oceans. In a second paper in 1999, Viswanathan and colleagues proposed something even bolder: They related their power law to a Lévy foraging hypothesis, which stated that foraging behavior based on the $\mu = 2$ scaling exponent is optimal in some instances, and that natural selection would thus have evolved to exploit it.

Viswanathan (now a professor in Brazil at the Federal University of Rio Grande do Norte), Stanley, and their collaborators, Marcos da Luz and Ernesto Raposo, have now published their ideas in *The Physics of Foraging: An Introduction to Random Searches and Biological Encounters*, which aims to synthesize anomalous diffusion and animal foraging. As with previous texts written (or co-written) by Stanley, this book provides many clear explanations of nonintuitive concepts as evidenced by the lucid presentation of random walks and critical phenomena in the first three chapters. Another example of the text's clarity is the discussion in chapter 4 of the difference between large values drawn from a power law distribution and classical outliers.

The Physics of Foraging is strong in its discussion of the development, during the past 10 years, of the Lévy foraging hypothesis, in which foraging can be viewed biologically or more generically as a random search problem. Chapters 5 through 8 of the book are devoted to the early experimental evidence, foraging by animals and humans, and the quality of collected data. The final 6 chapters focus on theory, particularly variants of the superdiffusive random walk and the notions of optimality behind the Lévy foraging hypothesis.

Unfortunately the book presents only seven figures drawn from experimental data; it also makes at least one error of fact in its presentation in chapter 4 of a 2007 paper revisiting the albatross data set, coauthored by Andrew Edwards, then at the British Antarctic Survey, this book's authors, me, and others. The book correctly notes that the longest "flights" in that data set were spurious, but mistakenly lays the blame on the idea that the birds "had remained for some time in captivity prior to release." In fact, the spurious "flights" were a result of the sometimes long intervals between attaching the tracking devices to the birds and their subsequent take-offs or between the birds' landings and the devices' subsequent removal.

I would also have preferred to see a wider variety of literature referenced in the book. Partially stimulated by the reexamination of the albatross data set, some recent papers on non-Brownian models of foraging present strikingly different viewpoints on simulation, data analysis, and statistical inference: A very recent example of which is the 2011 *Journal of the Royal Society Interface* paper "Assessing Lévy walks as models of animal foraging," by Alex James, Michael Plank, and Edwards. I also think the appendix on maximum-likelihood estimation, which discusses best practices for statistical inference of power laws, would have benefited from an explicit reference to, and discussion of, the 2009 *SIAM Review* paper, "Power-law distributions in empirical data," by Aaron Clauset, Cosma Shalizi, and Mark Newman.

Another unfortunate weakness is inadequate proofreading. The back cover, for example, suggests that the book will interest "ecologists with little familiarity with the concepts and methods of statistical physics," whereas the first page refers instead to ecologists "already familiar" with the same. Occasionally one finds apt neologisms, like a reference to "statistically coercive" quantities, though more often the proofreading misses typos like "VHS" radio waves or a reference to the albatrosses of "southern (instead of "South") Georgia." Hopefully such mistakes will be fixed in a future edition.

Despite those problems, I think *The Physics of Foraging* is useful and will find a place in the literature of the physics and ecology communities. Over the past 40 years, Stanley has given us a number of excellent books. His *Introduction to Phase Transitions and Critical Phenomena* (Oxford University Press, 1971) remains a classic. Three other books co-written or co-edited by Stanley are among a select few that have inspired many scientists, myself included, to pursue criticality-based approaches to the study of complex systems. They are *On Growth and Form: Fractal and Non-Fractal Patterns in Physics* co-edited with Nicole Ostrowsky (Springer, 1985); *Fractal Concepts in Surface Growth* with Albert-László Barabási (Cambridge University Press, 1995); and *Introduction to Econophysics: Correlations and Complexity in Finance* with Rosario Mantegna (Cambridge University Press, 2000).

As the exciting, cross-disciplinary field of complex-systems science develops, it faces the twin challenges of analyzing rich new data sets (see Stanley's review of *Complex Webs: Anticipating the Improbable* in PHYSICS TODAY, November 2011, page 58) and, at the same time, incorporating the relevant prior knowledge and expertise of existing disciplines. I expect to use *The Physics of Foraging* as part of that process. For advanced courses, the book could be supplemented by Klafter and Igor Sokolov's excellent new book on anomalous diffusion, *First Steps in Random Walks: From Tools to Applications* (Oxford University Press, 2011); both books would stimulate learning and debate among graduate students and postdocs.

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The Shaping of Life
The Generation of Biological Pattern

Lionel G. Harrison
Cambridge U. Press, New York, 2011.
$99.00 (247 pp.).
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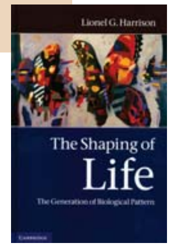

In 1917 D'Arcy Wentworth Thompson penned the classic *On Growth and Form* (revised edition, Dover, 1992), in which he argued, contrary to the Darwinian orthodoxy of the time, that structure originates before function and that growth and form can be explained through mathematics and physics. By the early 1950s, Alan Turing would demonstrate how spatial patterns could arise through chemical instabilities inherent in a simple set of coupled reaction–diffusion equations. Turing patterns, as they came to be known, are evident in nature; for example, some resemble the spots on a leopard, others the stripes on a zebra or the complex fractal-like patterns on seashells. But it was not until the 1980s that chemists could actually set up reactions that would produce Turing patterns.

Though embraced by mathematicians and physicists, Turing's mathematical approach to biological pattern formation is hardly accepted by most experimental biologists. The late physical chemist and theoretical biologist Lionel Harrison laments such resistance in *The Shaping of Life: The Generation of Biological Pattern*, which he drafted before his untimely death in 2008 and which was completed by friends and colleagues. Harrison pioneered a quantitative approach to developmental biology in the 1970s, an era when few thought it was useful to mathematically model the complexities of biological growth and development.

The Shaping of Life makes the case for simple coarse-grained mathematical models in biology—simple, that is, in comparison to models that explain the phenomena at a genetic or systems level. Many of the topics in the book's first half are drawn from Harrison's own research on plant development. His work had led him to investigate a variety of novel creatures such as *Acetabularia*, a seaweed that grows to several centimeters and generates multiple whorls of hair-like filaments along its exterior. Those organisms are ideal laboratories for studying the dynamics of growth, since they are mostly transparent and grow in two-dimensional sheets. Another favorite of Harrison's are the somatic embryos of conifers, such as the hybrid larch *Larix x leptoeuropaea*. As an embryo, *Larix* is a multicellular organism accessible to observation in much the same way as *Acetabularia*. Despite its multicellular nature, the development of outgrowths called cotyledons from *Larix* embryos greatly resembles the whorl formation in the single-cell *Acetabularia* and, indeed, can be modeled on a similar mathematical formalism.

In the second half of the book, Harrison turns the reader's gaze from plant development to animal development. Here one learns about segmentation in the *Drosophila* egg, amphibian heart development, the rearrangement of stripe patterns in angelfish, vertebrate limb development, the growth of slime molds, and much more. The examples are highly varied, some touched on in more detail than others, but taken together they clearly display that there is no shortage of complex developmental behavior that can be understood through mathematics.

One notable omission, which Harrison admits early on in the manuscript, is any discussion about the genetics of development. That is fair; as Harrison's numerous examples show, much can be said about understanding complex developmental behavior through course-grained mathematical models of pattern formation at the level of abstraction presented in *The Shaping of Life*. In fact, a mathematical approach to developmental modeling is the subject of numerous complementary books, including *Biological Physics of the Developing Embryo* (Cambridge University Press, 2005) by Gabor Forgacs and Stuart Newman and *The Self-Made Tapestry: Pattern Formation in Nature* (Oxford University Press, 1999) by Philip Ball. For a technical discussion of the genetic origin of bodily form, interested readers can consult *Imaginal Discs: The Genetic and Cellular Logic of Pattern Formation* (Cambridge University Press, 2002) by Lewis Held Jr; for a more readily accessible popular account on the same topic, readers can check out the immensely pleasurable *Endless Forms Most Beautiful: The New Science of Evo Devo and the Making of the Animal Kingdom* (W. W. Norton, 2005) by Sean B. Carroll.

Besides being a text about biological pattern formation, *The Shaping of Life* is an exposition on how human beings