REITH LECTURES 1950: Doubt and Certainty in Science

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Lecture 7: The Mechanistic Interpretation of Nature

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Throughout these lectures I have been speaking the language of a biologist. This is the way my brain has been trained to work—these are the words its rules produce. It is, of course, only one way of approaching the problems of life. Other people's brains are different, and it is not for me to say which is the best. I do believe, however, that there are some peculiar advantages in the biological method. By studying all the variety of life, including the life of man, biologists can include and transcend the other sciences. Moreover, by their emphasis on the continuity of life they give us some bearings to show us our position in relation to the past and the future.

In order to try to bring out the characteristics of the biological method I propose in this lecture to use it to study biologists themselves. I have shown that the value to the race of religious and scientific symbolism is to ensure co-operation. Advances are made by the doubters, who suggest new comparisons that produce better communication. What comparisons does the biologist use and how have they improved through the centuries? One of the most obvious ways of speaking about plants, animals and men is to assume that they can be investigated by dividing into parts. The supposition that the body 'is made' of a number of entities or 'parts' that can be revealed by dissection is so obvious that most of us cannot get away from it even now. We feel that it is natural that if we cut up a body and look inside it we shall find what is 'really' there. Of course there is a sense in which this is true. Man is a creature who makes special use of the information that he gets with his eyes. If he divides up complicated systems, such as living bodies, he will find parts inside to talk to his fellow men about. r am an anatomist by profession and should be the last to deny this. What I want to criticise is the idea that by dividing and dividing one will ultimately find in some way the real or true unit, which gives full knowledge of the body. This is an outmoded materialism which I am sure still lingers in many people. Physical scientists thought for a long time that they could manage by speaking about atoms in this way and they did indeed get useful results. But they are obtaining even more exciting ones now that they have abandoned it. Similarly, we biologists have made great progress on atomistic lines, but we shall now make more still if we can bring ourselves to modify them.

Let us look first at the parts we can find. A convenient single unit, that exists in all living things, is the cell. The dissecting tool that revealed it was the microscope. The human body contains more than a million million cells, each less than one-thousandth of an inch across. Every cell contains a central round body, the nucleus, made of some material that differs from the rest. Inside the nucleus are still smaller bodies, the chromosomes. The nucleus contains a fixed number of these in each sort of animal. Human beings have forty-seven pairs of them. They are the carriers of heredity. Each egg and spermatozoon has only half the adult number. When egg and sperm fuse in the union of male and female the full number is restored. So you get half your chromosomes from your mother, the other half from your father. It is by means of the chromosomes that hereditary characteristics are passed on. Each of them carries a number of genes or hereditary determinants. The fact that many combinations of chromosomes are possible makes it unlikely that any two individuals in a population will be identical. This shows us at once the value of the sexual method of reproduction to the race. It mixes up the genes of pairs of people in a random way. It ensures in fact that we shall not be all alike. Moreover the genes themselves change from time to time by a change in the chromosomes known as mutation. This change also happens in a random manner, but is speeded up by radiations such as X-rays or those emanating from explosion of an atom bomb. Geneticists, the people who study inheritance, have to work out the chances that particular combinations of chromosomes will occur. In this way they can in suitable cases forecast the probability that any given child will, for example, have blue or dark eyes. It is very seldom that they can make an exact forecast about any one child, but they can give the odds that it will be of one type or another.

Forecasting Probabilities

Biologists have had to make a careful study of the subject of chance. The physical scientists from Galileo onwards have tried to find, as we say, the causes of happenings. They arrange experiments in which everything is made as simple as possible, and then find out how one change only will influence the result. This is an extremely useful method for disentangling the different influences that affect any process. But many things in nature are influenced not by one but by a large number of different agencies. The combined action of many small influences produces what we call chance. Biologists also make experiments, but they cannot simplify things enough to be able to forecast exactly what will happen. The study of inheritance and of populations has therefore led to the development of special mathematical methods for forecasting probabilities—a branch of statistics.

Can we say then that the original hope of defining life by study of parts within the body has turned out right? The microscopist has succeeded in finding visible bodies, the chromosomes, that determine hereditary characters. This is certainly very satisfactory so far as it goes. Yet to say that we resemble our parents because we inherit some forty-seven minute dark-coloured rods from each of them is not enough. However enthusiastic one may be as an anatomist and microscopist it is difficult to feel that by dividing and naming alone one reaches the last word that can be said about living things; one tries to say what things are made of and how they act. Ever since the sixteenth century another group of scientists, the physiologists, have been at work describing man, animals and plants, using a different set of words. Before the seventeenth century biologists spoke about the actions of the body as if each part had qualities like those of a living creature. Thus, the gall bladder was said to be friendly and attracted the yellow bile, which was supposed to correspond to fire and gave liveliness to the temperament. Three sorts of spirits, natural, vital and animal, were said to control the bodily operations. The idea of spirits came from that of vapours—for example those of alcohol, which are invisible and yet able to produce effects. They formed a half-way house between bodily events and the controlling soul. Comparison with them was thus an attempt to bridge the gap between mind and matter that followed from describing man as a material body occupied by an immaterial mind. This all seems very primitive to us, but we can see how the system worked. In order to be able to talk and write about the actions of the body man must compare them with something and the most obvious comparison is with the sources of action and change that we know best, namely ourselves and the tools we use. Of course the actions of the nervous system were the hardest of all to speak about. The movements of the muscles and limbs were supposed by the sixteenth-century physiologists to be produced by the will of the anima or soul, which resided in the whole body. The brain was the place for refining the animal spirits, leaving ultimately reason, which is free from earthiness and thus able to think, to will and to survive the body. Notice the analogy taken from the process of extraction of metals.

Descartes began the analysis of the functions of the nervous system by making the comparison with a machine, say a clock, wound up to go and triggered off by stimuli in the outside world. This left us with the method of speaking about the nervous system in terms of stimulus, sense organ, impulses conducted along nerves to the brain and thence back again to make the muscles work. It is a scheme we all use daily, but as we have seen in earlier lectures it does not take us as far as we should like with talking about what goes on in the brain. Descartes himself got over the difficulty by the use of the very device that he was repudiating. The essence of his new system was to show that each part of the body acts as it does for mechanical reasons and not because it contains some occult spirit or faculty disposing it so to act. There was, however, a long tradition that the soul controls the action of the brain by operating on the pineal gland, which was supposed to regulate the flow of spirits between the ventricles of the brain. Descartes did not invent this view but he developed it, supposing that the valve could be operated either by the flow of spirits inwards from the sense organs, that is, as we should say, reflexly, or by the will. In doing this, therefore, he carried over directly the medieval system. He made possible the acceptance of much that was new by keeping the old system to speak about the most difficult part. The model of the body as a machine has been the basis of much of the most useful part of our biology. With it we can find out how the body 'works', how much food must be supplied to provide the fuel and so on. In fact the machine model is the basis of much of agriculture and medicine.

Then chemistry, as it expanded during the nineteenth century, provided very powerful new models for living activities. The practice of saying that living things are in some sense made of the same stuff as non-living ones is in itself a very original one. In most ways the two sorts appear obviously different. It is not easy to see that there is any sense in saying that the body is made largely of carbon like coal, and oxygen and nitrogen like air. It would be easy to make out that it is a ridiculous and silly thing to say. However, in the nineteenth century it was shown that it is possible to isolate from the body elements, such as oxygen, that are indistinguishable from those found in the non-living world. Moreover, it is also possible to make in the laboratory some at least of the substances that are found in living bodies, using only non-living material. So the great science of biochemistry began and is still rapidly expanding. Biochemists are of ten asked the question whether, if they knew a little more about the details, they would be able to 'explain' life fully in terms of chemistry. Some of them at least reply that they believe that they could do so. One admires the courage and persistence implicit in this hope, for living chemistry is very complicated. But perhaps it would be wise to consider carefully what might be meant by 'explain'. No doubt enormous progress will be made with current ways of speaking, but the changes in the use of symbols through the centuries suggest that the questioner and the biochemist were being too simpleminded in asking and answering such a question. No doubt man in the future will be able to say much more interesting and useful things about living creatures than he can now—but they will be in terms as different in content from those of today as electron is from angel. The use of symbols grows gradually. It is not easy for each generation to realise that the names it uses have a past history and that the concepts used in the future will be very different from those of today.

Living Patterns

When we come to look closely at the chemical interchanges between the body and the environment we find that the body does not maintain a static structure, as the comparison with a machine suggests. Oxygen passes into the body, is burned and is breathed out again as carbon dioxide. Was that oxygen ever part of the living body? I wonder how most of you would answer. Probably many people would say, 'No, of course not, it has merely passed through and been used by the body'. But the paradox is that if you say this you will find that there is no enduring body at all. For we now know that even the most apparently stable parts, such as the bones, do not remain always compounded of the same actual molecules. If living things consist of no steady fabric of stuff but are continually changing, what is it then that is preserved? What is it about those chromosomes that makes them the bearers of heredity? What is it that makes each life in some sense the same from year to year? Individual chemical atoms remain in the cells for only a short time; what is preserved must be the pattern in which all these interchanging atoms are involved. 'Pattern', you may say, 'what do you mean by that? Are you comparing me to a carpet?' That is just the trouble—we find it hard to get a proper model. Living patterns are not stable like those on pictures or carpets. A whirlpool might be a better simple analogy—the pattern of swirls in a river. The matter of these swirls is continually changing and yet there is a sense in which they remain the same. We might say that the flow through them is organised in a particular way. 'Yes, but organised by what or by whom?' In the case of the river it is by the historical events of the past that have left a certain arrangement, so that the water must flow through making just those patterns and swirls. So in the case of the body the organisation is such that the matter must flow through in certain ways.

Biology, like physics, has ceased to be materialist. Its basic unit is something non-material, namely normally an organisation. But the organisation is vastly more complicated than that of any river. It is kept in certain channels by the environment, acting in a sense as do the banks. If a stream stops, the banks remain. A river that has dried up may form again the same patterns. But the living patterns are so complicated that they are kept intact only by their continued activity. If they stop they are never re-started. The living patterns have developed a wonderful permanence none the less. They have in fact the characteristic that every time there is any change in the banks the swirls make a compensating change and keep intact. The river analogy begins to fail us here and I should like to recall you instead to quite a different one. If we want to understand an elaborate organisation such as the body we might find it useful to compare it with an organisation we do understand. In an earlier lecture I compared th brain with a vast office devoted to keeping itself intact. I shall not press the analogy again here, but development of the study of human organisations is beginning to provide us with powerful models for comparison with our own bodies. As sociology and the study of human organisations develop we are likely to find their terms useful in the very hard task of describing the living body, for which at present we have no proper model. The study of large populations and how they behave is one of the most recent human techniques. We now have methods of finding out what people do, by questionnaires, samples, market research and other techniques.

Comparison with a Clock

Statistics has a new set of symbols and methods of observation, and they may help us greatly in studying the body, which is after all described as well by saying that it is a population of cells and chemical molecules as by comparing it with a clock. We can understand in this way how an organisation endures although the separate individuals that make it up may change. Many of you may laugh at this comparison. Application of a new model always produces laughter, the symbol of certainty, among those who use the old. But it may be that we can find ways of controlling our ills better by speaking of ourselves as populations rather than as clocks. This is also of considerable help in solving the difficult problem that is left by the machine analogy, namely how this so-called machine, our body, is made. Machines are made by men and this was therefore at first no problem for scientists who could postulate a sort of superman in the background who created the machine. This particular use of the medieval model broke down in the nineteenth century for the same reason that the church's physics broke down in the seventeenth—because new observations were made that would not fit it. The religious system said that all plants and animals had been created as they now are, and even gave a date for the creation—4004 B.C. The studies of populations of animals and plants, past and present, showed that this could not be true and that plants, animals and men have changed continually to reach their present form.

We can follow how this came about. The early scientific naturalists proceeded by the method of classification. The practice of finding likenesses, even when these are not obvious, is a characteristic activity of the human brain. These likenesses are then emphasised by the act of giving the two things a common name. The early naturalists collected, compared, classified and, above all, named the varieties of animal and plant. By the end of the eighteenth century it was clear that quite an elaborate classification is possible. Some animals are much more alike than others, so that we can recognise sets. Cats and kangaroos are both mammals; they have fur and suckle their young. They differ in many ways from birds, but, like the latter, have backbones, as have fishes and all other vertebrates. The question arose why the creator should have produced this sort of scheme. There was, of course, no reason why he should not have done so of his own will. Another possible explanation was that there had been a gradual change. Perhaps cats and kangaroos both have fur because they are descended from a common furry ancestor. Perhaps birds, mammals and lizards all have backbones because descended from a fish and so on.

This idea of evolution was not new; there had been signs of it among the Greeks. It was put forward several times in the eighteenth century, among others by Charles Darwin's own grandfather, Erasmus Darwin. But how could it be proved? The answer came from the geologists, who studied the fossils in the rocks. In the early nineteenth century it gradually became clear that the fossils are arranged in a progressive series. The layers of rock that were laid down earlier contained animals very different from those alive today. The modem types of animal appear only in the more recent strata. Finally in 1859 Darwin showed that all the degrees of difference between animals and plants can be explained by the slow divergence of the creatures. The different stages in the rocks are a series of documents proving that the process of evolution has occurred. The fact that animals and plants have changed through the millennia is more certainly proved than most of the facts of history-book history even of a few decades ago. There is no doubt that man as we now know him has existed for at the very most a few million years, and that he and the monkeys and apes are all derived by gradual divergence from a common population.

But Darwin went much further than proving that evolution has occurred. He went on to show the connection between the fact that the animals in the population of any one species are not all alike with their evolution. His studies of the breeding of pigeons, sheep and other domestic animals showed him the great extent of the differences between individuals. He noticed that in every species far more are produced in each generation than can survive. This led him to the bold, if obvious, suggestion that the change we knot of as evolution is due to the fact that some members of a population are more likely to survive than others. This conception has been shown by more recent studies to be essentially correct. We now realise that every population of animals and plants is very varied and is in a state of flux. The bees or the blackbirds of Scotland are rather different from those of England, just as the people are different. Evolution is going on all the time as populations gradually change.

We are thus able to make a further step in purging our language of animism. We can speak about how animals and plants have come to their present state by a continuous process that can be observed, rather than attributing their state to sudden creation by a person like ourselves. From this we can go on to discern the influences that have controlled the direction of the change. The climatic conditions in any part of the world are continually varying. We do not know very much about this variation. There is some evidence that it goes in cycles. During the last million years there has been a series of colder periods in which the polar ice cap that at present extends only as far as Scandinavia has advanced, sometimes far enough to cover all Europe, and then retreated again. With such climatic changes the animals and plants resident in any region must change. As recently as 20,000 years ago there were woolly mammoths and rhinoceros and cave bears in the British Isles, which, by the way, were then connected with France.

The Changing Earth

Evidently the earth is not the unchanging place that it seems to the poor short experience of each of us. Once again we see how scientific study makes it impossible to maintain apparently obvious common-sense points of view. There is, then, a continual development of new forms of life suited to the changing conditions of the environment. But when we look at the whole sequence of evolution of a large group, say the animals with vertebrae, we see something more than a series of rhythmic fluctuations following the climate. Each group of vertebrates flourishes for a while and then disappears, replaced either by its descendants or by some other animal group. Thus the fishes first appeared 500,000,000 years ago, but the present-day fishes are very different from the first ones. Then some of the fishes came out on to the land, and became the amphibia. They were replaced gradually by their descendants the reptiles. Then about 70,000,000 years ago the land and the air became peopled almost entirely with descendants of the reptiles, the mammals and birds.

What is the meaning of this perpetual change going on in evolution? Why is, it that each type of animal lasts only for a certain time and then becomes extinct? Are the new types that are continually arriving in some way higher or more efficient than the old? It is often supposed that in some sense evolution is continually progressing towards a higher type, but few have ventured to explain exactly what this means. Man is a very recent product of evolution and it is tempting to look upon the whole process as leading in his direction. This attitude we must resolutely dismiss. Many lines of evolution have nothing to do with man or with the vertebrates. We must be able to find some way of describing evolutionary change that avoids the parochialism of supposing that its end has been to produce ourselves.

The full solution of this problem begins to be visible as we realise that each life is a complicated vortex of processes, maintaining a steady state. Evolution then is a change in the organisation of the vortex. If we look carefully I believe that we can see that the evolutionary change involves in many lines a steady increase in complexity of organisation. When we say that a monkey is a higher creature than a fish we do not mean only that the monkey is nearer to man. We mean that his whole way of life is more complicated, he has more parts and he does more things. Now the things that an animal does are its means of getting a living from its environment. So if it does more things that must mean that it has to work harder to get its living. This is exactly what I believe we shall find that the higher animals do. They live in surroundings that are less suitable for life than those of the lower animals and therefore they have to do more work for their living. To put it in another way, the higher creatures show greater differences from their surroundings than do the lower ones. As a physicist would put it, the higher are less probable, less random, systems.

This brings us back directly to the central theme of these lectures, the nature of the action of the brain and the alternation of doubt and certainty. The changes in evolution occur by natural selection of the differences among the members of populations. These differences are produced by the processes of mutation or random change of hereditary factors, and the random shuffling of these factors by sexual reproduction. Looking at the long course of evolution it seems that by the process of variation and selection populations have been produced that are able to support life under continually more and more difficult conditions. There seems to be a parallel between this finding of new environments by evolution and by the formation of new associations in the brain. In the brain by association and learning, things that were not previously significant for life are made to become so. The whole history of social man has been th continual discovery by random trial and error of new tools, technical and verbal, that enable life to be lived in ways not possible before. Man, in pursuing this alternate process of doubting and then applying the rules that he learns is carrying on the plan that evolution has always been pursuing. It is sometimes lamented that science seems to take us continually further and further from nature, that is to say it makes life possible by more and more elaborate devices. But this is just what animals and plants have been doing for 1,000,000,000 years or more. The biologists' method of description has certainly, much to commend it if it shows us how the learning process in our brains is part of a development that seems to have been going on ever since life began.