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BRAINS AND WORLDS: THE CEREBRAL COSMOLOGIES

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I hope it may not be too ambitious to spend our time asking again the old question 'What is the world really like?' I shall bring you a little evidence of how Dr George Bidder himself regarded this question, and I like to think that with his strong and freely ranging mind he would have approved our attempt to tackle even these very difficult matters.

Philosophers have wrestled for centuries with the problem of what we can certainly know to be true. Descartes believed he had brought us to the centre of it with his 'cogito ergo sum'. On the face of it this is an irrefutable truth – each of us can state that he is here. Nevertheless this approach is not so simple as it may seem. The biologist may emphasize that the very making of any statement already begs the question, because it uses the peculiar human adaptive feature of language. Of course there are many ways of interpreting what it is to 'think', but as soon as we start to talk about it we must beware of the limitations imposed upon us as a particular sort of creature. Saying is one of man's chief forms of action and like all animal actions it is a part of a forecast, a prediction of what is best to do next, given the way of life of the species and the particular conditions of the moment.

The point is that to proceed by saying with Descartes 'I think therefore I am' is to treat of the world only as seen through men's eyes. Of course it may be replied that this is a truism because that is the only way we ever could see it. While in a sense this is so we need not perhaps be too pessimistic about the possibility of extending our view. After all, with our artifacts we have been able to detect radio waves and X-rays and to explore all sorts of worlds that were hidden before. Popper (1972) goes so far as to speak of 'objective knowledge' or 'epistemology without a knowing subject'. He refers of course to our extra-corporeal information stores and claims that knowledge exists independently of who has found it out. There is something in this, and it appeals to us as scientists. But surely it goes much too far in one direction. Knowledge has been discovered by humans and they have both species-specific and individual propensities. Therefore in a sense what is found out must depend upon the nature of human brains. There is even evidence that at least for ordinary people reasoning is radically affected by semantic content, and influenced, moreover, in systematic and forecastable directions (Wason, 1974). The operations studied by logicians and the formal operational thought of Piaget are not *in practice* dependent only on the relations involved, but are influenced also by the content. Of course, philosophers will reply that they are only concerned with the formal side of the relations. We shall return to

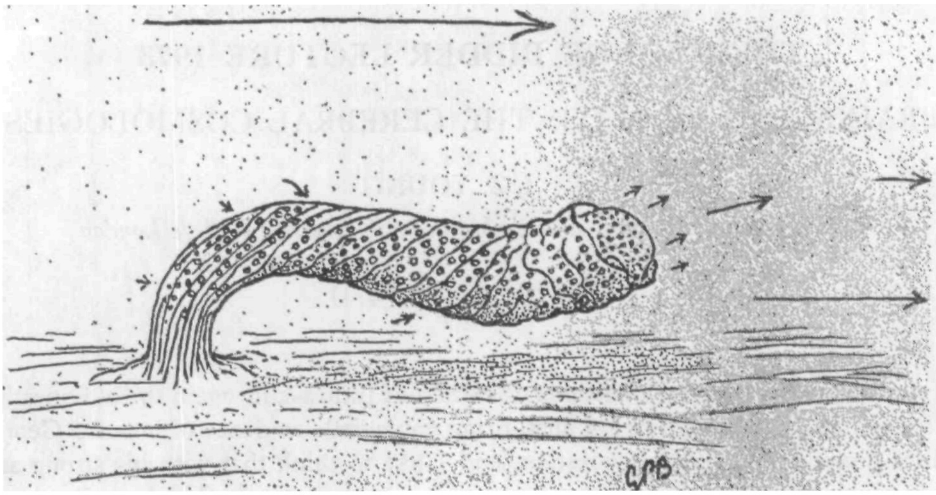

Fig. 1. A drawing by Dr Bidder of Venus' flower basket in the position he suggested it would be found when living. (From Bidder, 1930.)

this point, because I believe that the characteristics of the human brain are particularly limiting when we come to consider the grandest questions of cosmology, a subject in which purely formal treatment tells us only that we are ignorant, while our human nature tells us that this is not the end of the matter. Meanwhile we may note that other large schools of philosophers, represented today by the existentialists, take exactly the *opposite* view to Popper, namely essentially that *only* the knower is important. However, we as scientists are hardly likely to go all the way with a fully subjective approach. We may surely agree that human inquiry has given us not only strikingly new views of the cosmos but also an insight into the worlds of other creatures. Let us see what we can learn from examining some of these. Our principle may be that we can understand something about an animal's world not only from its sense organs, but especially by what it does. This is indeed the way it *tells* us what use it makes of its sense organs and brains, about which we can otherwise only guess, even with knowledge of their structure and physiology.

We may begin with creatures that have really no nervous system at all, the sponges. And here we can call upon Dr George Bidder, who made a close study of them. In discussion of the life of the beautiful deep-sea Hexactinellids, known as Venus' flower baskets, he suggested that they do not live upright as they are usually presented in museum jars, but stand, as it were, horizontally across the ocean bed (Fig. 1). He showed that they make use of the currents that continually flow over the deep sea floor. He continues (1923): 'Food is brought to them, waste is taken away. For them in their eternal abyss, with its time-like stream, there is no hurry, there is no return. Such an organism becomes a mere living screen between the used half of the universe and the unused half – a moment of active metabolism between the unknown future and the exhausted past.'

Perhaps Dr Bidder was partly concerned to debunk, in his impish way, the romantic idea of the beautiful flower basket. But he was clearly romantic himself and has thought about what the world means to an animal with no nervous system at all. I am tempted in this joint Society of Botanists and Zoologists to explore the further question of the world of plants, but perhaps it would be better to refrain. Nor do I propose to take you on an elaborate journey through the comparative study of receptors and action systems throughout the animal kingdom. Let us look only at a few worlds that are very different from our own before returning to consider the operations of more complicated brains.

We humans are such strongly visual creatures that we find it hard to realize that the eyes of other animals do not show them a world anything like the one we see. Simple crustaceans, such as *Cyclops* or *Daphnia*, have only median eyes and probably with them they measure the incident light and adjust their level in the water accordingly. In 1930 Worthington showed at the Linnean Society that these freshwater creatures move down as much as 60 m every day and then up again to the surface at night. Dr Bidder, who was present at the meeting as Secretary of that Society, commented that they seemed to rise 'a metre in three minutes, or half a cm a second. This seems good going for such small creatures.'

For measurement of light for such a purpose complicated eyes like our own are really too good. Many animals have photoreceptors with reduced dioptric systems or none at all. Indeed, in cephalopods there are photosensitive vesicles actually inside the body, even in an octopus or cuttlefish, where the tissues are not transparent as they are in many squids. These vesicles have been shown to produce generator potentials and nerve impulses on illumination, but their function in the life of the animals is not fully known (Nishioka, Hagadorn & Bern, 1962). However, the nerve fibres from some of them end in a centre close to the optic gland, which controls the onset of reproduction (Wells & Wells, 1969). It may be that these photoreceptors serve to measure day-length and ensure reproduction at the right time of year. They may also be related to daily vertical migrations. It has even been suggested that in some deep-sea squids these photosensitive vesicles are so placed as to measure the light emitted from the animals own light organs and compare it with that incident from above. Animals that have photophores on their undersides to produce countershading need to switch them off at night (R. E. Young, 1973). Of course cephalopods also have wonderfully good paired eyes with lenses and we have shown that octopuses can learn to discriminate shapes. But in an abyssal environment there is little to see except flashes. In order to locate these flashes some cephalopods such as *Bathothauma* (Young, 1970) and other juvenile cranchiid squids have eyes on stalks, presumably serving for better accuracy of judgement of distance. Other deep-sea forms seem to have developed a special form of touch. In *Mastigoteuthis* and *Chiroteuthis*, the whip-lash squids, although they have eyes, the tentacles have become fantastically elongated. In most squids these tentacles serve to seize the prey, but here they seem to act as distance receptors for groping in the dark. In *Mastigoteuthis* they are covered with tiny little suckers and the scanning electron microscope shows that these are covered with papillae, presumably sensory. The lines of deep trawls sometimes have tentacles from *Mastigoteuthis* wrapped around them. Presumably the tentacles are waved about in the dark, serving as distance receptors to find out what is there. Where there is little or no light an animal that can explore the surroundings at a distance greater than own body length obviously has an advantage. The information is carried by a special tract of nerve fibres direct to the magno-cellular lobe of the brain. This is seat of the giant cells of other squids but in *Mastigoteuthis* it is hugely developed, presumably as a tactile centre, and indeed it looks something like the inferior frontal lobes of an octopus brain, which are concerned with touch. We do not know what the whip-lash squid feels with these long tentacles but presumably they give him a knowledge of events at a distance such as is normally conferred by eyes, but is denied to many abyssal animals.

Responses to light may be used in various ways. The ammocoete larvae of lampreys live buried in the mud and to ensure complete coverage they have light detectors in the tail. They also have pineal eyes in the head, but these serve to detect day and night and possibly longer-term changes; these eyes have no lens (Young, 1935 *a*, *b*). Animals that live in caves and have lost their eyes are nevertheless rather specially sensitive to light, with their skin. Obviously if you are blind it is important to remain in the dark. For you the edge of the cosmos might be said to be a blinding flash of pain all over the body – but how inappropriate is the adjective.

Even the animals that have good eyes do not necessarily use them to see the world in anything like the way that we do. They select the features that are useful to them. Thus bees can be trained to fly to cut-up figures, like flowers, more readily than to circles; to honey-like scents, but not to other odours. Of course as von Frisch (1967) has shown they can also learn the way across country to a source of honey, and communicate the information to others, by a clever detection of the orientation of the sun.

Curiously enough it is only in recent years that the limitations of the responses of animals have been fully realized. For a long time biophysicists felt that the best way to study sense organs was to use what *we* call simple stimuli – spots of light of different intensities, pure tones and so on. But of course animals do not meet such pure events in their lives and are often not equipped to deal with them at all. Ethologists and more recently physiologists have found more about the nervous system by testing with situations that are significant for the species. A landmark was the paper in 1959 by Lettvin *et al.* entitled significantly 'What the frog's eye tells the frog's brain'. And the answer was that it tells it a very limited number of things – whether a small object had entered the visual field and stayed there (Lettvin and his colleagues called them bug-percievers), whether a large object had entered the field (perhaps duck-percievers), and just a few other features. For us the point is that the frog does not witness the fine scene we see, with the willows waving in the breeze. He sees only those things that are necessary for him.

The maintenance of life requires that creatures respond correctly to their environments; it is the secret of homeostasis. As physiologists we want to know how this is achieved. As cosmologists we want to try to penetrate the limitations that are imposed upon knowledge by this dependence on survival. Correct response is ensured by a correspondence between the very structure and organization of the animal and the demands of the environment. Animal structure might thus in a sense reflect the nature of the world itself.

The brain, like the body, and the sense organs, must match the world it lives in. Its computations must correspond to the relevant world events in space and time. To react properly it must make estimates that we might summarize as 'what is going on, where and how fast?' Having assessed the relevance to itself of what is happenin must then take appropriate action. This is what nervous systems are for. Let us look at the mechanism they use to do it or at least at some features that may show its limitations.

Brains contain cells that are sensitive to particular simple features of the surroundings. There are vast numbers of these cells, each tuned to detect a slightly different feature. The now classic examples are the contour detectors found by Hubel & Wiesel (1959) in the primary visual cortex of cats and monkeys. Passing to the second, third and fourth visual cortices we find cells committed to many sorts of different environmental features. Some respond to outlines of indefinite length, others only if the line is stopped at one or both ends, still others if the object lies at a certain distance away. In the fourth visual area of a monkey the cells are all colour-coded (Zeki, 1973). Each of them responds to stimuli of any shape, but it must be of particular colour. In the year of the second centenary of the birth of Thomas Young it is interesting that the cells found so far respond to either red, green, blue, white or purple (Young, 1802). Moreover, as Hodgkin notes (1974), they are much more sharply tuned than the colour receptors themselves, as studied in a turtle's eye.

There are hints that these further visual centres contain cells that will only respond to quite complex features, even, it is alleged, to an outline like the hand of a monkey, but less to a human hand (Gross, Rocha-Miranda & Bender, 1972). This raises fascinating problems. Have we, then, cells tuned to detect every feature that we recognize? It is difficult for us to imagine how this could be. Of course we should not think only of single cells but of many of each type and of graded types of cell interacting, as the visual cortex contains cells responsive to contours at many angles.

The question of how complex situations are analysed has been equally debated for auditory stimuli (Whitfield, 1967). Cells lower in the auditory pathway respond to pure tones but many of those in the auditory cortex do not. Some of them respond only to complex biologically significant sounds – for example, in a monkey to the call sounds of others. Of course we must be careful here. Call sounds produce responses, so the firing of these cells might be determined by these state changes (Worden & Galambos, 1972). One hypothesis is that a number of detector units for various features operate upon different elements of a complex sound and their outputs converge on a 'pontifical neuron' that recognizes the pattern. We also have to remember that all this is not a passive process of filtering. The brain continually generates activity to match the input and feeds back as it were a hypothesis through the filter, a process known as analysis by synthesis.

The problem of how the information selected by the various feature detectors is assembled and made to produce appropriate outputs has not yet been solved by physiology. Perhaps this excuses us for jumping rapidly forwards and making a hypothesis about how the brain constructs what, following Kenneth Craik (1943), I shall call a model of the world, out of all these separate cells, and how it uses its model to predict what action to take (Young, 1964).

It seems to me logically essential that if there are such feature-detecting or classifying cells each can produce more than one effect, either a motor action or an influence upon some other cell in the sequence. This provides us with the possibility of finding units of memory, which may be called mnemons (Figs. 2, 3). We may say that learning consists in altering the probabilities among the possible effects of action, the change

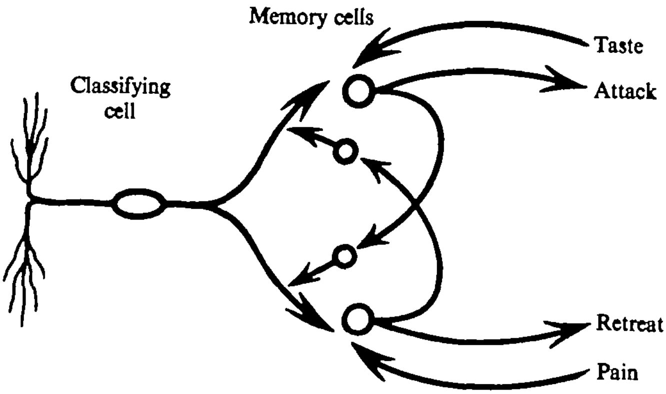

Fig. 2. Plan of the connexions suggested to be involved in switching of mnemons or single memory units. The hypothesis was developed to provide a scheme to explain learning by an octopus to attack a horizontal rectangle but avoid a vertical one. The classifying cells recording particular events have outputs allowing for alternative motor actions. The system has a slight bias towards one of these actions, say attack. Following this action, signals will arrive to indicate the results and either reinforce that action or produce the opposite action. Collaterals will activate the microneurons to produce inhibitory transmitter and so close the unused pathway. (After Young, 1965.)

being conditioned by the reinforcement signals of satisfaction or the reverse that the creature has experienced. We do not need now to consider what mechanism alters the probability. It is probably by decrease in the accessibility of the unwanted pathways as well as increase of those that are used. If so, such a memory system is partly selective, partly instructive. It depends primarily upon a set of cells predetermined to record certain features of the environment. The question of how much of the specificity of the cells is inherited from birth has produced some controversy, as has happened so often before in the history of biology when both genetic and environmental factors are involved (Wiesel & Hubel, 1963; Pettigrew, 1974). There is no doubt that cells for direction sensitivity, binocularity and bar-sensitive simple fields are inborn. New-born kittens and monkeys certainly have cells with many predetermined connexions, although only about 1·5 % of the adult synapses are there (in kittens; Cragg, 1972).

These large sets of detectors provided by heredity will then develop further or atrophy according to use or disuse. Experience teaches which are needed, by eliminating the unwanted ones and developing those that are used. This is basically the system of memory suggested by the mnemon hypothesis. We do not know yet how the unused cells are switched off or the used ones stimulated. But certainly these early memories are formed partly by selection from a predetermined set. As in so many parts of the body, the cells show a *double dependence*, upon hereditary influences from within and environmental ones from outside (Young, 1946). Thus Blakemore & Cooper (1970) have shown that kittens reared in an environment of either horizontal or vertical stripes later on no longer have the cells appropriate to the other one. The dendrites of the cells of the cortex in such kittens show orientations corresponding to their experience (Spencer & Coleman, 1974). Hubel & Wiesel (1970) and Blakemore & Van Sluyters (1974) have shown that there is a critical period of a few weeks in the early life of a kitten during which deprivation of vision for a few days or even

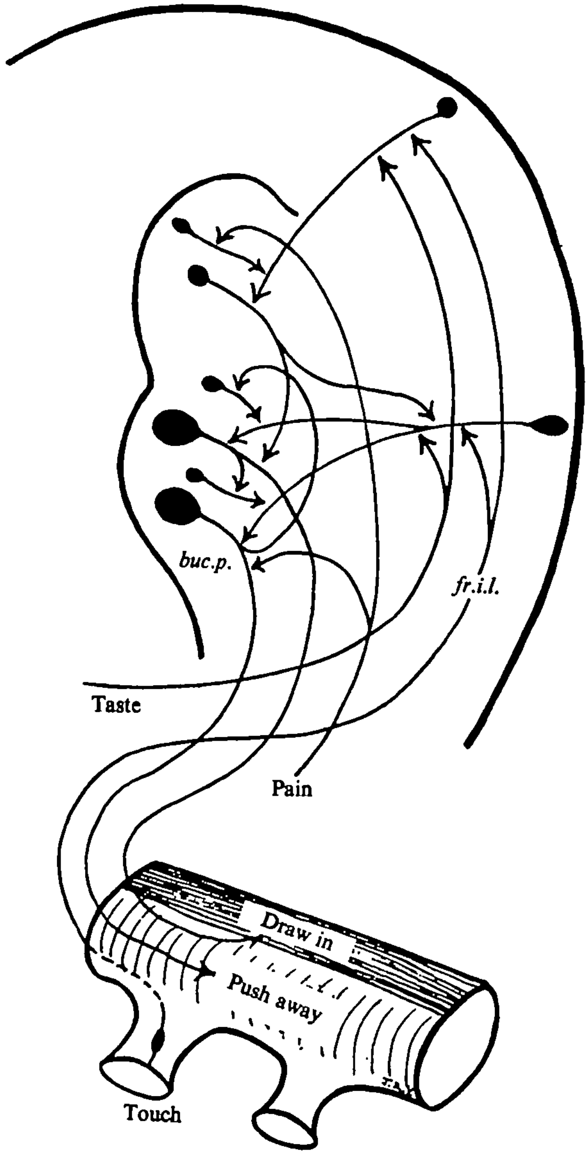

Fig. 3. Diagram of the mnemon system suggested for the tactile memory of an octopus. The animal can learn to draw in a rough object but reject a smooth one. There are postulated to be classifying cells in the lateral inferior frontal lobe (*fr.i.l.*), each tuned to respond to a particular degree of roughness. Each such cell can produce alternative outputs by the cells of the posterior buccal lobe (*buc.p.*). Signals of taste or pain besides deciding the appropriate response switch on the small cells to produce an inhibitor that blocks the unwanted pathway. (After Young, 1965.)

hours leads to marked loss of capacities. It is likely that humans have critical periods when they need the right input to learn certain skills. But the point for us is that heredity plays a large but yet unknown part in determining the set from which selection is made when our memory gathers information.

A further point very relevant to our theme is that signals from inner or personal

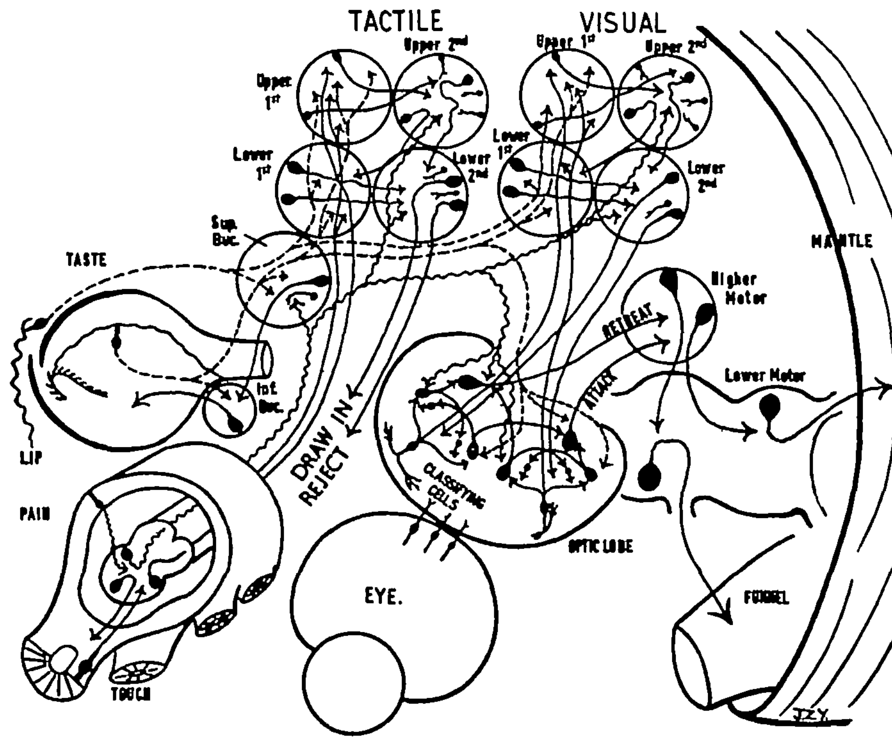

Fig. 4. The two sets of paired centres that are involved in the tactile and visual memory systems of the octopus, shown diagrammatically. The lower and upper circuits of the visual (vertical lobe) system on the right serve to mingle the signals of taste and pain with those from the eyes. They serve for generalization and probably also to maintain the 'address' of the classifying cells, in the optic lobe, until the reward arrives. The tactile memory system also contains four centres, constituting lower and upper circuits organized like those of the visual system. *Inf.Buc.*, inferior buccal lobe; *Sup.Buc.*, superior buccal lobe. (After Young, 1965.)

senses, such as taste and pain, must come into the system, because in the end these condition the knowledge that is acquired by building the model. In octopuses we can see something of the mechanism by which information about the results of the animal's actions is brought together with that from the outside world (Fig. 4). We can indeed see the interweaving system of fibres for doing this twice over, once in the visual memory and once in the touch memory (Fig. 5). Incidentally, this system also shows us how generalization is achieved; for example, it avoids the possibility that the octopus would have to learn all its touch lessons eight times over.

For our present purpose the point is that the memory system involves signals of what might be called satisfaction or the reverse – what the psychologist calls reinforcement signals. Is this also true of ourselves? If so it means that what we learn about the world is limited by the rewards we seek, by our emotions. Now it is of course a highly controversial subject in psychology as to whether learning always involves reward. Clearly it is not necessary for us to have a sweet each time we learn. Nevertheless there is direct evidence that the mammalian learning system is linked with signals of the satisfaction of need. Many recent studies show that the hippocampus is a part of the brain deeply concerned with memory, most clearly in man, where after bilateral removal of it little or no further learning is possible. This piece of cortex, though

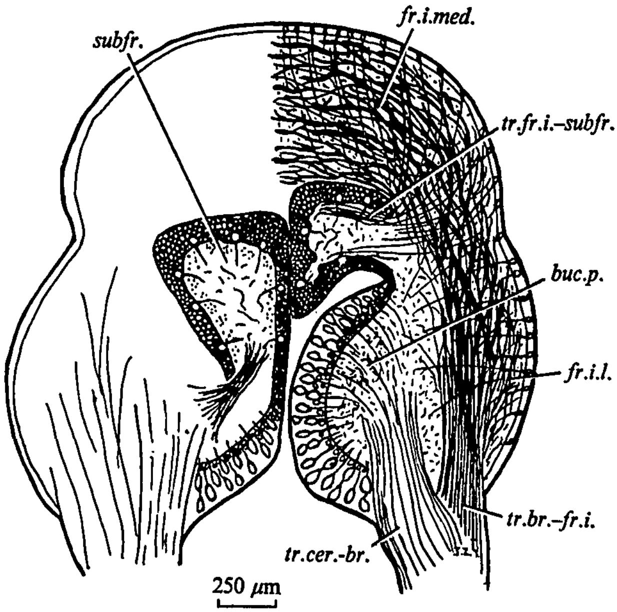

Fig. 5. Transverse section of the chemotactile memory centres of an octopus. Signals from the arms enter by the brachial to inferior frontal tract (*tr.br.–fr.i.*). In the lateral and medial inferior frontal lobes (*fr.i.l.* and *fr.i.med.*) the fibres from the different arms mingle with each other and with taste fibres from the lips, allowing for generalization. Cells with alternative outputs lie in the posterior buccal lobe (*buc.p.*) (see Fig. 3). *subfr.*, subfrontal lobe; *tr.cer.-br.*, cerebro-brachial tract; *tr.fr.i.–subfr.*, subfrontal to inferior frontal lobe tract. (From Young, 1964.)

relatively uniform structure, receives inputs via the cingulate and entorhinal cortices from all the main sensory systems of the brain. Recently fluorescence microscopy has shown a system of aminergic fibres ascending from the nucleus coeruleus of the medulla through the midbrain and hypothalamus to end (partly) distributed in the cingulate cortex. If the nucleus of origin of this tract is removed a rat can no longer be trained to run a maze for food reward (Anlezark, Crow & Greenway, 1973). The interesting point is that the nucleus lies just at the front end of the nucleus solitarius, the place where the taste fibres of the VII and IX nerves end.

So here is some evidence of how signals of reward may come to meet with signals from the outside world. This does not tell us indeed that in man all learning needs rewards. But we may remember that the hippocampus is part of a circuit leading through the mamillary body and anterior thalamus back to the cingulate cortex. This loop was long ago called by Papez (1937) the circuit of emotion, because injuries to it in man lead to emotional disturbance – and they also lead to gross disturbances of the memory. Very much is controversial about the hippocampus but we can go one stage further and try to see how it plays a part in building what I am calling a model in the brain. The point for our discussion is that if we knew something about how this model develops we could say what limitations it imposes on the human view of the world. It has been found that people with hippocampal damage are suffering from an incapacity to find the items in their memory, rather than an absolute loss (Warrington, 1971). In a task of recognizing objects where some clues are given such patients do nearly as well as normal people. This suggests that the addressing system for the memory in man is what the engineer might call 'content addressed', rather than 'list addressed'. We do not find items by looking along columns and rows but by seeking for their associations. Given one piece of information a whole large section may be evoked.

Just how the hippocampus is involved in this process is not clear. But recordings from single cells in the hippocampus of an awake rat show that each will fire only when the animal is in some particular place in a maze that it has learned (O'Keefe & Dostrovsky, 1971). The authors express it by saying that the hippocampus provides the animal with a cognitive map, telling it for instance where to go from the place it is now in. Other cells fire only when there has been a change – something is missing that was previously there, or the reverse. Still others fire when the rat begins to do something. We can vaguely see how all this might be achieved if the cells become so linked up that when each is active certain others are fired, following a learning between alternatives such as we have suggested in the mnemon hypothesis.

This gives at least some background to the suggestion that there may be restrictions on what an animal or man can learn, determined by selection of types of cell and possibilities of connecting them such as suit the way of life of the species. There is in fact some evidence that the human child is as it were pre-programmed for speech. As Lenneberg (1967) has emphasized, all children learn to speak in the same sequence and it can hardly be that all mothers teach them the same way.

If the human brain is programmed to learn language how much else in it is also so decided? It has been fashionable to suppose that we begin with a *tabula rasa* or clean slate and of course it is obvious that the new-born babe knows nothing of the world and will learn much. The question is can he learn *anything*, or does he tend to learn some things rather than others? I think the second is almost certainly true, and the further question then is what are his preferences and how do they determine the structure and limitations of human knowledge?

Man is a very social creature, he lives by co-operation with his fellows; it would not be surprising therefore to find that his brain has so evolved as to be especially ready to learn the skills of social interaction. Studies of child development suggest that this is indeed the case. The smile and the cry and knowledge of their uses by the child himself and by others are among the earliest of his attainments, and remain among the most important throughout life. Studies even show that a baby will fixate a human face rather than a similar round object. Could it be that he already has 'face cells' in the brain? Of course we do not know that this is the physiological mechanism involved, but some such system there must be. It seems likely therefore that human systems of thought are predetermined by heredity to revolve primarily around concepts of persons.

If this is true its special importance comes out in connexion with our ideas about a model in the brain and the system of content-addressing that it allows. You will remember that the scheme we suggest is that items enter the memory record by becoming associated with those already there. We can vaguely imagine how this will lead to the elaboration of a web of associations, which we will call the model. Recognition of any part will lead to the recall of neighbouring parts and any given item is recovered in this way. Of course the model does not operate only as a series of moments but sequentially in time over shorter or longer periods.

The system is admittedly vague and cannot yet be properly substantiated physiologically. Nevertheless you may feel that it corresponds rather well to what you know of your own memory system. If it has some truth in it the conclusion seems to be that the structure of a person's knowledge must at least be greatly influenced by this general nature of the model in his brain. And if this model is organized around persons, is it any surprise then to find that anthropomorphism is almost unavoidable in our thinking about what the world is like? Is this what we are getting at when we ask so insistently to be told what is the meaning of life? Perhaps we are so constructed that it is of our very natures to ask for a 'meaning'. And perhaps we are so constructed as to expect that the answer should be found in the terms of the existence of some over-ruling person-like power or God.

The fact that we have to think like this of course neither proves nor disproves that such a Being exists. Nor does it necessarily mean that we are incapable of further knowledge of the matter. Even if it is true that the model in our brains is organized around persons this does not exclude us from finding out about things. And surely the whole of modern science testifies to the enormous power we acquire by doing so. There is no need to elaborate now on all that has been found out about life on earth and the happenings in the cosmos. Yet it seems strange that in studying the stars we do not yet see clearly what could be called a pattern, let alone a 'direction' or 'meaning'. The attractive cosmologies of continuous creation or repeated expansion and contraction would begin to be what I should mean – but I gather that they are not acceptable to astronomers. Indeed I have found myself ridiculed for asking for a 'pattern'. Astronomers are proud of their radio stars and pulsars and quasars and black holes and they often think that as scientists we are wrong to ask for more. Perhaps they are right, but does not that also show that as scientists they are neglecting some very profound human characteristics?

We come back to where we started. The question is what sort of knowledge do we want. In order to have precise scientific knowledge we have to pass beyond the simple stage of anthropomorphism. But to have that knowledge does not prevent even the ablest mathematician from being human. I cannot help suspecting that at least considerable elements of the early model of the child, perhaps pre-programmed by heredity, must persist in the thinking of even the most abstract of us.

What I should like the cosmologists to tell us is whether they find any evidence of any self-maintaining systems in the universe other than terrestrial life. This seems to be a momentous question to which we should devote attention if we have this urge to find a meaning in life. I do not mean only the question whether there are any beings that could be said to be intelligent, but much more widely, whether actions that ensure the continuity of order are to be found and show us a direction, and hence a meaning.

I believe that biology can provide the beginnings of this answer – not of course for the Cosmos but for life on earth. It seems clear that during the course of evolution organisms have accumulated increasing stores of what may reasonably be called information. By this we mean the store of order that prevents organisms succumbing to the all-embracing tendency to increase of entropy. We biologists can hardly insist too much that attention should be given to the total dependence of life on its *history*. Here indeed is the continuity that provides the meaning for which we seek. The very concept of information, of knowledge if you like, only has meaning as the basis the maintenance of the order of a steady-state system.

To the zoologist it surely is clear that in some sense this information store has been increasing through the ages. The DNA of a monkey produces a creature that can meaningfully be said to be more complex than a mouse and this in turn more than a myxomycete. Of course there are many questions to be raised about this. Not all animal evolutionary lines show an increase in information and perhaps botanists will worry whether plant lines do. But yet it seems impossible to deny that there has been an accumulation of information if we consider that the earliest known organisms were bacteria or algae. In the higher animals the special capacity for acquiring information by learning in the nervous system becomes prominent. And man has developed this extraordinary power for accumulating extra-corporeal knowledge in books and the like. With his language he organizes this information store largely around concepts of persons and of social life, and this is the culmination of an age-long process of information storage.

For 3000 million years or more organisms have been evolving more and more elaborate systems of self-maintenance. They have been becoming more and more ordered, collecting information that enables them to resist in more and more diverse ways the tendency to dissipate into the surroundings. The whole living world, using variants of one genetic code, constitutes this store of order and continually gathers more.

Brains can acquire information very much more quickly than genetic mechanisms. Indeed higher animals have developed and refined all sorts of non-neural mechanisms for adapting the individual quickly to current conditions – the mechanism for acquiring immunity provides a useful example – and it is interesting that it operates by selection rather than instruction and the system I am suggesting for memory in the brain is similar. The implication is that what can be stored is limited by the items in the set from which selection can be made. Of course, if the individual has adapted to the local conditions it will not be appropriate that he should outlive those conditions and this holds one of the secrets of the significance of mortality. But man does not let all the information he has gathered dissipate, he can pass it on by word of mouth or in an exosomatic store.

Surely now with all this we can help with pointing to meanings. The evidence of 3000 million years tells us the way life on earth is going. This may not be a long time by cosmic standards, but is quite useful as a basis for induction for mortals for their three score years and ten. Surely it confirms what our own instincts tell us – that man is specially suited to carry still further this process of gathering information. We can, however, recognize that he is limited by his very brain structure to doing it in certain ways. He seeks for patterns of order similar to those personal and social ones that maintain his own homeostasis. But he is beginning to transcend these limitations in seeing something of the whole ordered pattern of life on earth and at least in looking for it in the Cosmos.

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