REITH LECTURES 1950: Doubt and Certainty in Science

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Lecture 3: The Human Calculating Machine

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In order that you may have some picture of how the brain works, I want you to think of it as a gigantic government office—an enormous ministry, whose one aim and object is to preserve intact the country for which it is responsible. Ten million telegraph wires bring information to the office coded in dots and dashes, like a Morse code. These correspond to the sensory or input fibres reaching the brain. In the office you must try to imagine nearly 15,000,000,000 clerks, that is to say nearly seven times as many people as there are at present in the whole world. They correspond to the cells of the brain, and we can imagine them sitting in closely packed rows, as the brain cells are arranged. Every clerk has a telephone and receives coded messages either from outside the office or from some other part of it. So each nerve cell of the brain receives nerve impulses, either from the sense organs or from other brain cells near to it or far away. Each clerk spends most of his time sending code messages on his telephone to some other group, which may be near or far. So every nerve cell has an outgoing fibre which may be long or short. But the clerks can also influence their neighbours by whispering 'silence': obviously if a group of them starts doing this then a wave of quiet will pass over that area and it will send no messages out for a while. You can see how in this way most elaborate patterns of activity will grow up between the huge numbers of clerks throughout the building. There are circuits by which messages are sent from one department to another and then back to the first and so on indefinitely. Messages will go round and round, but be influenced by incoming messages and by the waves of silence. However, the whole office is so arranged that some of the telephones eventually transmit instructions to workers outside, directing them how to run the country and bring food, drink, and other necessities to the government office. So some of the brain cells carry impulses that control the actions of the muscles, especially those of the hands, tongue, lips and so on.

How would this office be organised, how would it convert the information it received into orders for the government of the territory it controls? Everything, surely, would depend on its having arrangements by which all relevant information could be brought together to produce the right answer to every question put to it. This is just what happens in the nervous system. The sense organs transmit information to whichever departments of the brain can use it. But how does the brain bring this information together, so as to send out the right orders to the territory it is responsible for—the body? To find this out we may return to the comparison of brains with calculating machines. Information reaches the brain in a kind of code, you remember, of impulses passing up the nerve fibres. Information already received is stored in the brain, I have suggested, in some similar way. This is just what calculating machines do—they both store old information and receive new information and questions in coded form. The information received in the past forms the machine's rules of action, coded and stored away for reference. When asked a question, it puts it into code, and, by a process which is essentially one of adding and subtracting very fast, the machine can then refer the question to the rules that are already stored in it, and so produce the right answer. Similarly, the brain' is constantly relating the new impulses that reach it to the information already stored away in its tissues. To show the closeness of the parallel I can imagine a machine that would act as a cricket umpire. The wicket-keeper has whipped off the bails and called 'How's that?' A camera, rather like a television camera, turns the sequence of events into a code of dots and dashes. The machine already contains the rules of cricket, also in a code of dots and dashes. The machine could now proceed to fit together the coded report of the situation and the rules and answer with the word 'Out'. No such machine has in fact yet been built—but it might be. You can see that its action would depend on being able to fit together the input from the camera with the rules. Modern machines can do this sort of thing because the code is all in a simple form like dots and dashes, actually Os and is, and therefore involves adding and subtraction, though an enormous number of calculations would be necessary to determine the answer.

The brain, as we know, has an even greater number of cells than there are valves in a calculator and it is not at all impossible that it acts quite like an adding machine in some ways. In the last lecture I showed how the information was put into a code of nerve impulses, and how there are circuits of activity that might constitute the memory. However, we still do not know exactly how the brain stores its rules or how it compares the input with them. It may use principles different from those of these machines.

It is convenient to consider that in the brain the calculations are done at a series of different levels. The part of the brain just above the spinal cord, for example contains centres for regulating internal functions, such as breathing. These centres are vitally important for the working of the body. Even the smallest damage to them causes death within a few minutes. The surgeon, who, as we shall see, is sometimes prepared to remove some of the so-called highest parts of the brain, avoids even the sight of these lower centres, and the thought of touching them fills him with alarm. It is correct, however, to call them lower—not because they are without importance, but because they are regulators of a rather simple type. The responses that they produce are reached by the combination of information coming from few sources. There are many such simpler centres in the brain, regulating such activities as breathing, the action of the heart, of the kidneys, of the amount of sugar in the blood, and so on. For these simple calculations relatively small numbers of nerve cells are enough.

What happens in the Hypothalamus

The next level of the brain that I shall consider performs rather more complicated calculations. It is known as the hypothalamus (unfortunately I must use the technical name—there is no other) and lies near the centre of the head. What goes on there has a profound influence on the well-being of each one of us. Injuries in this region produce changes of some aspect or other of the basic internal functions of the man or animal concerned. Thus one part of the hypothalamus controls temperature, and injuries there may produce fevers. Another part controls appetite, and hence the amount of food consumed and whether we get fat. Still more elaborate functions controlled from here are the degree of activity or of sleepiness. One of the earliest clues to the action of the hypothalamus was that these centres are especially frequently damaged by the infectious disease known as sleepy sickness The person's whole state of activity is altered and periods of days and perhaps weeks are passed in sleep. Even the most complicated of our activities are effected by the hypothalamus. It has been noticed that patients who have recovered from sleepy sickness often develop a marked change in their moral character—usually for the worse. Thus Professor Kennedy, among others, has recorded that a high proportion of children get into trouble with the police after sleepy sickness; not all of them, of course. Some of them seem to lack all moral sense. They may be restless, bored, or liable to sudden outbreaks of cruelty and aggressive-, ness, and are without a proper feeling of responsibility for others.

We must not jump to extreme conclusions and say that every delinquent is just a person with a diseased hypothalamus. Things are not nearly as simple as that. Other parts of the brain have a great deal to do with social behaviour. Indeed, the hypothalamus does not by any means work as a separate isolated unit. Professor Le Gros Clark and his colleagues have shown that there are numerous nerve fibres conducting impulses in both directions between it and the uppermost parts of the brain. This corresponds to a fact which all of us know, that such conditions as aggressiveness or irritability, though partly independent of our intellectual life, yet both influence and can be controlled by it. The hypothalamus therefore is a place that receives nerve impulses from the internal parts of the body. From this information its calculations establish the general attitude or direction of much of brain action—the emotional tone, as we might say.

But it does not control the details of what we do. That is the function of the great sheet of nerve cells occupying the top of the head, the cerebral cortex. With its associated parts this makes our main calculating machine, containing thousands of millions of nerve cells. This is the chief section of our great government office, and employs ninety-nine per cent of the clerks. This is the part of the brain that sifts the more complicated sorts of information sent in from the outside world and calculates what we shall say and what we shall do. Receiving the nervous messages sent in from the eyes, ears and touch, it calculates suitable action by the hands and of the larynx and tongue in producing speech. In fact, if we could discover the patterns in which the cerebral cortex acts we should be well on the way to our aim of recognising, as biologists should, the special means that man uses to obtain his living. Recalling our model of the -government office, we shall be warned that the task will not be simple. Imagine trying to understand how an organisation including several times more people than there are in the whole world is planned. Somehow or other the activities of all these millions of cells ensures that suitable actions are performed. Consider the case of the eyes. Nerve fibres carry impulses from the retina to the centre of the brain. From there other fibres reach to a particular part of the cortex at the back of the head. Input produced even by a tiny spot of light on the retina—say from a star—will first influence a tiny area of cortex, but from that small area impulses will be sent far and wide through the cortex and eventually, if appropriate, to the output fibres that make the voice muscles say ‘star’.

The major problem is to understand the pattern of the activities in the brain by which the input is fitted with the memory and produces the action. Consider, for instance, what happens when you call a friend by name across the street. The image of your friend on the retina of your eye sets up a disturbance in the brain which results in speech. Our problem is to describe the brain disturbance. It is not a disturbance of a previously passive system but of one already fully active. There is an elaborate pattern of activities going on in the brain. When a sense organ sends input that fits in some way into this brain pattern we respond by a suitable action.

The cortex, therefore, is our great calculating machine for fitting together the parts of the sensory input at any one time and comparing them with previous inputs. Experience has left its mark on the brain, giving it the rules with which it operates, giving it in fact a system of law, of certainty. We can imagine how the circles of messages between the clerks in our government office would control their manner of proceeding, depending, of course, on past experience. The pattern of this activity would be the filing system of the office: its memory of past experience. If the laws embedded in the brain machine are efficient they will enable every input produced by a disturbance outside to be fitted into some pattern that will produce an effective action. That is to say, they will make the muscles do something that will restore the body back to its steady state, the state, you remember, which all organisms tend to preserve.

This perhaps gives you an inkling of the lay-out of the whole cortical system. I must emphasise again that I am giving only the very roughest outline. The details are of hardly imaginable complexity, and we have only begun to unravel them. We do not know much yet about what goes on in our brains and therefore cannot expect educators to educate them properly, psychologists to help us to correct their workings, or surgeons to know whether it is wise to cut pieces out of them. How can we find out more? We have a lot of apparently unconnected facts about the brain. We are seeking for the clue that will show how the facts are connected and give us a good general scheme for understanding the plan of brain action. I believe that we shall find that clue by consideration of the nature of these patterns within the cortex. That is why I have spent so long giving an analogy that may at least vaguely suggest what sort of patterns to look for. Meanwhile, what are the different sorts of evidence that we have in looking for our clues? Being an anatomist, I have put what are commonly called the structural facts first. I have been speaking of the arrangement of the cells.

Electrical Activities of the Brain

We have, however, all sorts of further information about the brain— for instance, of its electrical activities. In 1929 it was discovered that if you make proper electrical connections with the surface of the head, then you can show, with a suitable apparatus that small changes of electrical potential are going on throughout the life of every person. You will remember that we saw in the last lecture that the activity of nervous conduction is accompanied by electrical changes. There is no doubt that the electrical brain waves are in some way a sign of the activities of the brain cells. Probably, as Professor Adrian and others suggest, they are the result of a lot of cells acting together. It may be significant that the waves are most clear when the brain is idling—for instance, when a person is asleep or day-dreaming. Then, apparently, large masses of cells are working in unison. When the person wakes or begins to think, the electrical changes become more complicated. If only we could understand the patterns of these waves we should be a lot nearer to understanding what goes on in our heads. At present we can tell from the brain waves whether a person is awake or asleep, and detect some useful things about the brain—for instance in relation to epilepsy. But we cannot be said at present yet to be able to read a person's thoughts from his brain waves.

Another whole set of information comes from experiments in which the brain is made to work, as it were, artificially. This has to be done in some cases during brain operations. A pair of fine wires is placed on the brain surface, and small electrical charges are applied, which have the effect of starting the activity of the brain cells. In some brain operations it is best not to put the- patient to sleep, but to use injections of local anaesthetics to prevent pain during the cutting of the skin and bone. The brain can thus be exposed while it is still in its normal waking state, and the person is sensible enough to stay still and can describe what he feels. It has been known for a long time that activation of some parts of the cortex in this way produces movements of various muscles. Sir Charles Sherrington had shown this by experiments on apes. Professor Penfield of Montreal confirmed that, in man, electrical stimulation of points on a strip of tissue down the side of the brain produces movements of the body. When the part of his body moves, the patient feels as if he has to move it; he does not feel that he wills to do so. For instance, when the wires are on the part responsible for speech he may cry out rather like a baby. He is not in pain stimulation - of the cortex is never painful—he just feels, to his surprise, that he must cry out. If asked to try to stop he is unable to do so, and is most intrigued by the whole business.

The area of cortex controlling each part of the body is by no means proportional to the size of that part. Thus, the area of the cortex that produces hand and finger movements is much bigger than the whole of that controlling the legs. The area for the lips and tongue is very large. There are also large areas whose stimulation stops the patient speaking He later describes his experience by saying, 'My tongue suddenly felt paralysed', or, 'I just lost control of my lips'. In other cases he will say, 'I could not think any more'. Evidently the rather crude stimulus is not able to produce the complicated movements of speech, and indeed it actually seems to disrupt the fine patterns of action of the nerve cells that are responsible for speech. The extent of the cortex connected with each motor function is therefore proportional to the intricacy of the actions they perform. I want to emphasise this, for the fact that such large areas are concerned with the muscles of speech is direct confirmation of the thesis that man is primarily a communicating animal. From stimulation of various- areas there are reports of sensations—for example, flashes, balls of white or coloured lights or other vague dancing lights, never of well-formed or recognisable objects or pictures. Again, from the area responsible for hearing come reports of vague sensations of sounds—buzzings, ringings and knockings. These observations, therefore, confirm that the cortex deals predominantly with the receiving systems for touch, vision and hearing. But the areas that respond in this way occupy less than half of the whole cortex. The remaining parts are of two sorts. First the silent areas of the front part of the brain, whose stimulation produces no response at all. Secondly there are certain parts known as association areas, whose stimulation sometimes produces complicated sensations and memories.

Evidence from Surgery

Further insight into the functions of the brain can be obtained from seeing what are the effects of the removal of the various parts, as a result of injury or surgery. I can only outline a few points of this fascinating story. Removal of part of the motor area produces severe paralysis of movement on the opposite side. Thus if the left arm area is removed, the patient's right arm and hand will be completely paralysed at first. However, he will gradually recover, first, the cruder movements of the whole arm, and then, gradually, some finer movements, though never his full original range, of skill and dexterity. Severe damage, by an accident, of the receiving station in the cortex for messages from the eyes results in total and incurable blindness. Loss of the association areas I mentioned above produces very variable and complicated results. Sometimes the person is hardly changed by their loss. Yet in other cases there may be most curious defects. The patients may be able to recognise objects but not to name them, to name them but not to read their names, to read but not to write or vice versa, and so on. Injury in certain areas produces complete loss of speech. Evidently damage to these association areas upsets the pattern of action by which the brain produces communication. Evidently also this pattern varies, as we should expect, in different people. The rules by which the brain works are not inborn, they have in the main been learnt.

Some of the most interesting operations in which portions of the brain are removed, have been those in which parts of the frontal lobes are severed from the rest. These lobes lie in front of the motor part of the cortex, and are the region of the brain that is very much bigger in man than in any animals. That is why we have a higher forehead than the apes. Yet separation of this front part produces no loss of sensation or motor paralysis. Instead, there are changes of personality, changes that are usually in the direction of making the person more docile, often more communicative. The exact effects vary a good deal, however. Generally speaking, after the operation there is no loss of any actual function or power, but there is not quite the level of performance and efficiency that is necessary for perfect conduct of the business of life in our society. We cannot say that we by any means fully understand the functioning of this most characteristically human part of the brain. But it seems that in some way it operates the balance between action and restraint that is necessary for social life. Its actions are therefore connected with what may be called the highest levels of communication. Their loss does not involve any alteration of the power to speak or to understand words. Without the frontal lobes a person can still enunciate words properly, but he uses them in socially wrong ways. After such operations patients sometimes become embarrassingly frank, even rude in behaviour.

This 'Enchanted Loom'

We have therefore a mass of information about the functioning at various levels of the brain system that controls our behaviour. The information is quite new, and could hardly even have been imagined a hundred years ago. Yet it 'is still very scrappy, and I do hope that you will not get the idea that we understand all about the brain. The information from different sources is only beginning to fit together. We cannot yet say that we have a clear model by means of which we can speak of how the cortex works. The electrical changes going on in it suggest that when it is at rest large numbers of cells beat together in unison. The effect of stimulation is to disturb this unison. Professor Lashley of Harvard, one of the ablest students of the brain, has suggested that we may compare the complicated waves of action thus started with the pattern of disturbances set up when stones fall on a sheet of water. This analogy, like that of the government office which I used earlier, has the advantage of reminding us that we must concentrate attention on the patterns of action set up among the millions of cells of the brain. But we are ‘only just beginning to be able to imagine what they may be like. I have shown how we are searching for models to help us to understand this ‘enchanted loom’, as Sir Charles Sherrington has called it.

From the very number of the models I have mentioned, you can see how doubtful we are in this present phase of scientific research. I have compared the brain with a government office, a calculating machine, and with the waves on the surface of water, and one could go on with many more analogies. This whole business of making comparisons may seem to you absurd and useless. It is, I repeat, one of our chief aids to exploring the world and hence getting a living. Indeed, I hope in my later lectures to show that it is a tool we have been using in essentially the same way for thousands of years. For many purposes we have no other means of communication. It is not a question of whether or not to make comparisons but of which comparisons to make. We must use the rules—the certainties we have established by past experience. It is by comparison with these that each of us shapes his future. We must compare things; because that is the way our brains are constituted.