BOOKS: NATURAL SCIENCES

Patterns in Nature—No Assembly Required?

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At the end of *The Self-Made Tapestry: Pattern Formation in Nature*, Philip Ball concludes, "These self-made patterns are everywhere—in the vegetable patch, in the coffee cup, on mountain tops and in the city streets. I hope you enjoy them." Indeed I do, and even more so after reading this enjoyable book. Ball explores why similar patterns and forms arise in natural settings that appear to have no relation to one another. He guides us through numerous examples that illustrate the processes and powers of self-organization, the formation of patterns by means of simple, local interactions among their component parts.

The Self-Made Tapestry
Pattern Formation in Nature
by Philip Ball
Oxford University Press, New York, 1999. 295 pp. $37.50, £18.99. ISBN 0-19-850244-3. Paper, £8.99, ISBN 0-19-850243-5.

One of the pleasures of the book is the artistic and inspiring free style of the author's explanations, which do not conform to the strict logical and mathematical formalism of scientific papers. These accounts incorporate remarks about individuals who have contributed to our understanding of pattern formation and about some philosophical aspects of their discoveries. The style and contents make the book read as a novel, although a somewhat challenging one due to its scientific basis. And like many novels, the book tempts the reader to peek at the final chapter (on principles) immediately after the introduction to patterns, rather than waiting for the final clues.

Using this inventive approach, with illustrations and descriptions that convey beauty and wonder, Ball explains the development and procedures of the research into the supposed unity of pattern formation in nature. His account is presented in a way that maintains the standards of scientific endeavor; it is popularized only in the sense that he reports extracts of results without using the highly technical descriptions of natural sciences and mathematics. In this way, Ball opens this field's state of the art to educated general readers as well as to specialists in other fields. Throughout the book, we also acquire impressions of the sources of inspiration; the influences of various philosophical paradigms, serendipitous discoveries, differences in logical (or, sometimes, illogical) procedures; and the results of good luck and intuition.

Whether particular widely repeated patterns originate from similar processes, or whether they are based on the same simple principles that the author discusses, can be debated. Disagreements can arise from differences in philosophy, methodology, or definitions of concepts (such as simplicity, complexity, and similarity). The most important differences are in the identification of the main questions in geology and biology and of their acceptable explanations: causal, functional (Ball prefers "purposeful"), historical ("evolutionary"), and mathematical descriptions.

The main theme of the book is a description of the tapestry of the universe based on mathematics. We hear ideas from Plato, Goethe, and d'Arcy Thompson (we miss those from Geoffroy Saint-Hilaire and Thom, among others), and we see the results of modern computer simulations. Ball's method is to explain pattern formation as the result of a few simple physical principles that occur in matter itself. So the patterns are self-made: produced by mainly internal factors, constrained here and there by external ones. The author discusses many such principles, including surface tension in liquids, force resistance (stresses) and conduction, traveling waves, vibrations, activation-inhibition coupled mechanisms, convection and conduction, streaming fluids, and the behaviors of granular media.

Ball discusses the origin of patterns that are found in many settings and circumstances, including spirals, spots, stripes, branches, and honeycombs. He considers a wide range of physical and biological systems, such as bubbles, waves, fluids, grains, and ecological communities. It is a wonderful experience to see an enormous variety of very complicated patterns arise. But is the pattern formation indeed as simple as the author wants us to believe? On examining these principles more closely, we find that many are not. Sometimes they produce chaos and unpredictability instead of order. Moreover, different principles act simultaneously. For example, Ball discusses (pp. 73–75) the symmetrical patterns formed by the bacteria *Escherichia coli* in response to life-threatening conditions. One model for the pattern formation involves a delicate balance between attractive and inhibitive actions, with repulsive interactions between clusters due to the emission of a chemical signal. But it is not known whether *E. coli* exude such chemorepellents, and Ball, in summarizing Budrene and Berg's conclusion, states "the symmetric patterns are the result of a very complex process in which the cells alternate between foraging out into new territory and stopping to cluster into groups."

Analogous cases can be expected to occur in the formation of various other patterns. It follows that the crucial feature to be investigated in the examples described should be the interrelationship of various structures and processes. The conclusion that a handful of basic processes are sufficient for an explanation seems, to me, rather optimistic. The question then arises, how much of the result in such interac-

Constrained continuous pattern formation. M. C. Escher's print *Liberation*.

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tions is due to spontaneous formations (the self-made tapestry, autogenesis in development and in evolution)? There is no doubt that self-organizing principles—to which patterns, structures and their changes can be attributed—exist at many spatial and temporal scales and in many different kinds of matter. But the resulting patterns also greatly depend on the inside and outside connections in which constraints, directional information, and energy supply are always at work. These complications are responsible for the great variety within seemingly similar patterns. The situation is comparable to genetic expression. In genes, we have an almost self-made pattern, a high dominance of their influence, but the environment is necessary for their expression and causes the variation.

Symmetry and symmetry breaking are other aspects of pattern formation that require critical evaluation. The concept of symmetry is certainly very useful in modeling and classifying objects and phenomena; it makes processing, calculating and simulating much easier. Although in practice (in reality) symmetry only occurs after very strong averaging or at short moments when fluctuating dynamics pass through equilibrium points, assumptions of symmetry have been enormously helpful in the discovery of general rules and theories. Hypothesized symmetry seems to be an ideal, and even necessary, heuristic tool. But more care should be given to testing the fit of models; in such testing, we are confronted with an ongoing tension between the ideal (the model) and the real (the observed data). Symmetry can also be employed as a potential state, much like maximum entropy, toward which all processes tend but never reach, due to continuous or pulsating energy supplies. (This behavior is exhibited in many of the examples of pattern formation discussed by Ball.)

Investigators adhering to the idea of symmetry are usually satisfied by finding superficial symmetry at a specific level of organization or structure equilibrium or by noticing similarity in many directions. For example, in early embryogenesis (pp. 99–100) the egg is said to have an initial symmetry that is broken during the first division and subsequent development. (The process can be described by the Turing model, which invokes reaction–diffusion instability.) But, in actuality, as demonstrated in the vast amount of literature on this phenomenon, the egg's symmetry is broken from the outset and again at fertilization. These original asymmetries are of critical importance in development; they affect the physical, chemical, and informational interactions among the various well-distinguished parts of the zygote. At best, we might consider symmetry unbroken to a certain degree if we take the potential for mutual interchangeability as a criterion. Yet I would rather say that the tapestry originates by interaction of the parts, each with their own self-formation.

With this remark, I come to a most important implicit contribution of Ball's fine book. Self-organization is a plausible primary candidate for understanding the origin of new forms in a short interval of time. It can produce more—and better than random—variation and mutants on which natural selection can operate. Perhaps mutant forms are products, or by-products, of self-organization. Self-organizing processes also make it easier to explain the development of new emergent structures and the effects of perturbations on entire constructions and patterns. Because small changes can affect an entire tapestry, we arrive at the questions of how to best approach chaos and unpredictability.

The possible importance of self-organization in the generation of variation, one side of the coin of evolution (natural selection being the other), is only one of the many intriguing ideas raised in Ball's discussions. All who wish to understand the repeated appearance of similar patterns and forms will find much of interest in *The Self-Made Tapestry*.

NOTA BENE: PHYSICS

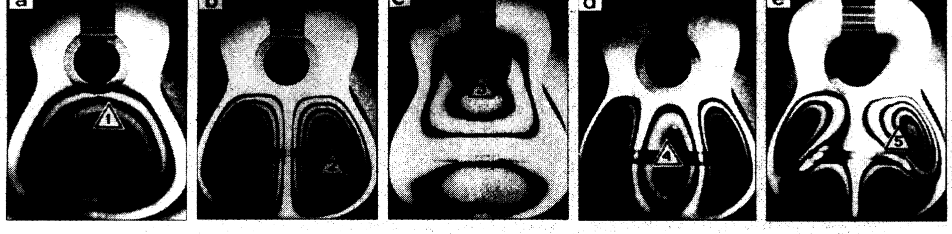
Unmasking Melodious Sounds

The Physics of Musical Instruments
2nd ed.
by Neville H. Fletcher and Thomas D. Rossing
Springer, New York, 1998. 776 pp. $69.95. ISBN 0-387-98374-0.

A flute may not sound sweeter just because you know that its notes are produced by the regenerative excitation of a resonant column of air. Nor will a kettledrum seem less imperious just because its vibrations can be reduced to a bunch of Bessel functions. Still, these connections between classical physics and the most sublime of human arts can make each discipline come alive.

No comprehensive quantitative analysis of music-making devices existed until Fletcher and Rossing published *The Physics of Musical Instruments* in 1990 (reviewed by D. E. Hall, 21 June 1991, p. 1728). The authors tackled everything from accordions to zithers in a mathematically rigorous way, and they did it with style and clarity. Early chapters presented the basics of vibrating strings, bar, and membranes. Middle sections discussed the specific behavior of sound waves in air—the medium of music. With the fundamentals in hand, Fletcher and Rossing then delved into the detailed physics of each family of instrument, including less familiar ones like Indian tabla drums and Japanese temple bells not usually found in the Western orchestra. As with the guitar vibrations made visible (see figure), each instrument's hidden workings provide insight into its unique sound qualities.

Now with the second edition, this impressive volume has been nicely revised and updated. The changes are less of the radical variety and more along the lines of nipping and tucking, with one exception. An entirely new and needed chapter on the materials of instruments has been added. Musicians have debated for centuries the merits and drawbacks of various substances for instrument building. Woodblocks sound different than cowbells, partly because of shape but also because of the vibrational properties of wood versus metal. But don't older traditional wooden flutes sound "warmer" than modern ones made from cold metals? Yes, but largely because flute design has undergone a radical change from tapered bore to cylindrical bore. Flute players may still argue hotly for their favorite material, but Fletcher and Rossing at least now have added materials science fact to the traditional wisdom of instrument design.



—**DAVID VOSS**

CREDIT: *THE PHYSICS OF MUSICAL INSTRUMENTS, 2ND ED.*