Alfred Korzybski Memorial Lecture 1967

TOWARDS A PHILOSOPHY OF BIOLOGY*

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I

The new biology has been built in the decades since the second war, in large part by young men whose careers the war had interrupted, and who had to make a fresh start at the end of it. Many of them had been employed on physical problems during the war and physics had come to seem rather barren to them, surrounded with unpleasant hints of regimentation and secrecy. By comparison, biology looked invitingly like open country. Leo Szilard characterized his unspoken belief and theirs simply as 'What I brought into biology was an attitude: the conviction that mysteries can be solved. If secrets exist, they must be explainable.' And the word was out that they were beginning to be explained: the chemists Linus Pauling and Desmond Bernal were already doing impressive work on the structure of proteins, and the physicist Max Delbrück led a program which might unravel the genetic tape or blueprint within the cell.

In moving to biology from physics, the newcomers naturally brought with them the habits of thought that had been successful in physics. For example, it had become commonplace in physics to think of any material body as an arrangement of large numbers of atoms, repeated in some regular way; and to explain the behavior of the body and derive its properties by going back to these basic units. Anyone now coming into biology was sure to look for a similar unit of structure there. Evidently, this unit of structure in living matter was the cell.

The most arresting discoveries that have been made in the biology of the cell concern the inborn instructions which regulate it — that is to say, the genetic material which goes from one generation to the next, and acts as a blueprint or program to direct the sequence of chemical processes that makes up the life cycle of each cell. The facts are now well known: the main activity of a cell is the manufacture of many specific proteins, and the instructions for the manufacturing process are carried in simpler material in the cell nucleus, the nucleic acids.

In 1950 bold men were asking themselves what could be the structure of the nucleic acids which would give them the power to copy themselves when the cell divides in two, and supply each daughter cell with an accurate copy. And in 1951 James Watson and Francis Crick revealed the startling simplicity of the double helix of the DNA molecule.

Since there are many varieties of living creatures, and many genes in each, there are many different forms of DNA, in each of which the sequence of bases is different and is characteristic for some chemical process to make a protein in that creature. Crick and his colleagues have since shown that the sequence of bases in a molecule of DNA spells out the twenty amino-acids which in turn make the proteins. We have a simple hierarchy: the four bases are the four letters of the alphabet, each set of three letters makes up a word which is a fundamental amino-acid, and the twenty words in their turn are assembled into different sentences which are the different proteins.

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A cell is not at all a simple unit: and the very fact that there are creatures that consist of a single cell shows that it is effectively a microcosm of life. Since life is evidently not a thing but a process, it follows that we have to study the cell not merely as a structure, but as a changing structure. The cycle of events that follow one another within the cell is a life cycle, but more than that, it is life. But the basic structures and sequences of life follow from those of dead nature without the intervention of any special powers or acts. I want to make this point clearly and with force. There is no place for vitalism in the analysis of the cell. Certainly life, the perpetuation of form and process from generation to generation, is extraordinary: but whatever is extraordinary about it is not at the level of the atoms, or the molecules, or the genes and chromosomes and enzymes and electric discharges, the interlocking sequences of instructions and communications, which actually make the body and the brain work. All that is understandable in physical terms, without the intervention of any mystic principles.

From the time of Henri Bergson and before, philosophers have been wrong-headed when they have tried to find a special sanction for the uniqueness of man in the mystery of life. What makes man unique is his command of cognitive knowledge, and that is not a property of life in the individual cell; on the contrary, it is precisely what man does not share with a cell — even with any other assembly of cells. The mystery is not in the cell: the mystery is that the cell is not a mystery to us — the mystery is that man can understand so much of nature.

None of this is to deny that life as a process has a different character from the other processes of the natural world. Life is a very specialized and accidental phenomenon: it derives its character (as well as its mystery) from the fact that it is improbable. I would put this forward as a philosophical principle, that life is unique, and the forms of life are unique arrangements of matter, precisely because they are accidental. I shall return to the statistical reasons and implications of that in good time.

If an arrangement of matter is unique, it must be accidental — that is, it must be singled out from all the other possible arrangements by an action which is arbitrary and highly improbable. Erwin Schrödinger took a similar idea from Max Delbrück, and Delbrück in his turn had been inspired to turn to biology by an essay on Light and Life by the greatest of all the quantum physicists, Niels Bohr.

Delbrück has recorded frankly what troubled him about physics in the 1930's and what he hoped to find in biology. Physics was exploring the behavior of matter on the minute scale of quantum changes. It seemed to Delbrück that there was something logically (and aesthetically) wrong in the disproportion between the tiny quantum effects and the vast apparatus which was required to demonstrate them. He hoped to find in living matter a kind of resonator or multiplier, which would express new physical laws because it would display in visible form the impact of single quantum events.

In any simple sense, Delbrück turned out to be mistaken in his hope. Yet the crucial thought in Delbrück and Schrödinger is exactly right; as so often in science, the wrong guess is better and more creative than no guess at all. The cell is sensitive to single and unpredictable events which abruptly change its potential and that of the generations of cells that derive from it. The development of life from one form to another is unlike that of the rest of the physical world, because it is triggered by accidents, and they give each new form its unique character. Life is not an orderly continuum like the growing of a crystal. The nature of life is only expressed in its perpetual evolution, which is another name for the succession (and the success) of its errors.

II

Since I began this essay by analyzing the cell, I should now round it out by discussing the process of evolution. There are five distinct principles which make up the concept of evolution, as I interpret it. They are:

a) family descent;

b) natural selection;

c) Mendelian inheritance;

d) fitness for change;

and e) stratified stability.

I shall present them in what is in effect their historical order; for evolution was not formed as an explanatory concept all in one leap; it grew by degrees from distinct strands, which came together one after another. The logic of evolution requires all five strands, in my view.

The first and central strand is simply the idea that the likenesses between different species of plants and animals are, literally, family likenesses; they derive from the fact that the species have a common family tree and ancestry. This idea is older than The Origin of Species, and goes back at least to Charles Darwin's grandfather Erasmus; yet (as a matter of history) this is what gave the book its shocking and decisive impact in 1859.

The principle of natural selection is the second strand in evolution; it is what gives the observations a structure and turns them into a theory. Selection is not strictly a causal mechanism, but a statistical one; and evolution is therefore the work of chance. Darwin was in no doubt about that —

> Heaven forefend me from Lamarck nonsense of a 'tendency to progression'

— and neither were his readers. We think of them now as outraged simply by the implication that man had not been specially created, as the Old Testament recorded, but was descended from the same stock as the apes and other mammals. But they were more deeply outraged, in their religious and moral convictions, by the central place of chance in Darwin's theory of evolution.

Darwin had no theory of inheritance that could account for the persistence of a variant form from generation to generation. In this respect, his trust in natural selection as an agent that could form permanent species was an act of faith, backed only by the known experience of plant and animal breeders.

In essence, this difficulty was resolved by Gregor Mendel in the decade that followed the publication of The Origin of Species, and Darwin should have known that. Mendel guessed and then proved that every heritable trait is governed by a pair of discrete units, what we now call genes, one from each parent — of which one may mask or dominate the expression of the other, but both of which will be preserved and handed on to some of the offspring. This theory of Mendelian inheritance is a third and essential part of a soundly based theory of evolution.

In my view, it is necessary to add to a realistic account of evolution two further principles which govern its operation as we witness it. These two strands are

d) fitness for change

and e) stratified stability.

That is to say, they are concerned, the one with the variability of living forms, and the other with their stability; and between them they explain how it comes about that biological evolution has a direction in time — and has a direction in the same sense that time has. The direction of evolution is an important and indeed crucial phenomenon, which singles it out among statistical processes. For in so far as statistical processes have a direction at all, it is usually a movement towards the average — and that is exactly what evolution is not. There is therefore something profound to be explained here, which goes to the heart of the mechanism of life; and it is natural that the disputes about the nature of life center on this. For the direction of evolution, which can be traced for about three thousand million years, gives it the appearance of a planned program: and the question is, how does this come about if there is no plan?

We need to be clear here what might be meant by a plan. For example, a vitalist who thinks it inconceivable that the orderly tree or pyramid of living forms could have evolved without a master plan might be content to say that the plan was conceived by a creator who simply understood the laws of chance better than we do. Indeed, he may claim (and no doubt he will, in time) that the two principles of variability and stability which I shall develop below demonstrate that the statistics of evolution have a scientific structure which an all-seeing creator understands at least as well as I do, and could employ to plan the future with perfect foresight.

Nevertheless, it is clear that such a statistical definition of a cosmic plan can satisfy no one, and is fundamentally pointless. For in the end it says no more than that the laws of nature take their course undisturbed, and move to their outcome with no other guidance than the edict which made them laws on the day of creation. Accordingly, we must suppose that those who believe that life follows some larger plan than the laws of physics constitute have in their minds a more literal picture of a plan.

For example, it is suggested that a living creature goes through a complex of cycles which are so matched to its environment that they have the manifest plan or purpose, they are patently designed, to preserve the life of the individual. But the fact that a living cell (for instance, a bacterium) is geared to go on living in the face of disturbance is no more supernatural than the fact that a falling stone is geared to go on falling, and a stone in free space is geared to go on moving in a straight line. This is its nature, and does not require explanation any more (or in any other sense) than does the behavior of a ray of light or the complex structure of an atom of uranium.

Therefore the vitalist must have some more sophisticated idea of a plan than the mere persistence of a cycle, or even of a linked sequence of cycles. Michael Polanyi, who claims that perpetuation of life cannot be understood except as an overall plan or purpose, uses a telling illustration. He says that to explain the machinery of a cell is like explaining the machinery of a watch; and that this misses the most important thing about a watch, which is that its machinery is planned for a purpose — to tell the time.

The design of a watch is the classical illustration for God's design in man that deists introduced in the eighteenth century. So what is telling is not that the illustration is fresh, but that it is oddly old-fashioned. Polanyi now gives the argument a new turn by saying that just as the design of the watch points to and is only understood in its purpose, so the design of the machinery of life points to and is only understood at a higher level of explanation by purpose.

However, the plan by which the watchmaker coordinates the totality of the machine from its sub-assemblies is not different in kind from the plan on which he forms a sub-assembly from its parts. They are all equally plans that are closed, in the sense that they describe the complete course or cycle which the operation runs. A closed plan is a rational sequence of instructions; the different levels of organization within it are merely levels of convenience; and there can be no level of design above the running of the machine, no overall purpose, unless there is an explicit designer outside the machine for whom it is a means to that purpose. We should have to believe in a creator with a conscious purpose, like a watchmaker who wants to tell the time.

III

Since I have stressed the character of what I call closed plans, it will be evident that I intend to contrast them with open plans. It is valid to regard an organism as a historical creation whose 'plan' is explained by its evolution. But the plan of life in this sense is an open plan; only open plans can be creative; and evolution is the open plan which has created what is radically new in life, the dynamic of time.

So it is timely now to consider evolution as an open plan, and to ask what are the additional principles that are needed to make it capable of creating the new living forms that we know. For it is essential that we recognize these forms as new and as genuine creations. They arise naturally in and from the course of evolution, as a work of art or an ingenious move at chess arises naturally in and from the march or play of each successive step. Yet the work of art is not implied in its beginning, and the elegant mate at chess does not sleep like a seed in the first move of the game. They are open creations, and so is life; it is not a closed plan like that which runs its rigid course from the seed to the full grown plant.

Put in this way, the issue is clear. There is a relation between the direction of evolution and the direction of time. In a history of three thousand million years, evolution has not run backwards. Why is this? Why does evolution not run at random hither and thither in time? What is the screw that moves it forward — or at least, what is the ratchet that keeps it from slipping back? Is it possible to have such a mechanism which is not planned? What is the relation that ties evolution to the arrow of time, and makes it a barbed arrow?

The paradox to be resolved here is classical in science: how can disorder on the small scale be consonant with order on the large scale, in time or in space. Evolution must have a different statistical form in which there is an inherent potential for large scale order to act as a sieve or selector on the individual chance events. The principle of a potential of order in the selection of chance events is clear, but what is never clear in advance is how it works. It is here that we need two additional mechanisms in evolution to turn the principle into natural selection as we know it, that is, with a natural order in time.

The first of the two additional mechanisms which we now see to underlie evolution is fitness for change, or (in more formal language) selection for adaptability. This important and unexpected process gives a special character to the variability which is inherent within any species. It is of course evident to our eyes that the members of a species are not identical; and in addition to this visible diversity, we know that there is an invisible diversity hidden in the mutant genes. This pool of hidden diversity supplies the variants which nature can select in order to modify the species. Thus we see that hidden diversity is an instrument for adaptation in the future.

But what is less easy to see, and is new and important, is that hidden diversity is the instrument for adaptability now, in the present. In order that a species shall be capable of changing to fit its environment tomorrow, it must maintain its fitness for change today. If this is to be done in the present, without some mysterious plan for the future, it must be by natural selection, not for this or that variant, but for variability itself.

And in fact it is evident that there is natural selection in favor of genetic variability. The selection is made by the small changes, up and down and up again and down again, by which the environment flutters about its mean. So the critical step in the conception of an open plan is certainly this: that 'the survival of the fittest' must be understood as the selection of those fitted for change as part of the total concept of fitness to a changing environment.

Adaptation has to match the changes in the environment, but adaptability has to match the rates of change: it is (so to speak) the differential coefficient of adaptation, and expresses the second order of difference in the organism and its environment. It is of course characteristic of cooperative phenomena in nature that they involve higher orders of relation, and therefore the matching of higher orders of difference, than do isolated phenomena.

It is evident that we cannot discuss the variability of organisms and species without also examining their stability. We have therefore also to trace a mechanism for stability, as the second of the two balanced mechanisms that are needed to complete our understanding of evolution. I call this, the fifth and last strand in my analysis of evolution, the concept of stratified stability.

Evolution is commonly presented, even now, as if it required nothing but natural selection to explain its action, one minute step after another, as it were gene by gene. But an organism is an integrated system, and that implies that its coordination is easily disturbed. This is true of every gene: normal or mutant, it has to be incorporated into the ordered totality of the gene complex like a piece in a jigsaw puzzle.

Yet the analogy of the jigsaw is too rigid: we need a geometrical model of stability in living processes and the structures that carry them out which is not so land-locked against change. Moreover, the model must express the way in which the more complex forms of life arise from the simpler forms, and arise later in time. This is the model which I call stratified stability.

There are evolutionary processes in nature which do not demand the intervention of selective forces. Characteristic is the evolution of the chemical elements, which are built up in different stars step by step, first hydrogen to helium, then helium to carbon, and on to heavier elements. The most telling example is the creation of carbon from helium. Two helium nuclei which collide do not make a stable element, and fly apart again in less than a millionth of a millionth of a second. But if in that splinter of time a third helium nucleus runs into the pair, it binds them together and makes a stable triad which is a nucleus of carbon. And every carbon atom in every organic molecule in every cell in every living creature has been formed by such a wildly improbable triple collision in a star.

Here then is a physical model which shows how simple units come together to make more complex configurations. The stable higher forms cannot be reached in one leap: they have to be built up layer by layer, and each layer must be a stable form at which evolution can pause and accumulate enough raw material so that improbable encounters can happen to create still more complex stable forms.

The stratification of stability is fundamental in living systems, and it explains why evolution has a consistent direction in time. For the building up of stability in organization has a direction — the more complex stratum built on the next lower, and so on — which cannot be reversed.

There is therefore a peculiar irony in the vitalist claim that the progress of evolution from simple to complex cannot be the work of chance. On the contrary, as we see, exactly this is how chance works, and is constrained to work by its nature. The total potential of stability that is hidden in matter can only be evoked in steps, each higher layer resting on the layer below it. The stable units that compose one layer are the raw material for random encounters which will produce higher configurations, some of which chance to be stable. So long as there remains a potential of stability which has not become actual, there is no other way for chance to go.

It is often said that the progression from simple to complex runs counter to the normal statistics of chance which are formalized in the second law of thermodynamics. But this interpretation quite misunderstands the character of statistical laws in general. The second law of thermodynamics, for example (which is often quoted), describes the statistics of a system whose configurations are all equal, and it makes the obvious remark that chance can only make such a system fluctuate around its average. There are no stable states in such a system, and there is therefore no stratum that can establish itself; the system rests around its average only by a principle of indifference, because numerically the most configurations are bunched around the average.

Time in the large, open time, only has a direction when we mark and scale it by the evolutionary processes that climb from simple to more and more complex by steps. It is evolutionary processes that give time its direction; and no mystical explanation is required where there is nothing to explain. The progression from simple to complex, the building up of stratified stability, is the necessary character of evolution from which time takes its direction. And it is not a forward direction in the sense of a thrust towards the future, a headed arrow: What evolution does is to give the arrow of time a barb which stops it from running backwards; and once it has this barb, the chance play of errors will take it forward of itself.

IV

Yet there is still a deeper question to be asked about time. It concerns our two experiences of time, one of which is the inner time of our body as an organism, and the other is the outer time of evolution. How does it come about that these two times, inner and outer, closed and open, have the same direction? Why does our sense of growing old and of going towards death point the same way as evolution, when we might well have expected the two to point in opposite directions?

The answer lies in the common mechanisms of life, which drive both the closed cycles of the organism and the open plan of evolution. In a living organism, growing old is not a thermal decay, and death is not a fall into the average such as the second law describes. As we understand old age, the cells in the organism age individually when they happen to make errors in their internal copying and when these errors are of a kind which repeat or perpetuate themselves. This is also and precisely the mechanism which underlies evolution. The cell cannot accommodate the errors because they do not fit into its organization, which is closed. But in the open field of evolution, the errors which are able to repeat or perpetuate themselves are the stuff of creation. The organism experiences the accumulation of errors in its cells as the direction of time towards its death. Evolution goes the same way because its mechanism is the same; and we perceive cosmic time as running the same way also because its direction is pointed by evolution.

Life as an evolutionary process is open, with no cycle in time; and it derives this openness from just such accidents or errors, at least in kind, as kill the individual. Here the mechanism is evolution, and evolution is that quantum resonator or multiplier, the exploitation of an accident to create a new and unique form, for which Delbrück was looking when he came into biology. The closed cycle of an individual life and the open time of evolution are dual aspects of life, driven by the common mainspring of quantum accidents, which are only properly understood when they are put side by side as complementary parts or processes of life.

The living creature and its evolution are the two matched faces of life. In this pairing, evolution is the creative partner: it does not solve a problem, as the cycles of the organism do, but makes a genuine creation — a creature. We can say of it what Piet Hein said of a work of art, in a penetrating phrase: that it solves a problem which we could not formulate until it was solved.

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Born in Poland in 1908, Dr. Bronowski lived in Germany during the First World War and came to England in 1920. He was educated in English schools and read mathematics at the University of Cambridge from 1927 to 1930. He was a Wrangler in that year and continued mathematical research at Cambridge, where he received the Ph. D. degree in 1933. In the following years, he published numerous papers in algebraic geometry and topology, and more recently in mathematical statistics and in mathematics applied to biology. He was Senior Lecturer at the University of Hull from 1934 to 1942.

Dr. Bronowski left University teaching in 1942 to become head of a number of statistical units dealing with the economic effects of bombing. In his wartime research he was a pioneer in the development of operational research methods. He was Scientific Deputy to the British Chiefs of Staff Mission to Japan in 1945 and wrote the classical British report, 'The Effects of the Atomic Bombs at Hiroshima and Nagasaki.' From 1945 to 1950 he was engaged in research for the Government in applying mathematical methods of analysis and forecasting to the economics of industry. From 1950 until 1963 he was first Director of Research and then Director General of Process Development in the National Coal Board in Great Britain.

In 1948 Dr. Bronowski was on loan to UNESCO as head of the Projects Division, and was on leave of absence as Carnegie Visiting Professor to the Massachusetts Institute of Technology in 1953. During his stay at MIT he initiated the discussion of the two cultures when he delivered the lectures on Science and Human Values, which have since become famous in book form. His other books include The Poet's Defence, William Blake and The Age of Revolution, The Common Sense of Science, and (with Professor Bruce Mazlish) The Western Intellectual Tradition.

In January 1964 Dr. Bronowski came to The Salk Institute for Biological Studies in San Diego, California. The work of the Fellows of the Institute is devoted to the study of man as a whole, including his biological, his mental, and his social development. Dr. Bronowski is particularly interested in the logical standing of mental processes, animal communication and human language, and in the structure of scientific laws and the place of science in human affairs.