Chapter 1
The Biological View

The Genetic Program

Life differs from other natural phenomena in that it has an internal genetic program that guides its development and behavior. Other, nonliving elements of nature are subject more or less entirely to external forces or occur at random. Consider the waves on the sea, the clouds racing across a November sky, a stone falling to the ground, a melting ice cube—these things respond almost wholly to external influences. Water has an internal structure that determines that it cannot burn, but this internal structure is mostly irrelevant to whether the ocean-waves are big or small, from the north or west. When physical phenomena do show behavioral regularities independent of external forces, they are chaotic and usually increase the total disorder of the system, in accordance with the law of entropy. Where order seems to increase, as in crystallization, the order is entirely predictable, repetitive, and uniform.

Biological phenomena have a different kind of individuality; they have a program. Organisms function and develop in a way determined largely by the genetic endowment, although some aspects of the way in which the genetic plan is realized depend on external factors. A rosebud swells and blossoms in a genetically determined process, but the appearance and strength of the blossom will be affected by factors like soil quality and access to light. A program encoded in the substance of the genes guides the growth of an organism and its functioning, exploiting various aspects of the external surroundings. There is a creative interplay between the internal structure of a particular living organism and its outside world.

In outward appearances biological and nonbiological matter are often difficult to tell apart. Readers may recall Jacques Monod's intriguing discussion of the problems in programming a Martian computer to distinguish artificial from natural objects, nonliving from living. Monod's machine had to recognize that the structure of a living being "owes almost nothing to the action of outside forces, but everything, from its overall shape down to its tiniest detail, to 'morphogenetic' interactions within the object itself. . . . External agents or conditions . . . are capable, to be sure, of impeding this development, but not of directing it, nor of prescribing its organizational scheme to the living object" (Monod 1972:21). So the rosebush is by no means a product of its environment: it owes its basic properties of shape, structure and coloring to its internal structure; it develops according to an internal, genetic clock by exploiting certain aspects of its environment, which may be available in varying degrees. For Monod, living matter has a genetic program, and nonliving matter does not; that is the difference between an amoeba and a crystal.

Modern biology has focused largely on this genetic program—its chemical basis, its effects, the kinds of things it can control, its methods of ensuring stability while allowing an enormous range of individual patterns, its ability to copy with accuracy and to change, its ability to explain why certain species flourish in certain surroundings, and so on.

This has not always been so. Molecular biology is less than thirty years old and modern biochemistry is not much older. But even in earlier times there was a similar perspective. A theory held sway for many centuries that the sperm contained a perfect miniature creature, a "Russian doll" or "homunculus," which simply grew bigger as time went on. This was Preformationism, and Stephen Jay Gould shows that it was quite a reasonable theory to hold in the eighteenth century (1978: 202–6). This theory of embryological development is now regarded as wrong, but it does suggest that the question of how to account for the way in which living things develop has long been a basis for theorizing and that scientists have long held that the development is internally directed in some way.

The modern study of heredity began with the work of Gregor Mendel (1822–1884), an Augustinian monk from what is now Czechoslovakia. Mendel grew pea plants, cross-pollinated them, and counted the number with certain characteristics in each generation. He compared the position of the flowers on the stem: they might be distributed along the main stem (axial) or bunched at the top of the stem (terminal). Crosspollination of axial and terminal flowers always yielded axial flowers in the first generation. Of 858 plants in the second generation, all of pure axial parentage, 651 had axial flowers (he called this the *dominant* characteristic) and 207 terminals (the *recessive* characteristic), a ratio of roughly 3:1. Mendel then compared factors like the shape of the seeds, the color of the albumen, and the shape and color of the pods. He found that under parallel breeding conditions, the second generation yielded about a 3:1 ratio of dominant characteristics (round seeds, yellow albumen, green pods) and recessive characteristics (wrinkled seeds, green albumen, yellow pods). The segregation of factors in this 3:1 ratio constituted Mendel's law of segregation. The various factors segregated independently of one another, so that all possible combinations arose: axial flowers with wrinkled seeds, terminal with round seeds, round seeds with green pods, and so on—the law of independent assortment.

These two laws describe a kind of regularity that does not normally occur in nonliving material; the properties are not regulated by external forces like the ocean waves, nor do they occur at random like molecules in Brownian motion. The laws are abstract, mathematical statements about pea plants. They tell us that certain surface properties occur because a principle of dominance affects the combinations of underlying factors. Mendel assumed that these factors and principles were physically encoded, but he did not know how. He postulated them as purely theoretical units, and, apparently because of that, his work was ignored until the turn of the century.

In the course of the last eighty years a theory of heredity has emerged that is one of the more impressive bodies of scientific knowledge. Mendel's main claims have been upheld by subsequent work, even if some of his results were not entirely justified by his experiments. It is known now that Mendel's "factors" can be reduced to material units, now called *genes*, and that the genes are arranged along chromosomes and contain DNA with instructions in the genetic code. The 3:1 ratio is known to follow from the fact that most plants and animals have two and only two copies of each gene and pass one or the other to the next generation. Since the gene copies can be on separate chromosomes, they can assort separately because of the method of cell division called meiosis: for each gene, each daughter cell receives only one copy from the father and one from the mother. That is what sexual reproduction is all about, or so they tell us.

Progress in this area has been rapid and a good deal is known about the chemistry of the genetic program. Biologists have broken down heredity into its basic combinatorial elements, the genes. The cells of a given organism have different functions and structures but the same genes. The genes of all organisms consist of the same substances, deoxyribonucleic acid (or DNA to its friends) and ribonucleic acid (RNA). After discovering the structure of DNA, Watson and Crick's famous double helix, geneticists have often worked at a chemical level and have related particular genes to particular portions of nucleic acid molecules. They have cracked much of the chemical code that conveys instructions for the functions of the genes, the devices that permit genes to be copied as new cells are made, and the mechanism for translating the chemical script of the genes into the chemical structure of proteins, the essential product of the genes. At this level the biochemistry of life turns out to be rather similar for all organisms. "What accounts for the difference between a butterfly and a lion, a chicken and a fly, or a worm and a whale is not their chemical components but varying distributions of these components . . . specialization and diversification called only for different utilization of the same structural information. . . . It is thanks to complex regulatory circuits, which either unleash or restrain the various biochemical activities of the organism, that the genetic program is implemented." (Jacob 1978)

The chemistry of heredity, molecular genetics, has been at the center of modern biology. Although much is known about the mechanisms that transmit various properties, much less is known about how those properties, say the blueness of the eyes or the roundness of peas, emerge from a certain genetic structure, whether they are specified directly in the genes or follow less directly (epigenetically) as a result of the mechanicochemical or maturational properties of a developing embryo. For many questions, therefore, the complexities of this chemistry can safely be disregarded, to the relief of most readers of this book, perhaps, not to mention the author. Thomas Hunt Morgan, who ran so many of the early genetic experiments with fruit flies, stressed this point in his Nobel Prize address in 1933:

What is the nature of the elements of heredity that Mendel postulated as purely theoretical units? What are genes? Now that we can locate them in the chromosomes are we justified in regarding them as material units; as chemical bodies of a higher order than molecules? Frankly, these are questions with which the working geneticist has not much concern himself, except now and then to speculate as to the nature of the postulated elements. There is no consensus of opinion among geneticists as to what the genes are—whether they are real or purely fictitious—because at the level at which the genetic experiments lie, it does not make the slightest difference whether the gene is a hypothetical unit, or whether the gene is a material particle. (Morgan 1935)

So Mendel and Morgan could formulate important biological laws without doing nucleic acid chemistry. I stress this point because it will be important in later chapters when I present claims about the genetic basis of language; there we shall engage in the abstract biology of Mendel and make no special biochemical claim. The subsequent success of molecular genetics confirms the fundamental approach taken by Mendel; his laws suggested other questions and hypotheses and can now be incorporated into a wider body of work of enormous explanatory power in domains far beyond wrinkled versus round peas. In the words of Salvador Luria:

Today man looks upon the specific materials of heredity, including his own, from the vantage point of a comprehensive, intellectually satisfying framework of knowledge. Future research will undoubtedly add new findings, but the basic structure of biology, resting on the twin foundations of evolution theory and molecular genetics, is here to stay. (1973:26–7)

The success of this research program now shapes the kinds of questions that biologists ask even when they are not doing molecular chemistry.

Alongside work on molecular genetics and also escalating in the second half of the nineteenth century, evolutionary concerns provided the second major thrust of modern biology. Under this rubric biologists have studied the interaction between the range of biological options and the environment such that certain organisms have emerged as the most successful. An individual organism inherits a set of genes, a *genotype*. The genotype determines the organism's potential for adapting to its environment; it sets the boundaries of an organism's performance by determining what its cells can do. In organisms with sexual reproduction, an offspring derives its genotype partly from one parent, partly from the other, according to the principles of genetics. Since parents differ in the structure of certain genes, new combinations may arise in the embryos of each generation. The range of genetic variability within a species is multiplied by this method of reproduction, therefore.

A species can be defined in terms of a range of genetic programs that occur in particular embryos, but another kind of variation occurs through *mutation*. Genes are extremely stable entities, and replicate themselves accurately through countless cell divisions. But sometimes the vulnerability of the chemical structure of the genetic material or an error in copying this material results in a changed or mutant gene, always a matter of chance. These mutations do not necessarily change the chemical structure of an organism but, rather, the regulatory processes. A minor modification, redistributing the structures in time and space, is usually enough to change profoundly the shape, performance, and behavior of the final product. Mutations occur all the time but at a low frequency, so that a given gene may undergo a mutation only once in several thousand generations. Such mutant genes provide the diversity essential for evolutionary adaptations. Some of these mutant programs may flourish in one set of surroundings or perhaps die out altogether.

A mutant program will survive and prosper if it yields a phenotype with some *adaptive* feature. This means that evolution is often fairly discontinuous. If some feature emerged in certain species that was highly adaptive, permitting longer survival and greater reproductive possibilities, it might be propagated rather rapidly. A lively debate has developed in recent years on this issue: Stephen Jay Gould, among others, argues that evolution does not occur as a gradual process of innumerable small changes, as Darwin had imagined. Instead, the fossil record suggests long periods of stability punctuated by short periods of rapid change, when new forms suddenly appear and spread.

Hugo de Vries discovered the proper role of mutations at the beginning of this century. He rediscovered the long-ignored work of Mendel and filled a gap in Darwin's view of the production of hereditary variety, which lies at the basis of natural selection. Identifying the role of mutations opened the way for investigating the biochemical basis of evolutionary theory. Monod observes that Darwin had no "idea of the chemical mechanisms of reproductive invariance, nor of the perturbations which affect these mechanisms. But it is no disparagement of [his] genius to note that the selective theory of evolution could not take on its full significance, precision, and certainty until less than twenty years ago" (1972:32–3). Again we see that it may be reasonable to make biological claims without necessarily providing the biochemical specifications.

Selection does not operate directly on genes but on *phenotypes*. An individual's phenotype is the set of acquired characteristics, like having axial flowers or being tall, dark, and handsome; it is the mature expression of the genotype within a given environmental setting. So the selection of reproductively successful phenotypes entails an increase of the genes that lead to those phenotypes. This view can be contrasted with that of Lamarck (1744–1829), who thought that acquired characteristics can be inherited. So swimming birds were thought to have webbed feet because their ancestors had stretched their toes and the skin between them during their swimming activities. Today this hypothesis is not accepted. Instead natural selection leads to exactly the result that Lamarck wanted to explain: the close interconnection of anatomical adaptations and specific performances. If a new feature serves the organism well, it is adaptive; genes yielding a more adaptive phenotype have a better chance of survival in the reproductive process. Under the modern view evolution makes the best of whatever genetic material is available at some time, tinkering with what is already there and not following the canons of optimal design.

Most aspects of modern biology depend on developments in the areas of molecular genetics and evolution theory. The idea of the gene is at the center of biology. The essence of the modern biological view of any organism is very simple: the genotype and phenotype are described, distinguishing the relevant chemical properties and functions. There will be a close, highly deterministic relation such that a particular genotype, exposed to a certain environmental setting, will develop into a particular phenotype. The scope for accidental variation in biological organisms is very, very small. Any two rosebushes share many properties of shape, color, internal structure, chemistry and development. The similarities arise by virtue of identical aspects of their genotypes interacting with identical aspects of the environment. The differences depend on differences in the genotypes or in the environments. Within a given species genotypical differences are small, but environmental differences may be substantial: access to soil types, light, and water vary, as do proximity to industrial pollutants, attention by an experienced gardener, and other factors. The biological view is that an organism develops along one of a number of possible paths made available by inherited, genotypical properties; this development takes place if certain environmental conditions are met. External, nongenetic factors may determine whether a person's arms are particularly muscular, fat, shaven or tattooed, but it is clear that human arms do not emerge as a result of people's upbringing as children; rather, human beings are designed to grow arms of a certain shape, size, and structure. This view has been elaborated since Mendel cross-pollinated his peas, and some aspects, notably the molecular chemistry involved, are now quite well understood.

The regularities noticed by Mendel are of a kind not found in the physical, nonbiological world. They have given rise to what may seem to be a highly mechanistic, deterministic view of organisms, but mutations and variations in the genetic programs of individual embryos afford enormous scope for variety, as is clear when one surveys the range of species that occur at this moment and the range of information that one gene can specify. There is also scope for enormous creativity, as we shall see when we consider human beings and their ability to know things.

Man and Mind

Genetic mutation, interacting with the demands of natural selection, gave rise at a certain stage to a new species of organism, one that could think and speak: *homo sapiens*. By virtue of their analytical and communicative skills human beings were able to change their relationship to their environment to some extent, pooling resources, migrating, protecting themselves against nature's elements, and even molding the environment to their own conscious wishes, thereby altering the demands of natural selection. From the first hominids the species developed slowly to the point that its members devised agricultural systems, apparently only within the last 10,000 years. More recently they invented the wheel and primitive machines, began to smelt and shape metals, and finally devised the whole apparatus of modern, industrial society. In the development from the earliest hominid forms, some genetic changes have occurred, brought about by chance mutations and perpetuated by natural selection. The changes in available skills and machines arose not so much through processes of mutation and natural selection, however, as through analytical advances propagated through cultural development and communicated traditions. Cultural evolution does not negate biological evolution but superimposes itself on it. Cultural traditions complementing the slower biological processes have led to some highly refined achievements, as manifested in the plays of Sophocles and Shakespeare, Beethoven's string quartets, the paintings of Vermeer, the ingenuity of Watson and Crick, Truffaut's movies, and even more everyday things like chess matches, crossword puzzles, and soccer games. The cultural traditions that give rise to such achievements depend on a rich communicative system.

The key to cultural evolution is the human mind, particularly that aspect of it which is responsible for the linguistic capacity. This is what enables people to develop machines, to exploit native ingenuity for conceptual novelties, to engage in complex cooperative enterprises, to think abstractly, to recall past experiences and categorize them as a basis for generalizations and predictions for the future, and even to express individual emotions in a form that can be interpreted collectively in a theater or a concert hall. Not all of these properties are unique to human beings, but human language differs fundamentally from the communication systems of other animals. Bird songs, for example, convey only a very limited range of messages, whether they are fully inherited, as with the European cuckoo, or learned in the nest, as with the male bullfinch or the nightingale.[1] Even chimpanzees, with brains physically similar in some ways to man's and perhaps also with an ability to represent things with symbols, can use "words" and sign language—features of human language—only in a highly restricted way, even after elaborate training (although popular literature sometimes depicts them curiously as having the same capacity as human beings but simply failing to exercise that capacity by some remarkable accident). Chimpanzees may be able to communicate with each other in ways that we do not understand, but those ways, whatever they are, differ from the ways in which human beings use language. Human language is unique in its flexibility and creativity, in ways that will be shown in later chapters. It provides a means of expressing ideas, of knowing the world symbolically and of communicating this knowledge. A human being does not have to live through an experience personally in order to know it, and novel experiences, generalizations, thoughts, and predictions can be communicated in elaborate detail. The capacity for symbolic language provides the basic means for our cultural evolution.

The biological basis for these special human developments was the brain, presumably emerging through the normal interaction of mutation and selection and now constituting the most distinctive anatomical feature of *homo sapiens*. Although the functions of the brain are not proportional to its weight, the brain's weight does impose limits to intelligence. This is how Luria sees these things:

In weight, but above all in complexity, the brain of man is unique. A few million years ago, more than a hundred thousand generations, and after a much longer period of relative stability, the hominoid brain started to grow to the enormous proportions that it has today, about one fortieth the weight of the body. [Recent work suggests that this growth took place explosively.] This growth has involved mainly those parts of the brain concerned with the higher functions of cognition and co-ordination—the cortex. The idea that some sort of directional process must have taken place seems inescapable. Biologically speaking, this means that once certain mutations started to produce a more powerful brain system, this system proved so valuable for differential reproduction that any new gene combinations that perfected it further were powerfully favored. One might also say that in the recent evolution of man practically everything else was neglected in favor of increased brain power. Man lost the protective fur of the apes, their early sexual maturity, and many other adaptations useful to lower mammals. In exchange he won the brain and with it the faculty of language, speech, thought, and consciousness.

The central role of speech and language in the development of thought-power and in the success of man as a species suggests that a major part of the evolution of the human brain from that of man's apelike ancestors must have been a continuous perfecting of the speech centers, which are located on the left side of the brain. (1973:138–9)

On the evolution of language, Monod argues that

It is evident that, once having made its appearance, language, however primitive, could not fail greatly to increase the survival value of intelligence, and so to create a formidable and oriented selective pressure in favour of the development of the brain, pressure which could never be experienced by a dumb species. As soon as a system of symbolic communication came into being, the individuals, or rather the groups best able to use it, acquired an advantage over others incomparably greater than any that a similar superiority of intelligence would have conferred on a species without language. . . . The selective pressure engendered by speech was bound to steer the evolution of the central nervous system in the direction of a special kind of intelligence: the kind most able to exploit this particular, specific performance with its immense possibilities. (1972:126–7)

There are other examples of evolution prizing one specialized faculty and producing an enormous development of the corresponding part of the brain. So electric fishes, which interpret their world via electrical fields, have a spectacular enlargement of those parts of their brains concerned with emitting, receiving, and analyzing electrical impulses. Similarly the bat's brain has tremendous enlargement of areas connected with hearing. Seven-eighths of the bat's brain is devoted to hearing, the means for the bat to interpret signals reflected off objects in its path, perhaps an obstacle or a nutritious insect. The workings of evolution are channeled in a certain direction because some new feature arising by chance mutation makes available a higher level of performance and adaptation.

If the capacity for symbolic language is so central to an understanding of humanness, if it is essentially the biological basis for human culture, the question arises: what does biology contribute to human language? Without human companionship a child does not develop a language, as is clear from so-called wolf children, who have lacked normal human interaction in their formative years. Under normal circumstances, however, a child may develop any one of the many natural languages, whether English, Hindi, Japanese, or Javanese. So it is clear that particular languages are not genetically encoded and that the environment has some kind of shaping effect; people speak different languages which reflect differences in the verbal environment to which they are exposed as children. In which case, why do "biologists believe that the structure of language is not fully learned by experience but is in part at least embedded in the network of connections of the human brain" (Luria 1973:140)? We shall answer this question in some detail in the next chapter, and the book as a whole will address the issue of how we can discover the biological and environmental contributions to the linguistic capacity that people attain in maturity.

Figuring out the proper balance between the contributions of heredity and environment, between nature and nurture, has become a standard activity for biologists. Consider the liver and the kidney, which have no mechanical functions, only biochemical tasks, for which their shape and surface are not important. On first principles a physicist might expect these organs to be spheres, the solid form of minimum energy. But they are not. The liver is shaped like a French beret, the kidney like a bean. There is no known functional or environmental reason for them to have these shapes, but the shapes result from our genetic endowment. Biologists do not know *how* the shapes of the liver and the kidney are controlled by the genes, but they design experiments to determine what the genetic contribution must be or at what stage elements of it are shut off (much of the genetic system is devoted to turning genes on and off, rather than to determining specific traits). The contribution may be complex, as with human body height, which is determined by many genes acting at different times to control the growth of an individual's bones.

It is uncontroversial to hold that human beings are designed to grow a liver and that an individual's liver does not grow as a response to purely environmental forces. It is uncontroversial because environmental conditions for the growth of the embryo are not such that one can claim that the liver is in any sense just a product of the external environment. In general whenever biologists see an intricate system emerging in a more or less uniform way and not simply determined by external forces, they assume a specific genetic structure that guides and directs the growth of that system if certain environmental needs are satisfied. The reasoning is based on arguments from the deficiency of the stimulus, showing that the stimulus, the shaping effect of the environment, is not rich enough to determine the intricacies of the mature system. So the shape of the liver is not determined by the demands of external factors, but is due to internal properties. Those internal properties may stem directly from some genetic specification or may follow less directly, being epigenetic, due to the mechanicochemical constraints that arise in the genesis of the embryo but are not actually encoded in the genes. They may also vary slightly from one embryo to another. For precisely the same kind of reason, arguing from the deficiency of the stimulus, biologists like Luria and Monod assume that cognitive and linguistic abilities "grow" along a predetermined, genetically directed course under the triggering effect of the environment.

This reasoning is pursued not only for linguistic abilities, as in this book, but also more generally for other aspects of our cognitive development. In fact, investigating the genetic and environmental contributions to linguistic capacities should be seen as one step toward understanding the human mind from this point of view.

> From thinking of language as a dual entity consisting of a genetically determined component inscribed in the structure of the brain and a learned component derived from experience it is an easy step to a more general conception of the human mind. . . . To the biologist it makes eminent sense to think that, as for language structures, so also for logical structures there exist in the brain network some patterns of connection that are genetically determined and have been selected by evolution as effective instruments for dealing with the events of life. . . . Perfecting of these cerebral structures must have depended on their becoming progressively more useful in terms of reproductive success. For language this must have meant becoming a better instrument in formulation and communication of meaning through a usable grammar and syntax. (Luria 1973:140–1)

This is not a new view: in his notebooks Darwin applied his materialistic theory of evolution to all living phenomena, including what he called "the citadel itself," the human mind.[2]

Life has evolved to its current state and will continue to evolve by the creative interplay of genetic variations and mutations and the natural selection that promotes any biochemical innovation offering increased fitness. The human brain and mind are among the most remarkable biochemical inventions, and biologists seek to unravel the nature of the mechanisms responsible for these complex phenomena. Monod, noting the shock of many philosophers at the idea that the basic shape of language is genetically determined, regards it "as a most natural conclusion . . . provided its implicit biological content be accepted I see nothing whatever wrong with it" (1972:129). He identifies two major domains of research for the immediate future: "The present challenge, as I see it, is in the areas at the two extremes of evolution: the origin of the first living systems, on the one hand; on the other, the inner workings of the most intensely teleonomic system ever to have emerged, to wit, the central nervous system of man" (p. 132). The second of these domains is the concern of this book.

Notes

1. We know this because cuckoos reared in isolation, deafened, or exposed only to noncuckoo songs still come to sing the typical song of their species. On the other hand, a young bullfinch raised with a canary will sing the canary's song and pass the canary's song on to its own offspring (even where the offspring is exposed not only to their father's "canary" song but also to the normal bullfinch song). See Tinbergen 1969 for many intriguing examples of this kind of thing. The work of ethologists like Tinbergen is designed to distinguish the contribution of genetic and environmental factors to animal behavior and takes a perspective similar to ours in many ways.

2. This is one respect in which Darwin differed from Wallace. Although also arriving independently at the idea of evolution by natural selection, Wallace held that the development of the human mind required some different kind of explanation.

Suggested Reading

For an introductory account of these biological considerations and the genetic underpinnings, Luria 1973 is excellent. For a more detailed account of the genetics involved, see Dobzhansky 1970.

Loren Eiseley's *Darwin's Century* (Garden City, N.Y.: Doubleday, 1958) gives a full and fascinating account of the emergence in the nineteenth century of the concept of evolution and of the biological perspective just described. Eiseley examines successful and unsuccessful lines of thinking, empirical foundations for various ideas, philosophical and religious influences, the effects on contemporary intellectual life. Darwin's materialist attitude to the evolution of psychological properties of man can be seen most clearly in his notebooks on psychology and metaphysics, published in H. E. Gruber and P. H. Barrett *Darwin on Man* (Chicago: University of Chicago Press, 1974). Horace Judson's *The Eighth Day of Creation: Makers of the Evolution in Biology* (New York: Simon and Schuster, 1979) gives a comprehensive but eminently readable account of the major discoveries in molecular biology "that drove the abstraction of the gene down to the physical reality" of the structure of DNA.

Gould 1978 and Gould's more recent *The Panda's Thumb: More Reflections in Natural History* (New York: Norton, 1980) are delightful collections of essays, most of which first appeared in *Natural History Magazine*. They cover many different aspects of evolution theory, and the later book has essays on the current debate about whether the evolutionary process is essentially gradual or discontinuous.