Book Reviews

Transformations in Biology

La Logique du Vivant. Une Histoire de l'Hérédité. FRANÇOIS JACOB. Gallimard, Paris, 1970. 358 pp. Paper. Bibliothèque des Sciences Humaines.

Is there progress in science, and if so, what is its direction? These questions are raised by the reading of this erudite and imaginative book by François Jacob. The questions may seem pointless in view of the current gloom over whether science has any future at all. Yet Jacob does not despair: "Today the world is messages, codes, information. What dissection tomorrow will dismember our objects in order to reconstitute them in a new space?"

In Jacob's metaphor, science is like a set of Russian dolls, one enclosed within the other, for it proceeds by a series of transformations from which entirely new views of nature emerge in succession. For Jacob, as for many other scientists and philosophers, science does not proceed in an orthogenetic fashion, moving inexorably forward along a straight line from the completed work of one genius to the thoughts and plans of another. Nor would Jacob accept the picture of scientific progress that used to be painted when I was a boy: of science radiating along many branching lines, like a growing tree or web, interconnected but constantly expanding into the outer space of the unknown. Rather, Jacob argues, science moves from one view of a natural phenomenon to a succeeding one by a large leap, the transformation being preceded by a radical shift in scientists' mode of thought, in their entire manner of regarding the objects of their inquiry. Jacob's vision of science is not unlike Thomas Kuhn's conception of scientific paradigms and their overthrow. For Kuhn there is no logical, direct connection from the paradigm scientists work with at one time to the one that eventually replaces it; the overthrow of the reigning paradigm is the result not of a gradual, continuous process but of a radically new view that often enters the scene from an unexpected direction and often meets considerable resistance. In any case, to prove his thesis for biology, Jacob offers to trace for us the development of our current view of heredity as a genetic program of instructions, as transmissible information for creating the architecture of an organism whose functioning depends upon the well-regulated interaction of its constituent parts.

How does Jacob see the history of heredity? At the risk of doing injustice to the comprehensiveness and thoughtfulness of his argument, the principal ideas may be summarized in the following manner. Prior to the scientific revolution in the 16th century, men viewed reproduction as the means of maintaining the permanence of living beings and their order. This order was expressed as a Great Chain of Being, a ladder or procession of species of increasing complexity and functional ability, leading from the smallest visible creature through man to God. God it was, moreover, who initially set this order and who endowed man with the rational soul or faculty that would allow him to perceive it. Following the rise of science, the notion of a regularity or harmony in nature persisted; things and beings acted in accordance with immutable laws. But the nature of things and beings could not be understood without finding the simpler units underlying their complexity. Reason and experimental science make it possible for us to achieve this. With Newton and Descartes nature becomes a mechanism, understood when we have recognized its parts and their manner of interaction. Moreover, there is no longer a distinct frontier between things and beings, for the nature of the living being is to be found in its complexity, in its parts and their relations. In the 17th and most of the 18th century, biologists are satisfied to discover the visible structures of which the living being is composed. This analysis leads to a resolution of the organism into its characters, and is the basis of systems of classifying species. The prevailing impression remains that of permanence, the permanence of the visible characters through succeeding generations. Preformation, or the enclosure of the structures of an entire individual within the "seed" of the parent, is a model widely accepted, for it accounts nicely for the observed continuity in the living world. This despite the fact that the enclosure of the visible structure of the organism, in however reduced a form, within the body of the parent reduces to absurdity given the numbers of generations any individual must hold. Nevertheless, the problem of reproduction as the repeated construction of organisms with identical (or nearly identical) visible structures is fundamental in the 18th century, although no entirely satisfying explanation of it is to be found in a literal persistence of visible structures through time. Toward the second half of the 18th century, with the rise of a corpuscular theory of matter, reproduction comes to be accounted for in terms of the invisible, albeit special, corpuscles of which living things are composed: there is an invisible order of particles behind the visible structure of living things, a second order of organization as Jacob puts it. What is reproduced, for the late-18th-century biologists, is the invisible organization of these primitive particles. But how is this organization reproduced? For Maupertuis a vitalistic "memory" of the past organization is retained in the germ cells and guides the development of the embryo, the primitive particles taking their proper places relative to one another. For Buffon there is a more mechanistic device, an internal template that shapes the particles into their proper organization; each species has its own "moule intérieur."

The important outcome of 18th-century biology is the attempt to reduce living things to combinations of invisible units. The idea of an internal organization, an architecture of invisible parts, is born, and this idea has several consequences. The organism is an integrated ensemble of functioning parts; its internal organization is such that it permits existence under the particular external circumstances with which the organism must contend—that is, it permits adaptation; adaptiveness is achieved by a plasticity of the internal organization, a capacity to regulate structure to assure existence and reproduction. Vitalism returns to the stage, for in order to account for life one must resort to an "internal principle of action" (Kant), a principle opposing disintegration, dissolution, disorganization. The invisible physical entities comprising the organism are harnessed by this vital principle. In the course of the century, too, the notion of a plan of organization common to all living things, based on the notion of a linear continuity between species and expressed by Saint-Hilaire and Buffon, gives way to Cuvier's view of discontinuity. For Cuvier species are isolated groups adapted to entirely different conditions of existence. "Jumps" separate the groups, and such "jumps" require fundamental change in the inner plan of organization.

With passage to the 19th century, improved methods of observation reveal what some of the previously invisible structures are: cells. The cell, moreover, is endowed with the power of continuity, and embryonic development is seen as the development of an organism from a cell. Development is not a simple enlargement of a preformed adult structure, but a truly epigenetic unfolding. This unfolding, however, must be guided by some agency, tangible template or intangible memory, that assures the achievement of the ancestral plan of organization in each generation. Most important of all, in the 19th century time plays a more important role in the genesis of living things. Living things have a history. Species are not immutable, because their plans of organization are subject to change. For Lamarck the transformation is always an adaptation. Given time and an inner capacity to respond to the challenges of the environment, the organism gradually changes its plan of organization so as to perfect itself, to make itself more adapted. Lamarck's concept is not yet evolution, for the old linear chain of beings is still there; a continuous transformation leads from one stage to the next, with spontaneous generation of the lower forms of life from the particles released by dead, disintegrating organisms assuring an endless flow but permanence of forms. In going from Lamarck to Darwin and Wallace, necessity changes to contingency. Evolution is the resultant of a constant production of small, heritable changes in the plan of organization, the propensity of living things to reproduce geometrically, and the limitations the environment imposes on the actual numbers produced. Changes arise gratuitously and are maintained by heredity, and those that confer advantages upon their bearers are chosen over the course of time. The race is to those organisms whose plans of organization permit the most rapid reproduction under the prevailing environmental conditions, and the inevitable result is adaptation. To replace the linear chain of beings, the image of a branching tree has arisen. With a theory of evolution, the old idea of a permanent harmony in nature disappears. The species that exist are not the result of necessity, they are the result of contingencies. Vitalism thus loses its force and can be readily overthrown by the end of the 19th century.

The contingency feature of the theory of evolution fits well with the idea of statistical thermodynamics which is developing in physics at about the same time. It is possible to understand phenomena in terms not of individuals but of populations. Statistical analysis permits us to discover the nature of a phenomenon when the events occurring to the individuals are too rare or difficult to witness but when they result in distinct classes of individuals that can be counted and the quantitative relationships between the classes can be discerned. Nowhere is this better seen than in Mendel's approach to the study of heredity. The success of Mendel's analysis lies in the postulation of a new group of entities, later to be called the genes and needing at first only symbolic or abstract representation, to account for certain statistical relations among classes of progeny resulting from experimental crosses. The genes correspond to a third order of organization, an organization within the cells, that makes possible the unfolding of the characters of the organism during its development. But biology was not ready for Mendel, and to catch up it needed to have a directly observable entity that behaved in the statistical fashion postulated for the genes by Mendel. In the last quarter of the 19th century and the beginning of the 20th century, the chromosomes made visible within the nuclei of cells provide these observable structures and a residence for the genes.

Gene mutations are discovered, and their contingent nature makes them an ideal material for the natural selection operating in Darwinian evolution. Nevertheless, the gene is still a black box, and to understand how it governs the development of a character requires an understanding of its structure, which amounts to a fourth order of organization. Such understanding requires the cooperation of genetics and biochemistry, the former to dissect still further the genetic unit of function and the latter to reveal the three-dimensional architecture of the gene product, the protein, and eventually the one-dimensional structure of the gene itself, a length of deoxyribonucleic acid. Indeed, from this union of biochemistry and genetics, coupled with the use of microorganisms, is born molecular biology, whose great triumph in the 20th century is to make possible an understanding of how the essentially one-dimensional, linear structure of the gene is translated into the three-dimensional architecture of a protein. The characters of the organism are now reducible to the specificities of the proteins latent in the structures of their corresponding genes. In this triumph the ideas of information theory and cybernetics play an important role, for the gene is conceived to be a message; its information implies order and opposes entropy. Regulatory circuits at the molecular level achieve the order and make possible an organism adaptively responsive to its environment.

Thus, by the latter half of the 20th century an organism can no longer be conceived without reference simultaneously to the logic of its plan of organization and to its history. For that logic is the result of its history. Indeed, the evolution of complexity is seen as a succession of integrations. Thus, we move from cell, the lowest level of integration, or *integron* in Jacob's terminology, to multicellular organism to society. Problems remain, however; for how is the origin of that first ensemble, the cell, to be imagined? And how is mind to be understood? In any case, with the development of man's rational faculty arose the possibility of cultural transmission, which is essentially a second system of heredity, and the beginning of cultural and social evolution, of which science is a part. And in the evolution of science, new visions of nature replace each other like the emerging Russian dolls.

At this point we return full circle to the questions posed at the outset. Do we have any grounds for expecting that further scientific transformations will occur, new Russian dolls emerge, other than that they have in the past? For Gunther Stent, like Jacob a molecular geneticist, we do not. In his provocative book *The Coming of the Golden Age,* Stent argues that the springboard of all intellectual creativity, including science, is a sublimated will to power. The will to power seeks to make the individual freer by increasing his mastery and control of external circumstances. Indeed, progress in science may be measured by the extent to which men collectively have gained such control. But the will to power is self-limiting, according to Stent, for when it achieves the security and affluence which are its end, the drive to know and to control is abated. Hence the end of progress, and for Stent this is in sight. Is Jacob's guarded optimism or Stent's determined pessimism justified? For me the concept of increasing levels of integration has provided an answer. If, as I believe it is, the progress of science is indeed measurable by the control it offers man of his environment, then there is a different way in which science is self-limiting. Man is related to his environment in a higher order of integration, such that a harmonious interplay must exist between them: man depends upon his environment, and the environment is shaped to a certain extent by man. These relationships must be regulated: there are constraints on man's control of his environment as there are constraints on the extent to which the environment can modify the plan of organization of man. Thus science itself is regulated in a feedback manner: the environmental changes it causes through technology come back to affect the evolution of man and all living things, thereby creating new challenges to the will to power. In this way science may be limited in its rate without being ground to a halt. The future may bring an entirely new way of looking at the integration of reproducible patterns of organization. And such a transformation will depend in turn on an evolution, of man, life, and their environment, along paths we cannot predict.

If Jacob's book helps to dispel the gloom of a projected end to progress, it leaves one with serious questions about the writing of histories of science. The picture I have of science is that of an evolving system: its direction is not strictly determined; what it is at any given time depends, of course, on what has preceded; it is contingent upon events that cannot be predicted but that assure still further transformation. In hindsight, the appearance of successive transformations, of new Russian dolls, may be hard to resist. The virtue of hindsight is that it permits one to order the events of history in a manner that fits some *post hoc* rational construction, no matter how disordered and unrelated the events may have seemed to the contemporary observer. As Jacob points out with respect to evolutionary theory, the gravest difficulty with history is its inaccessibility to direct verification. The historian might as easily see in our intellectual past the successive emergence of Russian dolls or a more continuous flow of ideas, or perhaps even share the Kuhnian vision of logically unrelated revolutions, depending on some theoretical conception or philosophical commitment (itself the product of evolution) that is consciously or unconsciously directing the vision.

It is interesting that in Jacob's book little is said about the personal lives of the scientists whose work he discusses with care, of the social and economic milieus of their lives and thought. Jacob comprehends their work after the fact, seizes upon it and synthesizes it in an esthetically satisfying plan. But have we really succeeded in knowing how the transformations have taken place? Was Mendel really imbued with a statistical approach to the study of heredity? If so, how did it come about? Was Boltzmann's statistical conception "in the air"? If so, in what manner did it take root in another mind? Are the receptivities of individuals to new ideas "in the air" a function of psychological factors, of the social milieu, of the "accidents" of their lives? The complete answers to such questions may require a degree of historical detail that is unattainable. But is this not the classic problem of historiography? Does one write a history or a likely story, an interpretation based on current views? These thoughts are not meant to depreciate Jacob's lucid account of man's changing ideas about heredity. Like a truly great intellectual history, it seizes and stimulates the imagination. It will stimulate biologists and philosophers of biology for a long time to come.

ARNOLD W. RAVIN
Department of Biology and *Committee on Conceptual Foundations of Science, University of Chicago, Chicago, Illinois*

Rich Material

Insect Ultrastructure. Royal Entomological Society of London Symposium No. 5, Sept. 1969. A. C. NEVILLE, Ed. Published for the Society by Blackwell, Oxford, 1970. viii, 188 pp., illus. $15.

At the 1860 soiree of the Entomological Society in St. Petersburg, Karl Ernst von Baer said that scientific studies involved an apprehension of general plans through the observation of detail and that for this pursuit no group of animals offered richer material than the insects. In the first contribution to this symposium on insect ultrastructure, D. S. Smith sets the stage for a modern justification of the claim. The book is the best evidence in print to support chauvinistic insect physiologists in their contention that insects provide uniquely suitable systems for tackling fundamental problems. Almost any of the ten chapters has ideas of general interest and makes an unspoken plea for studies on animals other than rats.

A. C. Neville considers the structure and mechanical properties of cuticle as a two-phase system of fibers and matrix. The fibers are oriented parallel to one another in laminae which may be arranged orthogonally, in preferred layers with a clockwise rotation, or helicoidally. The direction of rotation is the same on both sides of the whole animal so that insects are asymmetrical at the microfibrillar level. This finding perhaps supports the notion that cuticle architecture is determined by a process akin to crystallization. T. Weis-Fogh reviews some of the information on cuticle formation and contributes several new observations suggesting that microfiber orientation is determined by the intrinsic properties of chitin rather than through an orienting force exerted by the cells. The scanning electron microscope has given a new lease on life to insect morphologists, and H. E. Hinton contributes some beautiful pictures of insect surfaces, particularly cuticular diffraction gratings and interommatidial setae. The primitive surface microsculpture is a pattern of polygons reflecting the distribution of epidermal cells. W. H. Telfer and D. S. Smith discuss the problems posed by blood precursors being taken up and transformed into the intricately structured egg. The simplicity of insect organization in epithelial sheets and cylinders makes them particularly favorable for studies on transport and absorption. M. J. Berridge illustrates the role of extracellular compartments in the absorption of organic molecules, which may be linked to active transport of ions and water by the intestine. His model may also explain water uptake against an osmotic gradient. C. T. Lewis describes chemoreceptors that may be excited by a single molecule and mechanoreceptors that respond to distortions of 30 to 100 angstroms. The