could have been used to make reference to the approximation methods of Rashevsky and others, which have been used extensively. Also discussed in this chapter is the model system of Turing, in which diffusion, coupled with chemical reactions, leads to inhomogeneities of concentration which are stable. These inhomogeneities could be the basis for the development of patterns in morphogenesis. The arguments for this example are necessarily qualitative, but the graphical presentation makes the process understandable.

Although there are additions and changes that could have substantially facilitated the reading and understanding of some of the topics discussed, many biologists with diverse interests could profit from reading this book, becoming acquainted with unfamiliar areas of mathematics or gaining insight into the ways in which mathematical ideas can prove to be useful aids in understanding biological processes.

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Organization

The Art of Organic Forms. PHILIP C. RITTERBUSH. Smithsonian Institution Press, Washington, D.C., 1968 (distributed by Random House, New York). x + 152 pp., illus. $10.

Most scientists have esthetic reactions to their subject matter. On a plane of deep abstraction, a theoretical physicist may see beauty in a mathematical relationship. More objectively, to a mammalogist the teeth of beasts are beautiful, and a pathologist may apply that adjective to a suppurating abscess. An artist, professionally esthetic, is not likely to appreciate those examples, but there is a wide range of forms—a diatom, an orchid, an impala—appealing in an esthetic way equally to scientist and to artist. One might add a snowflake and a bird's song as further examples, but it is noteworthy that most of the examples that rise to mind are organic and are visual.

That community of reactions among scientists and artists does not in itself constitute a functional connection between science and art. Some connection may be claimed in terms of search for truth along different paths, but the two concepts of truth involved are so equivocal that little concrete sense emerges. It is more significant that the sciences and the arts have in common a search for organization and relationships that in scientific terms are rationally meaningful and in esthetic terms are emotionally satisfying. That, too, may be especially evident in the organic and the visual.

It is that sort of connection that is traced historically by Ritterbush in a broad sweep from the botanist Nehemiah Grew, born 1628, to the painter Michael Clark, born 1946. The thesis is that organic forms, that is, the forms of living things, are in fact organized to unique degrees and in unique ways, that this kind of organization often has been taken as an exemplar by artists, and that artistic or esthetic perception conversely sometimes has been a guide for scientific comprehension of organisms. This history is a fascinating one, and it is here well and succinctly told—the text in the volume totals only about 75 pages.

It is emphasized that reference is not to the literal copying or illustration of organic forms on the part of artists. "Rather than imitate the external forms of nature, which [Kandinsky] compared to trying to recreate the sound of the chicken farm in music, the aim of art should be to represent the innermost quality of nature, its atmosphere." And indeed the 24 reproductions of paintings in this volume are almost completely nonrepresentational. Those that do most nearly resemble actual organic forms, for example Kawashima's "New Symbolism," are not the most esthetic, and they suggest parody more than organic creativity. Others, for example "Geography of Phantasy" by Tobey, have no evident relationship to the concept of organic form, or indeed of organization. Nevertheless, the collection as a whole does illustrate artistic concepts that do embody organic analogies without homologies. However, some of the works given special emphasis in the text, for example those of Ernst Kupferman, are not illustrated.

The other side of the thesis is the influence of esthetics on science. It is demonstrated that such an influence exists, but the impression left is that when esthetic considerations became really dominant over scientific enquiry the result was, at best, a blind alley. Goethe's idealistic morphology, treated at length in introducing this side of the matter, is a good example of the flat failure of the primarily artistic approach to scientific problems. Unfortunately Ritterbush's devotion to the idea of fruitful reciprocity of science and art has led him to some extremes that are false or inane. It simply is not true that "the progress of biology beyond the cell theory has consisted in large measure of demonstrating the existence of significant symmetry properties in the organisms themselves (or in forms abstracted to represent them)." It is absurd to impute connection between Harrison's invention of tissue culture and an observer's expectation that figures painted by Kandinsky will similarly flow or extend.

This book was prepared with reference to an exhibit of paintings, also entitled "The Art of Organic Forms," and a catalogue of the exhibit is included. The exhibit has been dispersed, and many of the paintings are now neither visible to the public nor here illustrated.

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Biophysics of Ecology

Energy Flow in Biology. Biological Organization as a Problem in Thermal Physics. HAROLD J. MOROWITZ. Academic Press, New York, 1968. xii + 179 pp., illus. $9.50.

This book is a biophysicist's view of the complex levels of organization of biology, ecology, and the biosphere. It is an effort to resolve the deep contradiction felt by many physicists in the biological tendency toward order in systems whose molecular components have tendencies toward disorder. The book starts with two chapters on physical theorems concerning the behavior of energized populations of molecules, including aspects of steady-state thermodynamics, and a chapter that recapitulates biology into 13 generalizations as seen from the molecular stance. Chapters 4 and 5 are lucid statements of the thermochemistry of protoplasm, including calculations of the entropy contents of formation that will allow more biologists to change their calorimetry data on heats of reaction to potential energies instead of incorrectly using one to approximate the other. Included is the quantitative statement of the effect of temperature on the maintenance requirement of biological structure. The book's central concept is then introduced in the final chapter with an order function, $L = \Delta A/(kT/h)$, the ratio of Helmholtz free energy (ΔA) of the biological structure to the temperature-dependent disordering flux that must continually be overcome if that structure is to be held at steady state. Morowitz's order function is similar (reciprocal) to a quantity which I have called the Schrödinger ratio (*Pollution and Marine Ecology*, T. A. Olson and F. J. Burgess, Eds., p. 135) and which is identical with the very old empirical variable in ecological measurement, respiration-to-biomass (turnover) ratio. Morowitz uses Helmholtz free energy, whereas most biologists use Gibbs free energy and thus sweep pressure-volume changes under the rug. At the end he does some elegant manipulations showing, for example, that as temperature rises the difference in behavior of numerator and denominator causes the order function to pass through a maximum. Following Margalef he believes that nature maximizes the ratio of structure to maintenance metabolism. In this he is probably wrong, because he ignores the role of natural selection by which energy flow is maximized instead, so that sometimes high biomass is produced and sometimes low, depending on programs for adaptation to temporary irregularities in input energies.

This book's elaboration of the Schrödinger theme and related functions will irritate many biologists because old concepts are generated *de novo*, as if new, whereas what is new is putting them in the language of the molecular physicist. This Yale professor was trained in a setting in which the ideas of A. J. Lotka were influential. Without citation of Lotka's writings or of others in the literature he now writes the same story of the self-correcting homeostasis of the closed mineral cycle, general reaction kinetics of light on a cycling receptor system, and other well-established principles of systems ecology.

As the diversity of scientific schools of thinking and scientific languages increases, it may be increasingly frequent that synthesizers will use the notation of one field to generate theory concerning the material of another without mastering the literature of the latter and without realizing that the theorems are as clearly established in other forms. If it is quicker for a keen mind to generate knowledge anew than to be responsible for the huge literature of other fields, what is his obligation? A real difficulty may be the Ptolemaic arrogance with which those working at one level of integration tend to regard a theory as unproven until it is stated in the notation of their own discipline. This is a pitfall for students of the small who undertake to deal with the large, mainly because education for the small often omits the large as if it didn't exist.

In any case, ecologists and biologists will be fascinated to find their familiar concepts restated in the (to them) more cumbersome molecular formulations which they must now master. The book will help their colleagues in physics to discover complex open systems and will show biologists who among the molecular contributors to unfamiliar journals have written papers pertinent to the old problem of order.

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Evolution by Orderly Law

Der gerechtfertigte Haeckel. Einblicke in seine Schriften aus Anlass des Erscheinens seines Hauptwerkes "Generelle Morphologie der Organismen" vor 100 Jahren. GERHARD HEBERER, Ed. Fischer, Stuttgart, 1968 (U.S. distributor, Abel, Portland, Ore.). xii + 588 pp., illus. $19.50.

Nomogenesis, or Evolution Determined by Law. LEO S. BERG. Translated from the Russian edition (1922) by J. N. Rostovtsov. M.I.T. Press, Cambridge, Mass., 1969. xxiv + 488 pp., illus. Paper, $3.95. Reprint, with a new foreword by Theodosius Dobzhansky, of the 1926 edition.

To review either the volume of selections from Haeckel's *Generelle Morphologie* or the reprinted translation of Berg's *Nomogenesis* would be interesting in itself, but the opportunity to review both permits a most fascinating comparison, for these books, extremely different in many ways, are yet so similar. Haeckel's *Generelle Morphologie*, published in the decade following Darwin's *Origin of Species*, was one of the most influential evolutionary treatises ever written. Haeckel was committed to the spread of the Darwinian view of evolution and to the discovery of basic evolutionary mechanisms; indeed, he was one of the few workers in the 50 years following Darwin who considered the problem of evolutionary mechanisms rather than merely constructing phylogenies (a word coined by Haeckel). His basic concept—the famous Biogenetic Law—that "ontogeny recapitulates phylogeny" provided evolutionists with a working method whereby they could unravel the otherwise unattainable phylogeny of living organisms. Because of its simplicity of statement, the clear symmetry it postulated between the two known developmental processes of ontogeny and evolution, and the considerable evidence apparently supporting it, the biogenetic law was widely accepted by biologists and served as the basis for the surge of embryological research that continues unabated to this day. Moreover, the biogenetic law has become so deeply rooted in biological thought that it cannot be weeded out in spite of its having been demonstrated to be wrong by numerous subsequent scholars. Even today both subtle and overt uses of the biogenetic law are frequently encountered in the general biological literature as well as in more specialized evolutionary and systematic studies. And references to it appear in the most unlikely books, such as the well-known Dr. Spock's *Baby and Child Care*. The chapter "Your baby's development" (Cardinal Giant edition, 1957, p. 223) opens with the statement, "He's repeating the whole history of the human race," and includes the following passage:

> Each child as he develops is retracing the whole history of mankind, physically and spiritually, step by step. A baby starts off in the womb as a single tiny cell, just the way the first living thing appeared in the ocean. Weeks later, as he lies in the amniotic fluid of the womb, he has gills like a fish. . . .