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The origin of adaptation.

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3

Index.

Chapter 3

Neutral points

Chapter 4

Equilibrium

Chapter 5

Breaks.

Chapter 6

The animal as machine

Chapter 7

Equilibrium and adaptation

Chapter 8

The solution

Chapter 1

The problem.

§1. The true test of our knowledge of a structure is our ability to copy it and to produce something which will imitate it, — at least in principle. Let us try to build a brain. We assume we have in front of us a vast number of healthy neurons, with all the necessary sense-receptors to provide them with stimulation, and also all the necessary muscles attached to bones to enable the arms and legs to jerk about.

We now want to know how to put the bits together to make something which will behave essentially like an ordinary man or animal. We begin to realise that knowledge of the principles necessary is just not available.

(2) The difficulty is not one of getting our nervous system to do something. On the contrary, ~~nerve~~-cells are so easily excited, and conduct ~~it~~ the excitation to other cells and excite them so easily, and the motor nerves excite the muscles so easily that any haphazard collection of nerve cells & muscles ~~way~~ will easily respond to stim- -ulation by excitation, and by

a wild activity. Yet unless we assemble our system properly this activity will be merely chaotic. There is, therefore, no difficulty about getting a collection of nerve cells to do something.

(3) Previously we saw that the behaviour of a haphazard assembly of neurons is apt to be chaotic. But in practice it is worse than this. The possession of organs of locomotion is an advantage if they are properly used, but unless they are used sensibly they actually increase the body's chance of self-destruction. Thus, suppose someone invented an "intelligent", self-steering motor-car. We might

perhaps, be prepared to trust the self-steering mechanism at 5 m.p.h. but not if the throttle was set to do 60 m.p.h. And in a general way we recognise that the greater the effectiveness allowed the better, if used properly, but the greater the danger if used improperly.

(4) At this point we meet a fundamental obstacle — the ignorance of the average neuron. Consider for a moment its life. Firstly, it lies buried in the skull in perpetual darkness. Consequently "light", "vision", "colour" can mean nothing to it. Yet later on it will have to play a part in reactions

which use, and depend on, light and colour. Thus, the hand of the engine-driver rests on the throttle and he is looking for the signal. If it is red, the Betz cells which control his arm must do one thing; if it is green another. Yet none of the cortical cells can form any notion of red or green.

(In this particular case "red" and "green" might be considered unitary quantities which might be transformed to some- -thing else to which the nerve cells are sensitive. But this case is peculiarly simple.

Much more common is the case where the behaviour of a neuron does not depend on any one factor but on a ~~[illegible]~~ large number of them. Thus consider the word of four letters

EMIT

It starts with the sound "ee". Now transfer the letter E to the other end and read it again

MITE.

The "E" letter is no longer pronounced.

Here we have a reaction to a stimulus (the letter E) which depends on the relation of the stimulus to other stimuli. This situation is intrinsically much more complicated than the simple "red-green" stimulus of the previous case.)

Still thinking of the ignorance of the neurons concerned, consider "walking" and the balancing

involved. Here all sorts of neurons have to send out impulses (or not send them, which is equally important) and the timing and distribution to the muscles must be correct otherwise the person will fall over. This (again) is no longer a matter of a single quality but of a complicated arrangement and organisation of a mass of neurons, not one of which has the slightest idea of what "balance" means (for they have spent all their lives supported at every point, and are totally indifferent to gravity). The whole idea of "balance" is meaningless to a neuron buried in the skull. Yet somehow they find out the right arrangement, without even knowing what

"right" is!

(5) It may be suggested that the balancing is due to fixed inborn reflexes and paths of conduction which never alter and which function automatically. This may be true in some cases but it does not answer all the problem. Bears, for instance, can learn to ride bicycles. Yet no one would suggest that bears are born with special "bicycle-riding" tracts in their nervous system, awaiting the day when men shall invent bicycles and circuses! Yet the bear <u>does</u> learn to ride, in spite of the fact that the individual neurons on whom his performance depends have not

the slightest idea of what the <u>bear</u> is doing. Yet the neurons do their work correctly!

In order to emphasize that the concept of inborn organisations of neurons is insufficient we may quote the work of Marina*. He crossed (surgically) the internal and external recti muscles of the eye on one side in apes and found that, as soon as the wounds were healed, the eyes moved normally and together. Here we start with a state which might possibly be reasonably due to an inborn, fixed arrangement of neurons. Yet clearly this

* Marina, A. Neurol. Centralbl., 1915, xxxiv, 338.

is disproved, for the same apparatus later produces different reactions.

A more ordinary illustration is given by the acquisition of speech. At first we are apt to think of speech as depending on fixed paths in some "speech centre." Yet the fact that a child can learn to speak any language, depending solely on where it lives, shows clearly that at first there is no special organisation at all. Yet again we want to know how can the nerve cells join up to form the "right" patterns, when the individual neurons have not even any experience of sound, much less of speech, or of the things

spoken about.

To say that these cells are controlled by a higher, coordinating centre is merely passing the responsibility elsewhere — and is no answer. Sooner or later the responsibility has got to settle.

(6) So far I have attempted to establish that beyond the fixed, inborn, reflex behaviour there is a far vaster ~~rela~~ realm where behaviour is not laid down in advance but it left open; Nature saying, as it were: no, you must work this out for yourself. There is surely no need to stress the importance of this type of behaviour. The mammals, and above all, man

owe their pre-eminence in the world entirely to their ability to develope this flexibility of behaviour, which brings in all the advantages of personal exper--ience, learning, development of new modes of behaviour, improvements, and so on.

In building a brain, the fixed reactions offer little difficulty, at least in principle. Only ingenuity is needed to construct each individual piece of neural apparatus so that a given stimulus shall be followed by a given response.

(7) But here we are concerned with the far more difficult problem of the neural apparatus required

for variable behaviour. Firstly, our neurons ~~can to little more~~ ~~[illegible]~~ live in a world which includes little more than fluctuating tastes, (as various chemical substances diffuse to them) and the passage of electric impulses. Next we have to leave both the problems and their solutions entirely open, for we want our brain to deal with any problem which comes along.

Thus we arrive at the fundamental problem which is: that we have a collection of utterly ignorant neurons joined together so that if the collection is presented with a difficult situation, the collection, as a whole, will work out the answer correctly (i.e. the 'person' solves the problem) while the individual neurons, while not having the slightest understanding of the problem, or where they play their part in relation to the others, nevertheless find out individually what is the "correct" thing to do. The above ~~this~~, is simply a description of what does happen every time, say, a person learns to do something.

It is important to remember that we are supposing the neurons to be entirely on their own. No "deus ex machina" is to help them in their confusion. We are particularly not allowed to call in the concepts of "intelligence" or "adaptiveness" since it is our problem to explain them.

(8) Finally, we must list the parts of behaviour with which we are not concerned.

Firstly, we are not concerned with problems relating to fixed, [illegible], reflex behaviour. Here we simply assume that a fixed mechanism is sufficient to explain fixed behaviour. If the fixed mechanisms are inborn, then evolution and the "survival of the fittest" will ensure that the mechanism is appropriate to the purpose.

Secondly, sex and reproduction are avoided entirely since these are not primarily concerned with the survival of the individual (We shall be satisfied if we

can plan an intelligent brain, without also asking that it shall be able to reproduce itself).

(9) Finally, (a much more severe restriction), the book deals only with reactions to direct, real dangers and not with all the difficulties and subtleties of reactions to "signals" (i.e. stimuli which in themselves are quite harmless or meaningless but which have importance by association or conditioning). This last restriction is a severe one, for most human behaviour consists of reactions to endless symbols and signals: it being rare for a human being to be

in actual contact with a real danger. Even in getting out of the way of a bus one reacts to the sight of the bus, not to the pressure of a bus beginning to run one over.

On the other hand, in the lower animals the signalling aspect becomes much less marked. I shall be content if I can explain simply the adaptive behaviour of lower animals to directly dangerous stimuli.

(The final, exact statement of the problem is given on p. 165)

Chapter 2.

Organisation and machines

(10) In order to solve the problem of the previous chapter we find that we must know much more about the organisation of units into wholes, or of "parts" into "machine." It was a suspicion of the author that the neurons managed to solve the problem not by virtue of their individual 'efforts' but by their organisation, i.e. by their

relations to one another.

(11) Further, it was, and is the author's opinion that there is an abstract science of organ-isation, in the sense that there are laws, theorems and discoveries to be made about organisation as such without asking what it is that is organ-ised. Lest this sounds incredible I hasten to point out that there is an abstract science of numbers (mathematics) by which we may make true statements about things but without having to specify exactly which things. Thus, we say that 2 + 2 = 4; and this is true without our having to specify two of what.

The rest of the book will, I think, give abundant evidence that the same is true of organisations. And we shall find that this new knowledge is directly pertinent to our study of the brain.

(12) But we must sharpen up our definitions, and clearly* the first word is "organisation." There appear to be several types of organisation, but in this book we shall dealing exclusively with one type — the "dynamic" type, or "machine." By "machine" it is important to note that I shall be using the word in the widest possible sense. I wish to include not only ordinary machines like the lever, a bicycle, and

* Final definition given p. 43.

a printing press, but any collection of interacting parts whatsoever. That is to say: it does not matter how peculiar, unusual, fantastic, pointless, or even insane the collection is, — if the parts act and interact on one another so that it changes with time — then it is included in my definition of a "machine" or "dynamic organisation." Thus the following are included:

① The solar system; for the planets pull, by gravitation, on each other and are pulled on by the sun so that they are endlessly in movement.

② A "house" of cards as it falls down; for one card hits another and upsets it, and the latter

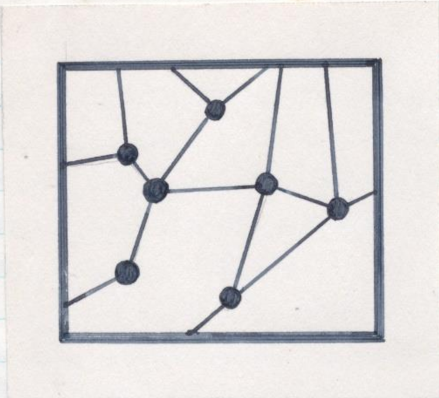
knocks over others, & they in turn hit the first one, and so on.

③ The wind as it blows, the "parts" being the air-molecules; for the movement of the wind is a product of the endless movings and collidings and re-collidings of the molecules.

④ Any system of interacting chemical substances; for similar reasons.

A particularly instructive example of a dynamic organisation, and one worth remembering as showing many of the main principles very clearly, is a frame with a number of heavy beads in it, the beads being joined together by thin elastic to form an irregular network:

(see over)



Such a network, if plucked, will tremble all over like a jelly. It is an organisation since the movement of any one bead depends on what the other beads are doing, and in its turn it influences the others.

(13) The next thing we have to do is to specify such a machine. And our method of

specifying must be applicable to all the many examples. Thus, merely to make a list of the masses of the beads, and the elastic tensions in our example does not show us how to proceed with other examples of very different type. A lot depends on our discovering a really good method. The ideal method is one which, naturally, will give every minute detail which is essential, and will avoid everything which is non-essential.

(14) To do this we notice firstly that the machine must be "measureable", i.e. it must be capable of being specified by numbers. Thus, our elastic

network, in its oscillations, may be specified accurately at any moment ~~that~~ by giving the position of each ~~b~~ bead, and its velocity. Since each bead-position ~~movement~~ has three dimensions and as the velocity also has three components to specify it, the precise state of each bead is described when we have given these six numbers. And as there are seven beads we shall need in all 42 numbers to specify the state of the machine at any moment.

(15) Our machine, then, ~~is~~ may be said to have 42 parts. These are functional parts. They are the 42 aspects of the

machine which can vary independantly. Thus we notice that it is not necessary to mention the lengths or positions of the elastic links, simply because: if the positions of the beads are fixed, then the positions of the elastic links follows at once.

It very important to distinguish clearly between "mechanical" parts i.e. our seven beads, and "functional" parts, i.e. our 42 variables. In this theoretical study of the subject we are concerned exclusively with the latter.

(16) We now proceed to specify the behaviour of such an organisation. This, it should be noted, is the

really important thing about a dynamic organisation. What it does is far more important than what it is.

To specify the behaviour of our dynamic organisation we start by labelling each functional variable, $x_1, x_2, x_3, \dots$. In our network these would go up to x_{42}. Then if these 42 x's are given actual numerical values, we shall know exactly what is the state ~~of~~ of our machine at a given instant. But this does not describe the future development of the movements of the beads.

I now propose to assume that the machine moves in small finite jumps instead of continuously. It seems to make the discussion

easier. I shall show later (§19) that it makes no essential difference.

We therefore take a new set of variables $x_1', x_2', x_3' \dots x_{42}'$ which are what x_1, x_2 etc become one interval later, i.e. after one small jump. Each of these new values will depend on the values at the preceeding stage. Mathematically we write this:

$$x_1' = f_1(x_1, x_2, x_3, \dots, x_n)$$
$$x_2' = f_2(x_1, x_2, x_3, \dots, x_n)$$
$$\dots\dots$$
$$x_n' = f_n(x_1, x_2, x_3, \dots, x_n)$$

(n is the number of functional parts, i.e. 42 in our example above).

This set of n equations is called a "substitution operator". It turns $x_1, x_2 \dots$ into $x_1', x_2' \dots$

So it has the same effect on the variables $x_1, x_2 \ldots$ as does one small jump in the actual machine.

For convenience we may write the operator more briefly:

$$x_i' = f_i(x_1, x_2, \ldots, x_n) \qquad (i = 1, 2, \ldots, n)$$

or, more briefly still:

$$x_i' = f_i(x)$$

the n being understood, and x, without a subscript, standing for all the x's.

(17) By these equations, or this substitution, we mean that if we are given the numerical values of all the variables, then we can determine what will be their values at one 'jump' later. It

should be noted that there are no restrictions whatever on the f's, such as continuity, differentiability, etc. The f's may, if necessary, exist merely as tables of numerical values of $f_i(x)$ with the x's as argument.

I hope to show through this book, and particularly in this chapter, that such a substitution operator specifies in the completest and most economical manner the inner "organisation" of a machine.

This, then, is my final definition of a dynamic organisation.

An "organisation" as discussed in this book, i.e. of "dynamic" type, is defined as being a substitution operator, and vice versa. Thus, if

any system of material parts can be specified by numbers, and if these numbers change by the interactions of part on part, and if we find that all the time-changes in the system can be covered by a substitution operator of type $x_i' = f_i(x)$, then the system forms a (dynamic) organisation.

(18) It is important to appreciate that the equations given specify what happens for one stage ~~only~~ or jump only. Of course, by applying it again after the first jump has been made, we can then calculate where the machine will be after two jumps. And in this way we can follow the

changes of the machine for any distance. But the substitution operator itself only gives explicitly one jump. The process of finding what x_i will be after s stages is "solving" the equations. In the language of the calculus of finite differences we have:

$$x_i(s+1) = f_i\{x_1(s), x_2(s), \ldots, x_n(s)\}$$

It may be possible to do this solving by some explicit method, but this is rare and solutions will usually have to be obtained simply in numerical form. When a solution is found, whether explicit or numerical, it will in either case be of the form

$$x_i = F_i(x^\circ; s)$$

where x° stands for the set of initial values $x_1^\circ, x_2^\circ, \ldots, x_n^\circ$ and

s is the number of jumps made.

(19) If the jumps become smaller and smaller, the changes in the machine gradually become continuous. So the change in each x, $x_i' - x_i$, has to be multiplied by some small ~~number~~ fraction, κ. So

$$\Delta x_i = \kappa \{ f_i(x) - x_i \} .$$

Put κ equal to an arbitrary infinitesimal dt, proceed to the limit and we get

$$\frac{dx_i}{dt} = \phi_i(x),$$

a set of ordinary differential equations. $(\phi_i(x) = f_i(x) - x_i)$. All the variables x_i are functions of one variable t. The solutions of these will give us equations of form $x_i = \Phi_i(x^0; t)$

(compare with p. 44).

(20) It is easily shown that the dynamic equations of physics (e.g. Newton's laws) represent organisations from our point of view. We therefore ask whether the important physical principles are of importance generally. It appears they are not. Thus, is it important whether our machine does or does not possess free energy? It appears not. All possibilities both ways are covered equally by $x_i' = f_i(x)$ and we make, and need make, no mention of why these relations (between x' and x) should hold. We are just not interested. We also note that a very important point

about physical systems is that they commonly obey some "conservation" law, e.g. conservation of energy, conservation of momentum, etc. These again are of no interest to us here. We note that they are merely various invariants of the very restricted types of substitutions used in physics.

(21) We must notice an important feature of these substitutions. It is that although $x_i' = f_i(x_1, x_2, \ldots x_n)$ looks rather like $y = f(x)$ and therefore looks as though we should be able to say how much x_i depends on x_k, yet this is wrong. It is not possible to assess the effect on a given variable of how much it is affected

by, or controlled by, the other variables. The impossibility may be shown most clearly by assuming that x_i' is given simply as a numerical value when we are given numerical values of the other variables. In such a case it is obviously impossible to say how much x_i depends on x_k. (Further, we are trying to commit an unforgivable sin: we are trying to split a whole into the sum of its parts. This is only possible when f_i is a linear function).

(22) If, e.g. $x_2' = f_2(x_2, x_4)$, we can say that x_2 does not depend on x_1 for one jump. Yet if x_4' is a function of x_1 it is clear that x_2's development

in time will be dependant on x_1's value, but it will be one stage later. (This delay and its importance will be referred to again in § 28). To find if one variable is permanently independant of another we assume the substitution solved. Then suppose, e.g.

$$x_2 = F_2(x_1^0, x_2^0, x_4^0; t)$$

(§18), then x_2's development in time is quite independant of what x_3 starts at, and this is the only way in which "x_2 is independant of x_3" has any meaning. Before we can say anything of general linkages we must trace these effects right round the circuit of f's. (In my notes p. 961 are given three ways of doing this, two of them very

elegant).

(23) So far we have thought of a set of variables which are organised. We now extend our ideas to a set of variables which may have several organisations. This means that the functions f_i must change to, say, ϕ_i for one change, and to ψ_i for another change. But this is too clumsy. We therefore introduce parameters p_i, as many as are necessary. Our equations now take a new general form:

$$x_i' = f_i(x_1, x_2, \ldots, x_n; p_1, p_2, \ldots, p_m)$$

or more simply,

$$x_i' = f_i(x; p)$$

(the f's are not quite the same as before, of course).

A simple example of ~~a~~ a change of organisation is given by our standard example of the elastic network. The elastic strings with their lengths, tensions and pattern control the organisation of the 42 variables. If we alter one of these, say by cutting it through, we now have a different organisation. And the variables will now behave differently from before. Clearly, cutting an elastic string has the same effect as reducing its tension to 0, so our cut has the same effect as altering the numerical value of a parameter.

(24) A final point to notice about these substitutions is that

they do not contain the time explicitly. This is necessary for the completeness of the machine. For if t were mentioned, i.e. if $x_i' = f_i(x; t)$ then t as parameter would be varying the organisation while the machine was working. This means that some outside influence is altering the nature of the machine. In other words, it would mean that we have not included in our system all the variables necessary.

(25) We now proceed to some definitions. In § 23 we wrote our parameters as p; but in practice variables are not labelled in this way — we have to identify the variables + the

parameters. Thus if:

$$x_1' = f_1(x_1, x_5)$$
$$x_2' = f_2(x_2)$$
$$x_3' = f_3(x_1, x_3, x_4)$$
$$x_4' = f_4(x_2, x_4)$$
$$x_5' = f_5(x_1, x_4, x_5),$$

then we must find the parameters, for some of the x's are *functionally* parameters.

To investigate this we complete the dependancies (§ 22) and find that

x_1	depends	on	x_1°	x_2°		x_4°	x_5°
x_2	"	"		x_2°			
x_3	"	"	x_1°	x_2°	x_3°	x_4°	x_5°
x_4	"	"		x_2°		x_4°	
x_5	"	"	x_1°	x_2°		x_4°	x_5°

Definitions: If x_i depends on x_k°, and x_k does not depend on x_i°, then x_k is said to

"dominate" x_i. Next, one variable is "parameter" to a set of variables if it dominates all of them. Thus, in our example above, x_2 dominates all the others, and is therefore a parameter to the set.

(26) We may note some interesting physiological features of dominance. It is the method typically used in an army, where the soldier's behaviour depends on the officer's orders but where the latter does not depend on the former. Another example is the switch & the electric motor — the motor's behaviour (stopping or going) depends on what the switch is set at,

but spinning, or forcibly stopping, the motor does not alter the switch.

Examples in physiology are given by the nerve impulse which makes the muscle give a twitch, while making the muscle twitch with an electric shock does not make an impulse start in the nerve. Here the motor nerve dominates the muscle. Again, and similarly, the pyramidal tract dominates the anterior horn cells. The ordinary reflex arc is built on the same principle except that here we have a chain of dominances: the stimulus dominates the sensory cell, the sensory cell dominates the sensory nerve, and so on.

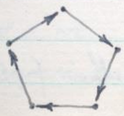
One important thing to notice is that as, in dominance, there is no back-action, ~~[illegible]~~ the dominated variables will have to do what suits the dominating ones, and not what suits themselves. Under these conditions it is possible for the dominating variables to run the others to death without even noticing it.

(27) A substitution is said to be "reducible" if we can divide it into two parts so that one part is a substitution on only some of the variables, and the other is a substitution on the rest; and if neither substitution needs information about the variables of the other, then the

machine represented by such a substitution really consists of two (or more) entirely independant organisations. (The proof is given in my notes, p. 987)

(28) In § 22 we mentioned "delay". We must note some further points. In actual practice, and by the theory of relativity too, there is always some slight delay in transmitting ~~and~~ an effect from one place to another. This means at least that we can make no fundamental distinction between systems where the variables interact instantaneously and simul-taneously and those where there is some delay. Now it is the

necessity for simultaneity which makes the "wholeness" of an organisation (§ 27). So if there is some delay in transmitting an effect from one variable to another, then this will mean a partial loss of "wholeness". This is true, for if it takes a time T for the effect to get from one variable x_i to another x_k, then if we observe the system for less time than T we shall conclude that x_i and x_k are independant; while observation for more than T will show that they interact. Or suppose we have five variables acting thus:

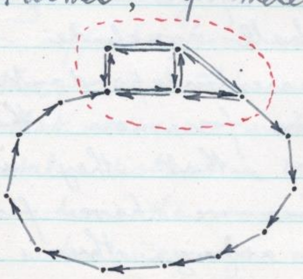


where the arrows

mean that an effect from x_1 is transferred to x_2 and so on; and suppose that a disturbance takes 2 minutes to get round, then one minutes' observation will make us think that the organisation is a chain of dominance

while observation for three minutes will demonstrate the circuit.

Further, if there is, say



then over a short time the five

variables in the dotted line will behave like a small, complete, whole, but if observed for a longer time it will be seen to be only a part of a larger whole.

So delays introduce all sorts of possibilities of breaking up a whole into parts, this division being valid over a short period of time. This means, in other words that the other variables may, over short periods, be regarded as parameters.

(29) Just as in § 26 we had "chains" of variables each dominating those below it, so we may have chains of organisations, each dominating

those below it. Our system deals with these straightforwardly and comprehensively. We have an organisation $x_i' = f_i(x; p)$ to start with. If the p's are an organisation, then they will develope in time in accordance with some equations

$$p_k' = \phi_k(p; l) \qquad (k = 1, 2, \ldots, m)$$

with parameters l, which may perhaps themselves form an organisation dominating the p's:

$$l_j' = \psi_j(l; g)$$

and so on.

Then the equations (substitutions) for the whole chain will consist of all the above together.

(30) Finally, it may be mentioned that if a starting point

x_i° or a parameter be unknown in ~~g~~ detail, but its probability distribution known exactly, then we get a distribution of solutions which may be studied as in statistical mechanics (see my notes, p. 971).

Chapter 3

Neutral points.

(31) So far we have specified our machine or organisation by a substitution $x_i' = f_i(x)$. This algebraic form may be rendered much more understandable by converting it to ~~an~~ equivalent geometric form. This helps us, in a sense, to visualise the organisation. Not, it should be noticed, to see the original machine with all its

impedimenta, but to visualise the essence of the organisation. We proceed as follows. If there are n variables in our organisation we "imagine" an n-dimensional space so that each variable mentioned has a dimension. If we consider our machine at a given instant its state will be specified by giving actual numerical values to the variables $x_1, x_2, \ldots, x_n$. These same numerical values will also specify a point in the n-space. And there is an exact one-to-one correspondence between the various instantaneous states of the machine and the points of the n-space.* (If this is not so, it means that

* So the point in the geometric space is called the "representative point" of the machine

we have, by mistake, taken too many, or too few variables; and this may be corrected).

Next, the substitution tells us that a state $x_1, x_2 \ldots x_n$ leads at once to a state $x'_1, x'_2, \ldots, x'_n$. This means, in our n-space that the point x (as we may call it) leads at once to the point x' also in the same space. We now join x and x' by an arrow pointing from x to x'. But since x is any point in the x-space this means that the whole of the space is filled with arrows. It is thus essentially a vector field. Its state now is that if we pick any point in it at random, we shall always find that there is an

arrow which will lead us to another point.

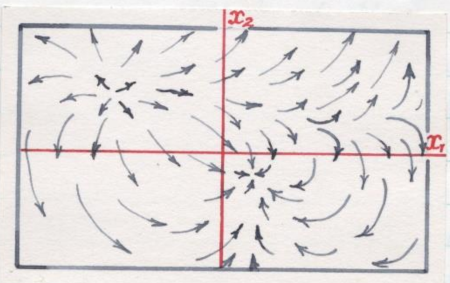
We should notice that one point corresponds to one instantaneous state of the machine; while the whole n-space filled with this field corresponds to one substitution and to one machine (through all its changes) and to one organisation. They are simply different ways of looking at the same thing.

As the end of each arrow is a point, it will be the start of a new one. So these arrows lying head to tail will join together to form a path. The path is such that if a point is started anywhere ~~at~~ along it, the point will

endlessly follow the path. Such a path describes accurately the events occurring in the given machine. Another path in the same field represents the same machine and the same organisation but gives the result of starting from a different starting-point.

Each arrow marks one interval of time.

The illustration shows (in two dimensions) what is meant.



(all the arrows cannot be drawn in since it would become solid ink).

(32) We may notice that the field, drawn graphically, is sufficient to define an organisation without one having to find analytic expressions for the functions involved.

(33) (How to explore an organisation experimentally and objectively in order to discover & set up its field is described in my notes p. 982).

(34) Definition: If we can find a point $X_1, X_2, \ldots, X_n$, briefly written X, such that

$$X_i = f_i(X)$$

then the point is called a "neutral point". This means, in practice, putting $x_i' = x_i$

so that our substitution becomes n equations in n unknowns x_i. The solutions are the neutral points.

(When we have differential equations, the neutral points are found by putting $\frac{dx_i}{dt} = 0$ and then solving the n equations in n unknowns x_i as before).

If we have several points $X^{(1)}, X^{(2)}, \ldots$ such that the substitution applied to one of them gives another of them, i.e.

$$f_i(X^{(p)}) = X^{(q)}$$

then the set of points is called a "neutral cycle".

(With differential equations we have a closed line described by one parameter, $x_i = x_i(w)$ where x_i is a periodic function.

If we operate on x with the substitution implied by the differential equation, we shall get an adjacent point on the line, i.e. some definite (and single) value of dw must give all the new coordinates of the new point. See my notes p. 988)

(35) So far, one field means one organisation. And a change of parameter will mean a change of organisation and a change of the whole field. This will change the positions of the neutral points. So a change of parameter(s) changes the neutral points. The parameters of a machine are, by definition, arbitrarily under our control.

As the machine works, so its representative point will follow a particular path in the field. As we can change the parameter, and therefore the field, and therefore the path, so, by ~~[illegible]~~ changing the path, we can steer the point to some extent. But it will be important to notice later that this control which the parameter has over the movement of the point is not direct but is done entirely through the field.

Chapter 4.

Equilibrium.

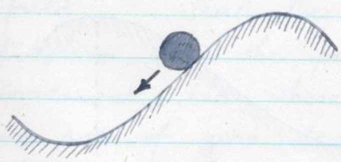
(36) We now have sufficient foundation on which to build an adequate study of "equilibrium". The subject is usually dealt with rather casually. Many first-class text books use the word without any attempt at definition. Usually the only precise definitions are given in elementary books where equilibrium is treated as a balance of mechanical forces, i.e. "forces" in

in the narrow sense of "that which produces acceleration". But this is far too restrictive. Thus the definition ("that the vector sum of the forces be zero") cannot be applied to the thermal equilibrium of a thermostat.

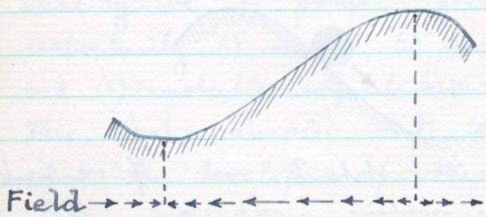
But, to start at the beginning, the standard examples of equilibrium are (1) a cube resting on one face, (2) a billiard ball at rest on a table, and (3) a cone balanced exactly on its point, giving respectively (1) stable, (2) neutral and (3) unstable equilibrium. This looks simple but the subject must be developed further. Thus, consider a square card balanced, if possible, exactly on one edge. To pushes at

right angles to its plane it is unstable, while to pushes parallel to the plane it is stable. So the same physical body may be stable and unstable at the same time. Clearly "equilibrium" belongs to a variable, not to a physical body.

(37) Next, consider a ball on a wavy surface like corrugated iron, and which is just rolling down one of the slopes:



What is its state? — If we think of it as rolling away from the top, then it is unstable, while if we think of it as rolling towards the valley, then it is stable! Clearly, the real answer is that it is <u>neither</u>. The proper way is to think of the top of the hill as being an unstable <u>point</u>, and the valley as a stable one, whether the ball is there or not. The field for the ball (excluding inertia) is a straight line (one dimension as there is only one variable) with arrows always pointing from hill top to valley:



The valley is a stable point because

if we move the ball a little way from the valley, the arrows controlling the movement of the ball move it back again. And at the top of the hill, if we leave the ball exactly balanced it will not move, but if there is the least movement sideways the arrows will move it further and further away.

Clearly the concept of equilibrium belongs to points in the field. And the points of equilibrium are the points of no movement, i.e. where the arrows are of zero length. It follows that <u>the states of equilibrium of a dynamic organisation are given by the neutral points of the field.</u>

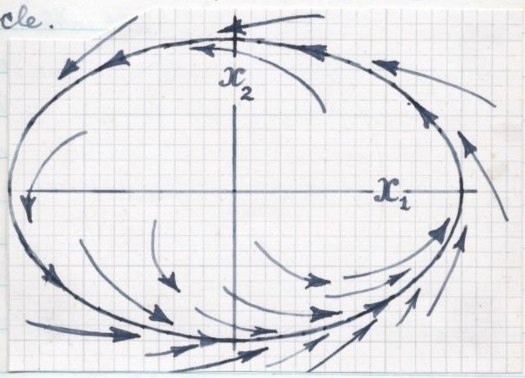
(38) The field picture thus gives us a much more comprehensive view of the nature of "equilibrium". According to this view, "equilibrium" simply means that the representative point of the machine is at a neutral point of the field. At all other places the representative point is moving. Further, ~~[illegible]~~ every path either terminates or goes to infinity. A point to which paths come and terminate is a point of stable equilibrium. So every machine, under all conceivable circumstances, moves towards a point of stable equilibrium or its variables move to infinity. Further we notice that if a ~~machine stops~~ dynamic organisation

stops, it cannot stop at any point other than at a point of stable equilibrium. Thus, <u>all stationary organisations are, and must be, in stable equilibrium.</u> (The chance of their being in true unstable equilibrium is infinitesimally small).

(39) The neutral cycle mentioned in § 34 corresponds to the type of equilibrium met with in a clock pendulum. Here the pendulum is continually moving and cannot be said ever to reach a neutral point (if the clock is ~~go~~ kept wound). Yet the amplitude of swing of the pendulum is constant. For if we give it a push to increase the amplitude of swing,

this will gradually die away until it has got back to its old swing. Equally, if we damp it down (not too much), its amplitude will increase again. Of course, we can treat "amplitude" as a single variable, stable at a certain point. But amplitude is not in the variables necessary to describe the movement of the pendulum. These are (1) degrees swing from the mid-line, and (2) its momentum. With these two variables we get a field with an elliptic curve ~~in~~ in it, and the representative point goes round and round the curve. It is therefore a neutral cycle. The pendulum does not leave this cycle

because the other arrows of the field around point towards the cycle.



Sometimes there are neutral regions. A billiard table is a good example since its whole perfection is that it shall be neutral. In the field (of the billiard ball) this means that there is some space where the arrows are all of zero length.

(40) We are now in a position to handle our machine with complete accuracy and certainty. As an example we may go back to the case of §29 (p. 60) where we supposed that a set of l's dominated a set of p's

$$p_k' = \phi_k(p\,;\,l)$$

while the p's were themselves parameters to a set of x's:

$$x_i' = f_i(x\,;\,p).$$

The l's are parameters not altering with time and under our absolute control.

Suppose the l's fixed, and that the p's have found, and settled at, a neutral point. Here they will not change, so the x's field does not alter (§35),

nor the neutral points. So assume also that the x-point has reached one of its neutral points. The whole is now completely at rest.

We now proceed to disturb it. This can be done, it should be noticed, only by altering the l's. It is not permissible to alter any of the other variables since to do this would contradict our own equations.

Suppose we alter the l's suddenly to a new value, & fix them there, at once everything begins to move. For we have altered the p's field and the neutral points. So the p-point suddenly finds itself no longer at a neutral point but in the middle of a field. The p-point accordingly starts to move along the path it happens to be on. But this change of p's alters the x-field and keeps on altering it. x's neutral point will move away and the x-point will start to follow it.

Eventually the p-point reaches its neutral point + stops moving. At this moment x's field stops changing. Now x can move towards a stationary neutral point and can reach it. And having done so the system comes to rest again.

Clearly this method enables us to discuss these more complic-

-ated cases with complete ease and precision.

(41) Finally we must note one remarkable property of the system when one organisation dominates another. We start as before with the l's dominating the p's, and the p's dominating the x's. The l's are fixed and the p's are assumed to have settled at a neutral point.

We now notice particularly what happens to the x's field, i.e. to the x's organisation, when a slight disturbance is applied to the l's. First we alter the l's slightly. This changes the p's field and neutral points and moves p's neutral

point slightly. The p-point starts to move towards the neutral point. When the p-point has moved appreciably we return the l's to their original value. p's neutral point now jumps back to its original place, and the p's begin to move back again.

Now ignore the p's + observe only the l's and x's organisation, i.e. x's field. First we apply (by altering l's) ~~[illegible]~~ a disturbance to the x's field, and the field changes. Then we remove the disturbance (return the l's to their first value) and watch the x's organisation. It has been changed, but as we watch the original organisation

is rebuilt up before use. We come, therefore, to the remarkable conclusion that it is possible for an organisation to be in stable equilibrium so that if the organisation is altered it will come back again to its original form. It is unnecessary to stress its importance. Its application to such things as the regeneration of complete limbs in Arthropoda etc is obvious. In a word, the reason is that if one organis-ation dominates another, then the variables of the dominating organisation are the organisation of the dominated one.

Chapter 5

Breaks

(42) Previously, in §38, we said that any machine moves to a point or region etc of stable equilibrium, or to infinity. This is not quite true for in practice if any variable tries to increase indefinitely it goes so far — and then some-thing breaks. Thus increasing strains at first lead to quicker

movement in the machine, but if they increase too much a mechanical break will occur. Similarly an increase of temperature in a thermo-stat makes the capsule alter the gas flow, but if the temper-ature increases indefinitely it will eventually melt or burn the whole apparatus. The only case I can think of where a variable can actually increase indefinitely is in the case of a comet or other body in space which can wander to infinity without breaking the equations which govern its motion. But this is rare, and at any rate all terrestrial machines are subject to this restric-tion.

We must now examine in much

more detail what we mean by a "break"* and in particular we must harmonise this with our previous mathematical methods.

(43) In popular language we say that a machine has "broken" in the sense that it is thereby finished. But by our definition we recognise that the result, no matter how chaotic, is still a machine, except that it is now a different machine. A break is therefore simply a change of organisation. In our substitution language, before the break we had $x_i' = f_i(x)$, while after the break we have $x_i' = \phi_i(x)$, and this, by definition (§17),

* Final definition p. 106

is a change of organisation.

(44) The next point we must consider is whether the changes which occur when something 'breaks' are to be considered ordinary, i.e. ~~=~~ representable by a substitution, or extraordinary.

First it is clear that there is no question here of anything going against the fundamental laws of nature. All the breaking events, whatever they are, are perfectly natural: e.g. the breaking of a cord, the fusing of a wire, the bending of a bar, etc. Therefore they are subject to the rule that they are deducible from their immediately preceeding states.

And this means that the events of a break are representable by a substitution. Further, it means that the series:

machine 1 — break — machine 2

may be treated as one straight-forward substitution

$$x_i' = \psi_i(x)$$

such that the first part of ψ (in time) corresponds to, or equals f (§43) while the second part corresponds to ϕ.

(45) This fact that we may represent the event of a break by a substitution is so important that I will give an example in some detail.

*Consider a pendulum swinging. To specify its motion,

*Better example, see my Notes, p. 1087.

we need two variables x_1 and x_2 (position and momentum) and there will be a substitution on these variables $x_i' = f_i(x)$ giving the swing. Actually the steps will be infinitesimal but this makes no difference (§19). Now imagine that the top of the pendulum, instead of being held by a completely flexible spring, is held by a soft metal strip which bends easily enough but which, after 20 bends, breaks and allows the pendulum to fall to the ground. We have to show how the whole series of events (swings, break and fall) can all be dealt with in one comprehensive substitution.

Let p be a ~~param~~ variable

representing the "supportiveness" of the wire. Assume it to be 1 before, and 0 after the break. Next, as the the ~~wire~~ strip breaks after 20 bends, something must be accumulating. Call this q: the "crackedness". Our observed events now are: first, the two x's oscillate with $p = 1$; p stays at 1 but q is slowly increasing. Then q becomes greater than 20, p changes at once to 0, and the x's now develope ~~in~~ quite a new move-ment (i.e. fall to the floor) $x_i' = \phi_i(x)$.

We now translate this into the precise language of substitutions. We have

$$x_i' = p f_i(x) + (1-p)\phi_i(x).$$

This gives us correctly x's development in terms of p.

p's development depends on q so that $p' = \lambda(p, q)$ where λ is a function such that

if: $p = 0$, $q =$ anything, $\lambda = 0$

$p = 1$, $q < 20$, $\lambda = 1$

$p = 1$, $q > 20$, $\lambda = 0$

This defines λ, and thus p' with complete precision.

Next q's development depends on q and x. As x_1 moves to and fro, q increases from 0 to 20 and onwards. Let $q' = q + \text{str}(x_1)$ where $\text{str}(x_1)$ is a function representing the strain (always positive) on the metal due to x_1. In this way q keeps accumulating bits of effect from x_1 (for q' equals

q plus something, so q' has all that q had already, and then adds some more on).

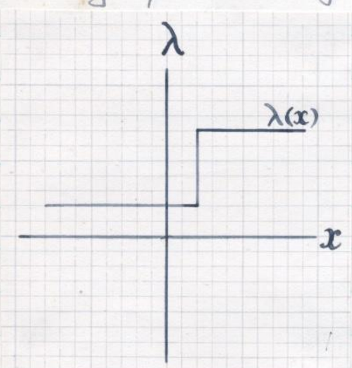
So the substitution:

$$x_i' = p f_i(x) + (1-p)\phi_i(x)$$
$$p' = \lambda(p, q)$$
$$q' = q + \text{str}(x_1)$$

with starting points $p = 1$ and $q = 0$ completely covers all three stages of the development in time of our pendulum.

(46) We must notice here the important part played by the function λ. Firstly, although "unnatural" from the analytic point of view, yet we must also appreciate its great naturalness and common occurrence in the real world. It is easier to

discuss if we suppose its type to be of one variable so that when graphed we get $\lambda(x)$:



Since it has this characteristic shape I propose to call it a "step-function". It is defined as any function which, within a restricted region if necessary, is continuous and equal to one value when x is less than a given quantity, and equal to another

value when x is greater than the given quantity. (It is deliberately not defined when x is equal to the given quantity as this is more convenient theoretically and is of no practical importance.)

A step-function of more than one variable is defined similarly, except that it depends on whether a given function $\vartheta(x_1 x_2 \ldots x_n)$ is greater or less than a given quantity q. If ϑ is a continuous function of the x's, the surface

$$\vartheta(x_1, x_2, \ldots, x_n) - q = 0$$

will divide up the x-space into regions so that on one side of the ϑ-surface λ has one value and on the other side of the surface another. Thus the single dividing point on the

* x-axis of the graph on p. 99

has spread to a surface through the x-space.

These "step-functions" are of wide occurrence in nature. They are far more commonly met with than parabolas, & are at least as common as a straight line! The fact is that every object in nature represents, in its surface, a step-function. Thus the distribution of specific gravity in and around a table is that the S.G. has the value 0·0013 (air) outside the surface of the table, and the value 0·7 (wood) inside the surface.

Thus the distribution of specific gravity alone will provide examples of step-functions wherever we look. The reader must convince himself here of the commonness of these step-functions, since otherwise he will feel that we are dealing with artificialities — which they are not. The reason why step-functions are common in nature and rare in mathematics is because the mathematician, when he comes across them, finds it easier usually to split the problem into two parts, solving each separately and then putting the two solutions together again.

(47) In § 44 we saw that it is always possible to consider the series:

machine 1 — break — machine 2

to be just incidents in the life of one machine. We now ask: under what conditions is it possible to split one machine into the series above?

We can, of course, merely change the name of the machine half way through, but this solution is trivial. And when we inspect the ϕ's (§44) of the second substitution we shall find them to be the same as the f's of the first.

The only way seems to be that there must be, among the variables, one which stays constant

for a time and then changes to a new level. In other words, one of the variables must be a step-function of the time. It is easily shown that if one of the functions ψ_K is a step-function, then x_K will be a step-function of the time (see my notes p. 1039). If this happens, then as x_K remains constant for a time, we may, if we like, ignore this variable, lessen the variables in the substitution by one, and simplify the functions ψ & f. And the f substitutions will be valid and true as long as x_K stays at its settled value. The moment x_K should change to its other value, however, the f's no longer represent ψ, new functions ϕ must be formed and, if we like, we can say that the f machine has "broken"

(48) We must now specify more clearly the conditions that a break should occur. (I am thinking here of the changes introduced by starting our machine at different points so that it may follow different paths.) We have our field specified by the f's, and we want to know how the conditions of break appear in the field.

Firstly, we must deal with f, and not ψ, for the latter has no break. Also, f does not mention all the variables for we have left out our step-function x_k (which I shall now call h for

We see, therefore, that "break" and "step-function" (§46) are entirely equivalent and may replace each other. If a variable is a step-function of the time we may regard this as an ordinary development or we may, if we chose, say at the moment when it changes value that the machine or organisation has "broken."

convenience and keep it quite separate) h is constant at the moment at its starting value h°. As long as it stays there the f substitutions hold valid. We have, therefore, our field described by $x_i' = f_i(x)$ (x_k omitted). The machine, however, is more truly,

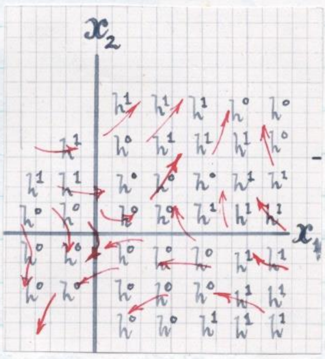
or extensively, described by

$$x_i' = \psi_i(x, h)$$
$$h' = h(x, h)$$

(using h as the functional symbol for convenience). This has the property that $\psi_i(x, h^\circ) \equiv f_i(x)$ and we assume that our starting points x°, h° are chosen so that h stays at h° for the first steps (i.e. so that the machine does not break instantly on starting). h is the step-function; and the machine will 'break' when h° changes to the other value h^1. How may we 'graph' this possibility in our field of the x's?

Let us write $h' = \text{step}_q\{\vartheta(x, h)\}$ meaning that h' is a step-function of ϑ, h' having two possible

values h° and h^1, which depending on whether ϑ is greater or less than q. Now fix h at h° and calculate, for all positions in the x-space, the value of h' and enter this at that point. We shall get something like:



(The field arrows are in red).*

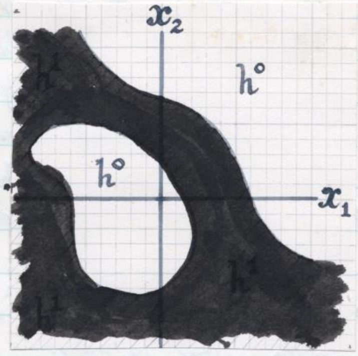
If we now start in the diagram at any point marked h° and follow the path from that

* Of course, the distribution would be different were we starting at h^1 and 'breaking' to h°.

point, then it is clear that the condition of break is simply that the path should meet an h^1 point.

In this example ϑ is perhaps discontinuous, and it is necessary to allow for this in the general case. Usually, however, ϑ will be continuous. In that case the value of h' will depend on whether $\vartheta(x, h^\circ) - q$ is positive or negative. So the dividing surface will be that described by $\vartheta(x, h^\circ) - q = 0$ considered as an equation linking the x's. With two x's there will be a line as in the next diagram, such that on one side h' will be h° and on the other side h^1. The conditions

of break are now that we start in an h° region, follow the path, and if the path meets the surface the machine will break.



(For clarity the h^1 region has been blocked out ~~cross hatched~~ and the field arrows omitted).

Such a surface will be called a "break-surface".

(49) A final point to consider

is whether the conditions of break, i.e. the break-surfaces will change after a break.

The answer is straightforward. Suppose there are three step-functions h, j, k. And suppose

$$h' = h\{\vartheta_h(x, h, j)\}$$

with 0 as the ~~boundary~~ critical quantity for the step-function. (note that ϑ_h is not a function of k). Suppose h, j, k have two values $h^\circ, j^\circ, k^\circ$ and h^1, j^1, k^1 starting with the former. Then at first we have

$$h' = h\{\vartheta_h(x, h^\circ, j^\circ)\}$$

and h's break-surface will be given by $\vartheta_h(x, h^\circ, j^\circ) = 0$. Now suppose k changes from k° to k^1. Clearly h's break-surface undergoes no change. Next

suppose j changes from j° to j^1, i.e. suppose j breaks. h's break-surface is now

$$\vartheta_h(x, h^\circ, j^1) = 0,$$

a different surface.

It is now obvious that h's break-conditions will, or will not, change when, say, j changes according as h' is or is not a function of j.

Chapter 6

The animal as machine.

(50) It is commonly accepted as axiomatic in biology that the animal is a machine. But as the word "machine" is capable of several meanings or aspects and as I have given my own exact definition of the word (p. 43), I shall here examine the question more closely in order to make sure that the animal does count as a "machine" within my definition. I shall

take the various points in order.

The first necessity is that all the necessary states of the animal shall be specifiable by numbers. This is certainly true to a very large extent. Thus all movements whatever may be adequately specified by using ordinary Cartesian coordinates in order to specify the successive positions. (We are not concerned here with whether it is practicable but whether it is logically sound). Secretions may be specified by volume per minute and by grams per minute of the constituents. Muscular contractions may be specified by so many kilograms pull at particular times. Electrical activities in brain and

nerve may be specified by so many volts at various times.

(With "thoughts" we are not concerned, except so far as they are associated with measurable brain changes, for we are concerned here with the purely objective study of the animal. Similarly, with "feeling." we are concerned only with the objective cause and the objective result, such as hair standing on end, pupil dilating, etc.)

The next necessity of our definition is that the system should change with time. This is obviously satisfied for even when an animal is not running about (i.e. changing position) there are still endless internal activities going on (heart beating, respiration, metabolism, etc). The only really still animal is a dead one.

The next necessity is that the substitution-operator be applicable. This is another way of saying that if we know all about the animal at one instant, we must be able to predict what its state will be one instant later (ignoring the environment, which will be brought in later, § 52). This is a difficult point to settle for it is a basic assumption behind most science. This is, in a sense, what is supposed in "determinism" and it is the break-down of this hypothesis

in atomic physics which has caused so much trouble. Since it is one of the basic working hypotheses of science we need have little hesitation in following its lead here. We assume it to be true and will abandon it only when it is proved to be insufficient.

The next necessity is that the various functional parts of the animal interact one one another. This is obviously true. Thus, physical movement causes the CO_2 in the blood to increase, which stimulates the respiratory centre, which increases respiratory movements, which sets free more CO_2 from the respiratory muscles, and so on. Were these interactions

not to occur, physiology would be a very simple science!

These four points are those necessary to be sure that the animal's properties agree with our definition of a "machine".

(The other two common properties of machines; — equilibrium and breaks — will be dealt with later, e.g. Chap. 7 and § 68.)

(51) When we study the behaviour of our animal we soon find that it has no relevance or point unless there is an environment present. Thus, teeth are meaningless unless there is food to eat, legs are pointless unless there is an earth to walk on, balancing

reflexes are pointless unless gravity is trying to upset the animal, the pupil is pointless unless light exists, and so on. Further, if we try to think of behaviour without an environment we find the behaviour to be both causeless and effectless. It is causeless for most behaviour starts by something in the environment disturbing or stimulating the animal. Also the behaviour would be effectless for most animal's behaviour is ultimately directed to altering or "correcting" the environment in some way.

It seems clear that the environment must be brought into the picture.

(52) We next notice that as the animal affects the environment, and as the latter equally affects the former, the two together form a dynamic whole. Both must be considered equally before we can form a sufficient system. Our "machine" must, therefore, refer to the animal and its environment considered as one thing. Anything less inclusive is demonstrably insufficient.

We now have one system, which may, if we like, think of as being composed of interacting parts. Thus we may, if we like, consider it as composed of (1) "animal" and (2) "environment." Or we may equally, if we like,

consider it as composed of the two parts (1) "Cerebral cortex" and (2) "the rest". This latter division is perfectly valid for the second part is actually the environment of part 1.

But this dividing merely refers our way of looking at it. Actually there is only one machine, specified by one substitution, $x_i' = f_i(x)$, where some of the x's refer to the animal and some to the environment.

The distinction between "animal" and "environment" has now become very slight. In fact, the distinction almost disappears when we think of the many things which may, functionally, be intermediate or indecisive.

Of course, anatomically, there is usually little difficulty: the animal is usually a compact body which has cohesion. But this introduces ideas quite extraneous to those we are considering here. We require functional criteria. Thus, from the functional point of view, what are we to consider the hands of a carpenter making a table? From the point of view of the wood they certainly count as "animal", yet if we are thinking more particularly of the man's brain and how it is working and controlling the muscles, then the hands are more like "environment" to the cerebral cortex. It is suggested here that there is no functional difference and

that if we mark off any part, then the rest of the system is its "environment."

(53) Yet somehow we must specify the "animal" part of our machine, for our original problem (Chap. 1) is a problem in animal behaviour, not a problem about the behaviour of environments or machines.

In practice our problem usually turns on questions of self-destructiveness (§3), (i.e. will one part of our organisation destroy another part due to faulty ~~organ~~ coordination.) Under these conditions we find we can resolve the difficulty fairly well by noticing that every animal has a certain, small, number of "vital" variables such as pulse-rate, respiration rate, blood-pressure, body temperature, etc. We recognise in practice that a dog may lose a leg and still count as a dog. In fact it may lose quite a lot and we may still say the dog survives. (This is an important point since in some species, e.g. the Arthropods, the animal may save its life by sacrificing a limb. Clearly we must be able in a difficult case, to say which we mean by "animal" and "limb"!)

But these "vital" variables are different. We know that if, say, the respiration rate drops to 0, it will not be long

before the pulse rate, and the blood pressure also drop to 0. And it is universally agreed that that this change is fundamental where the loss of a leg is not.

Another fact which makes the situation even simpler is that these variables tend to have two possible values, and they all tend together to be in one of two sets. Thus, for a human being we have:

Variable	Value 1	Value 2
Pulse rate	70.	0.
Respiration rate	20.	0.
Blood pressure (syst.)	120.	0.
Body temperature	98.	60.
Urine secretion (cc./hr.)	60.	0.
Blood sugar	100.	0.
Bacteria in blood stream	0.	++

and in the great bulk of cases the variables are all ~~either~~ in value 1 or value 2, corresponding roughly to "alive" or "dead". This correlation means that there is really little more than one variable concerned.

It appears, therefore, that the essential point of the "animal-environment" machine, as different from other machines, is that ~~is~~ it contains a special small group of variables which we agree to consider as of central importance. This is our "animal". If these variables remain within specified limits the animal is considered to be still alive; and if not, not.

Chapter 7.

Equilibrium and adaptation.

(54) We have now assembled all the materials necessary for the final steps. We shall proceed by two stages:

Firstly we will assume that our system is in stable equilibrium and we shall study the rather remarkable properties of all systems in that state. We show that many of the problem-features of Chapter 1 are simply

the features of any system in stable equilibrium.

But this leaves open the question of why a system should so organise itself as to get a point of stable equilibrium where it needs it. This will be dealt with in the next chapter (8).

In this chapter we shall assume that the "animal-environment" system, and the others we discuss has a field with a point of stable equilibrium. This means that we shall be discussing the behaviour of systems in a field around a point where all the arrows are of zero length and where all the paths wind inwards to the point. (E.g. see

the field of p. 68, where one of the points is of unstable, and one of stable equilibrium).

(55) First, as a very simple case, we will consider a simple pendulum hanging from a hook and able to swing right and left, and also forwards + backwards, i.e. to and from myself. It is in stable equilibrium when it hangs vertically downwards. We now disturb it by giving it a little push to the left. Immediately the pendulum responds by developing a force directed to the right. Equally, if we move it to the right it will devellope a force tending to move it to the left. Further, if we push the pendulum

away from us it at once pushes towards us; and vice versa. So the reaction of the pendulum varies according to the way we disturb it. In the middle ages scientists would have treated the pendulum rather like a living thing, and they would have said, as the law of pendulums "Pendulums seek the centre". And this (mistaken) statement does notice an important truth: that systems in stable equilibrium do look almost intelligent. In particular we see from the pendulum example that: a system in stable equilibrium subjected to a given disturbance will automatically produce that particular response

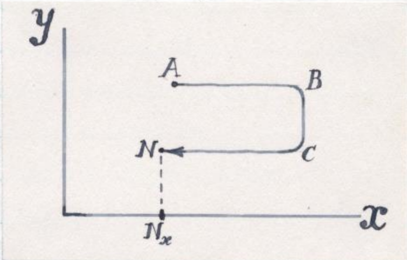
which will oppose the disturbance. As a more general proof we consider the field around a point of stable equilibrium. The latter is one where all the arrows, and paths, lead inwards to the neutral point (e.g. p. 68, the point just below and to the right of the centre). "Disturbing the system" means taking the representative point a small distance away from the neutral point and then allowing it to follow the path it is on. Clearly, by definition, all points near a neutral point will tend to move inwards, i.e. to "oppose" the disturbance which moved them away, if we care to think of it that way.

It should be specially noted

that this variety of responses is obtained from one (constant) organisation. The variety of responses with one organisation corresponds to the variety of paths around one neutral point.

(56) The next fact to be noticed about systems in stable equilibrium is that the arrows of the field need not point directly at the neutral point. This by itself seems little, but it becomes more interesting when the arrows point (partly) away, for a short distance. This means that when we observe our system, some of the variables may go away from their final values only later to turn and get back by a more roundabout

route. Thus, consider the field: (only one path is given for simplicity)



Suppose the field around the neutral point N has the shape given. There are only two variables in our system — x and y. Suppose we disturb the system by displacing x and y to A. We now observe carefully our machine. x, it should be noted, is near in value to N_x, its final value towards which it is "aiming". At first y hardly alters. x, however, starts moving more and more away from N_x. Presently x reaches B and almost stops there. Here, however, y starts moving until we reach C, when y stops changing and x starts moving. x then moves till it reaches N.

Now the shape of this field will, and must, depend on the inner mechanical and other necessities of the machine, i.e. upon its construction. The set-up of the machine prohibits the direct path from A to N; the passage through B and C is a necessity. This being so, an observer, if he thinks of the machine as being alive, may say, as he sees x moving away from N_x:

"How clever! See, x can't get straight from A to N because this bar is in the way; so x goes to B, thus making y work; y carries it to C and then x can get back to N. I do believe the machine shows foresight, for x went towards B _before_ making the B to C trip."

The important point in this particular case is that both points of view are right. The machine is just moving to a point of stable equilibrium, and it does look intelligent.

(57) The next feature to examine in the behaviour of a system in stable equilibrium is the

"orderliness" of the interrelations and interactions of the variables. If we consider first a haphazard collection of variables joined together with haphazard rules of interaction we find, naturally, as noticed in §2 at the beginning of the book, that the activity of such a system is quite chaotic. Yet the same system, near one of its own neutral points loses that chaoticness. For consider the field of the system around a point of stable equilibrium: all the paths, in spite of all their meanderings, inevitably terminate at the neutral point, and this means that the different variables must work together. A simple but clear example is

given by the figure of p. 136. Here x and y are adjusted to one another so as to bring the ~~the~~ path to N. The proof is simple: if the behaviours of the different variables are not properly related to one another then there will not be a point of stable equilibrium. (It will be remembered that throughout this chapter we assume there _is_ a point of stable equilibrium).

(58) Another feature we may notice, intimately connected with the last section, is that there is no question of these variables having to "know" what to do in order to maintain the equilibrium. What the variables

will do is entirely ~~f~~ decided by the nature of the functions f in $x_i' = f_i(x)$ (§31). And the assumption of a point of stable equilibrium necessarily carries with it the assumption that the variables x_i will do the correct thing (to bring the system to its stable state). But this applies not only to neurones in the brain but also to quite non-living organisations like the elastic network of p. 35. This shows at once that it is quite unnecessary to suppose any "intelligence" in the reacting parts.

(59) We now proceed to the discussion of examples of stable

equilibrium known to occur in living organisms. We notice that in the simplest organisms — the Protista — such equilibria are common. Thus all of them go through a neutral cycle like that of §39 when we consider their size: growth — fission — growth — fission... follow endlessly. Many of them seek an optimum pH, e.g. Paramecium, and will recoil and go back should they wander into a region of higher or lower pH. Many have an optimal rate of ~~feeding~~ growth so that if this is disturbed, e.g. by starvation, then the animal responds by feeding faster. Again, many are sensitive to

light and may swim towards it. This orientation is in stable equilibrium, for if we deflect the organism off the line it will at once make the necessary movements to bring itself back to the line again. In some cases the animal swims from the light, but it is still in stable equilibrium.

It is chiefly in the lower organisms that "equilibrium" is shown most clearly. Nevertheless it still remains of vital importance in the more complex animals. Thus the regulation of the pH of the blood gives a clear example. The main events are: Increase (say) of pH in blood → decreased activity of respiratory centre →

decreased ventilation of lungs → decreased loss of CO_2 → increased accumulation of CO_2 in the blood → increased formation of HCO_3^- ions → decreased pH of blood. Thus we have completed the cycle of interactions and have shown how a given disturbance leads to changes which eventually oppose the original disturbance. The system is therefore in stable equilibrium. If we change a single "decrease" (above) into "increase" or vice versa, we at once change the system into one in unstable equilibrium.

But there is more than this. All animals live only by having the capacity, as soon as their blood-sugar falls, of setting in motion behaviour which will bring it up again (i.e. "feeding"). But we may perhaps conclude with a summary by Haldane*:

"Biology must take as its fundamental working hypothesis the assumption that the organic identity of a living organism actively maintains itself in the midst of changing external circumstances."

(60) Finally, following closely on the last section, we see that the problem of self-destructiveness (§ 3) is answered, or the tendency avoided, by any system

* Haldane, J.S. Respiration. 1922. p. 391.

in stable equilibrium. (By "self" we mean "vital variables", (§ 53), and by "destruction" we mean "a break due to the variables going too far from some central value" (§ 42, 43)). Actually, our argument is much stronger than this, for, as we saw in § 38 (p. 80), "all stationary organisations are, and must be, in stable equilibrium". It follows, therefore, that the only way in which a dynamic organisation may avoid self-destruction (by breaking itself, § 42) is for it to stay around some point of stable equilibrium.

(61) Summary of Chapter 7.

In this chapter we have

shown that every dynamic organisation, when at a point of stable equilibrium, has certain properties. It is suggested that these properties would explain some of the problems of Chapter 1, provided we assume the animal and environment to form a system in stable equilibrium. Thus:

§	Problem	Solution	§
2	Haphazard organisations are chaotic	Not chaotic near point of stable equilibrium	57
3	Tend to be self destructive	Near point of stab. eqm. are self-preservative	60
4	Neuron is very ignorant	This does not matter	58

§	Problem	Solution	§
4	Neurones cannot organise themselves	They are properly organised at a point of S.E.m	57

But there still remains the fact that all this is entirely subject to the system being able to find the right organisation to get a point of stable equilibrium. And so far we have not said a word on this.

But this needs a new chapter (to be precise, § 68).

Chapter 8.

The solution

(62) The solution of the problems of Chapter 1 is not a simple matter of giving one answer: there are a number of aspects, all of which must be dealt with. I shall deal with the solution in stages.

First we have what may be called the "exact" case. Here we have an interacting dynamic system, like the

elastic network of p. 35, and we assume that all necessary inform--ation about the parts and their interconnexions is given. In such a case, the results of the previous chapters provide, I believe, complete answers to all questions about the behaviour of such systems. Thus, we can give or answer (reference sections given):—

(a) The exact future behaviour of the system (§18)
(b) Whether the system is a whole or whether it consists of several functional wholes intermingled (§27)
(c) The various types of organisation present or possible in it. (§22,23).
(d) Whether it is stable (§37).
(e) Whether it has more than one point of stability (§37)
(f) The various possible stable points for the various possible internal organisations (§37)
(g) If not stable, how the organ--isation must be altered to make it stable (§37).
(h) Whether it will be stable to given disturbances, (§37)
(j) Whether its organisation is stable, repeating (e), (f), (g), (h) for "organisation" instead of "variables." (§41)
(k) Should breaks occur or be possible, a complete account of them may be given (Chap. 5).
(l) All ranges of stability are calculable (§33, 48)
(m) If the system is "animal and environment" we can

a test to see whether the animal will, or will not, survive (§ 53).

It will be seen that all the main problems of the dynamic system may be considered solved (at least in principle), at least, in the "exact" case.

(63) But this, though true, is not quite what we want. Suppose we examine more closely a particular "animal-environment" system. We find that if we are given all necessary information we can predict what will happen, and this is completely fixed from the very beginning. Given the exact starting point, the exact substitutions (including

the step-functions, § 44) and the break-surfaces, then the system is completely determined. And in particular the future variations of the 'vital' variables are settled, i.e. it is already settled whether this particular animal will live or die in this particular environment. But this, though perhaps philosophically true, is not quite what we want. Usually we are not given all information down to the last detail. This applies particularly to the nervous system for we would almost never be given all information about all the neurons in the brain at a given moment. Such detailed information is at present unobtainable. We must,

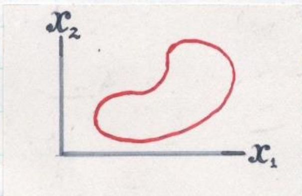
therefore, adapt our solution.

First we must go back and consider the general aim of these studies. Our problem, as stated in Chapter 1, is chiefly to set up a system which, while having no fixed organisation, shall nevertheless avoid the marked self-destructiveness so characteristic of haphazard organisations. From Chapter 7 we conclude that if we can get the animal-environment system to a point of stable equilibrium we shall have succeeded, provided that our special "vital" variables do not go outside their proper range (§ 53).

(64) We ask, therefore, will

this happen in the general case, i.e. invariably and necessarily? The answer must be — no.

Proof: Suppose we have two vital variables x_1 and x_2, and suppose they may not go outside the region bounded in red:



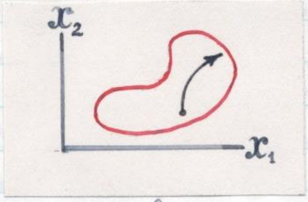
We suppose naturally that they start inside (since otherwise the animal will die at once).

As before, because it is part of a dynamic system there will be the usual field present. (We cannot draw it because our diagram is only a cross section

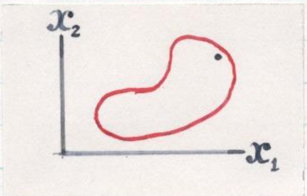
 Source: W. Ross Ashby Digital Archive

of the whole field, and will vary according to which cross section we take.) But we can at least observe the behaviour of the two variables. In any case, if the point at which we start the experiment leads to a neutral point within the region, then the animal will appear to be "adapted to its environment" and it will live. In the general case, when we are given only the previous figure (p.156) and no field, we cannot say in any way whether there is, or is not, likely to be a point of stable equilibrium within the red line — the conditions are too open. Even the presence of a break-surface

does not necessarily help us. For suppose the field is such that the point is just going to leave the area:



and suppose that at the boundary there is a break-surface (p.110) so that just before the point oversteps the boundary something "breaks" (p.106). A new field is instantly formed and we now have the new state of affairs that we have a (new) field and our (new) starting point is just inside the boundary. Is the new field more likely to



move the point inwards or out-wards? Clearly the conditions are far too open to allow any definite statement.

We conclude, therefore, that in the general case there is no necessity for survival. Or, in other words, to improve the chance of survival some special arrangement is necessary; merely being a dynamic organ-isation is not sufficient.

(65) At this point, while we are trying to find how it is

that an animal avoids self-destruction, we must beware of wandering into an error. (If the reader read the preceding sentence without protest he has himself fallen into the error!). Thus, suppose our animal-environment system consists of an earthworm in a tin box with the lid fixed shut, the whole, at the zero instant, being in a large furnace. Then demonstrate how that earth-worm's nervous system will react so as to ensure the earthworm's survival! Clearly the proper answer is that it doesn't.

Again, set up the system: a fish (with its nervous system, eyes, fins, etc) in its usual water + bait with a hook and line. "Demonstrate how the fish's nervous system will react so as to ensure the fish's survival." The proper answer here is that (as every fisherman knows) the eyes and nervous system and muscles of the fish will (often) ensure its destruction.

The point is that the nervous system does not ensure the organism's survival. In some cases, as in the "fish and bait" example, it actually tends to the destruction of the fish. It is therefore useless for us to try to ~~[illegible]~~ demonstrate or prove "how the brain leads to the animal's survival." What then are we to prove? The brain, after all, is probably of

some use to the animal!

(66) We must remember at this point that we are dealing here with the reaction of an animal only to direct dangers. (§9). (Reactions to dangers represented by signals or associations which are themselves harmless are much more difficult and are not dealt with here.)

When we think of the various direct dangers which surround an animal we find that there is one outstanding characteristic: namely, whether or not the intensity of the stimuli increases with increase of the danger. Thus when an animal approaches a fire for

the first time, it is well ~~warned~~ informed of the danger for there is a continuous parallelism between the sensation of heat on its face and the approach of the real danger, i.e. the red hot coals. Compare this with a person walking on ice which is getting thinner towards some spot. Here there is no sensory stimulus gradually altering with the thickness of the ice. And what is apt to happen is that the person goes on getting nearer to the danger without there being any stimulus to change steadily and provide information. And the person is apt to find quite suddenly that they have

reached the real danger, i.e. the ice breaks. Or, as another example of this latter type, consider a mouse approaching a mouse trap. As the mouse approaches the fatal spot there is no increase in any sense of danger or injury. And every designer of mouse-traps knows that the result would be very different if there were.

The point we have to note here is that when the increase of actual danger is not paralleled by some increase in sensory stimulation, then *the presence of a brain does not guarantee survival.* This means that we must restrict the scope of what we are trying to explain. And it also gives a hint as to how to proceed.

We therefore confine ourselves to the question: If the animal is in a situation of danger where the nearness of the danger is paralleled by some sensory change, show how the nervous system will ~~[illegible]~~ develope the right organisation so as to avoid the danger. This is the final statement of the problem of Chapter 1, modified as was found necessary in Chapter 6 and this Chapter.

First we must translate this into the more exact terms which I have taken so much care to provide & develope.

Thus, by "danger" we mean a dynamic organisation (including animal and environment) having an internal organisation likely to make the vital variables go outside their accepted range (§ 53). According to this view the "danger" is neither in the environment nor the animal but is a product of the inter-actions of the two. By "develope the right organisation" we mean that within the system there are possibilities for changing the organisations (by breaks or other means), and by "right" we mean any organisation in which ~~[illegible]~~ the vital variables have a neutral point (stable equilibrium) within the accepted

range. The "any organisation" should be noted, for it is not for us to lay down how an animal should survive as long as it does.

(67) At this point we must notice that in practice, animals always do conform with two rules.

(1) They are always more or less well provided with sensory receptors and these sense receptors are adapted to "inform" the animal of the approach ~~[illegible]~~ of most common physical dangers. Thus there are "heat" and "cold" receptors to warn the animal of unusual temperatures. There are "touch" receptors to warn the animal of ~~[illegible]~~ excessive pressures likely to cause injury,

and so on. It is true that there may be gaps here, i.e. that there may exist real dangers which do not excite the receptors such as tasteless poisons, but in these cases commonly the animal does not survive, thus leaving us nothing to explain.

Further, these receptors all work on the system that they send no or few impulses to the centre if and as long as they are in some standard state. (One cannot say "~~[illegible]~~ no stimulation" here for the temperature receptors, say, do not take absolute zero as their point of no stimulation) As the receptors are forced further from this standard state so do they send more and more impulses to the centre. It is important here to notice the parallelism between the two variables: "Deviation of the receptor from its standard state" and "number of impulses per minute emitted by receptor".

(2) We must also notice that animal behaviour rather tends to go on the principle that if the nerve cells and receptors are all within reasonable limits of stimulation (i.e. if the animal is "comfortable") then the vital variables will also probably be within physiological limits. ~~In practice, animals tend~~ The problem is treated in practice, therefore, as a problem in keeping the variables associated with

the receptors and nerve cells within physiological limits. If this is ensured by the animal's behaviour then bodily survival will probably occur. It is, of course, the business of heredity ~~and~~ to see that the animal ~~is~~ is born with suitable receptors to ensure this. Thus a mammal must have a cough reflex to keep water out of its lungs, and a lachrymal reflex to wash particles out of its eyes, and a bladder reflex to make it empty when it becomes overfilled, and so. Clearly, animals are very dependant on being provided ~~t~~ with these necessary receptors. Here I merely hypothesize that such receptors are provided

This is all on reflexes, not receptors.

and that they are of such a nature that keeping them within their physiological limits will ~~the~~ result in the vital variables staying within physio-logical limits.

(68) We now come to the solution. Suppose each nerve cell has some mechanism by which something "breaks" and alters its behaviour whenever it is being intensively stimulated and getting driven beyond its physiological limits. (We know exactly what is meant, functionally, by "break" from Chapter 5). The hypothesis is reasonable and is quite ordinary for all machines show this pro-perty (§42). We need not

notice here anything about what sort of break – that is a problem in practical physiology – we merely suppose that something which was constant alters to a new value so that that neurone's functional relations with its adjacent neurones ~~are~~ altered.

We now go back to the "field" concept (Chapter 3) in order to study the effect of this hypothesis. If there are n neurons we shall have an at least n-dimensional space to consider. In it will be a region, approximately "cubical", within which all neurons are within physiological limits. Our hypothesis is that surrounding this space are "break-surfaces"

(p. 110). And our representative point naturally is assumed to start inside this region, since otherwise the animal is apt to die instantly on starting the experiment. As the representative point moves about with the passage of time so we get several possibilities. Thus, it may move to a point of stable equilibrium within the region without going outside it. In this case no change of organisation occurs and the animal behaves as one quite correctly adjusted to the environment.

Much more commonly, however, this will not happen. What will happen is that the moment the system is released the

representative point will start to move out of the region. This corresponds, from the physiological point of view, to an arrangement where the initial organisation is leading to some one or more neurones being forced to extreme values. Thus, if the animal is put with something hot near its foot, the first tentative movement has taken the foot nearer the burning object.

At this point, however, by hypothesis, a break occurs and this means that a change of organisation has occurred (§43). So now the animal starts to react in some way differently from before. It should be noted that the

second reaction is not necessarily better than the first but only different. Under the new organisation, and new field, the representative point starts to move again. If it should move to a point of stable equilibrium within the region, then it goes there and stays there. But if it does not, but starts to wander again outside the region, then again, by hypothesis, a break occurs and a new, third, organisation is formed. And so on.

We have now reached a point where I must state the fundamental principle:

Dynamic organisations stop breaking when, and only

when, they reach a state of stable equilibrium. The reasoning is simple: if they are not in stable equilibrium some of the variables will tend to extreme values, causing a break; while once a system reaches a stable equilibrium, its variables do not wander from this value and further breaks will not occur. ~~The~~ More picturesquely we may say that the system follows the rule: Heads — I win; Tails — we toss again! The end of such a system is clear. Usually it will find some organisation which will have a point of stable equilibrium within the break-surfaces, and having reached this it will stop there.

Or it may happen that all the breaks, in endless combination, persistently fail until other, long-term, effects alter the basic conditions. In the first case the animal will appear to be working by trial and error until it finds the correct response, when it will keep to that organisation. In the second case, all trials result in failures until some-thing quite different happens (e.g. the animal dies of starvation, etc). This second case corresponds to that of § 65 where the "worm in tin" and "fish + bait" examples showed that survival is by no means guaranteed. The "worm

in tin" is a case where all possible changes of brain-organisation fail to lead to the survival of the worm. In the "fish + bait" example we notice here that the real danger, (the hook and being pulled out of the water, etc,) must be kept care-fully hidden from the fish as we noted in § 66.

(69) According to this view the brain behaves purely blindly and like any other physico-chemical system or machine. According to the principle of p. 175 it arrives at the right organisation because it must, if we agree that "right" or "adapted" is equivalent to

"stable equilibrium" (Chapter 7).

But there is a point worth noting in comparing the brain with man-made machines. The latter are always most carefully made to avoid breaks. Cases where a break is deliberately used are rare. The only common example is the electric fuse, which is specially put in to break should the current exceed some value. After an extensive search I have, so far, only found three examples in ordinary machinery. But the brain, I would suggest, goes to the other extreme. It is specially developed to use the principle of p. 175 and to use it efficiently.

Thus, a simple, if crude way of changing one's organisation by a break would be to break one's neck. But this involves far more than we want. Not quite so injurious would be to break one's arm. But this again involves far more than is necessary. Breaks, in fact, seem to have two aspects: ① the "damage" aspect, and ② the "change of organisation" aspect. The brain, according to this point of view is specially adapted to make maximal use of the "organisational" property while involving a minimum of the "damage" aspect. The brain, therefore, and particularly the cerebral cortex, is built specially to use breaks freely and in large numbers. It invites the environment to do its worst, so to speak, and to break as much as it pleases, knowing that the more the brain breaks the more accurately will the brain become adjusted to the environment.

It will be seen that the main theme of the book is that when a thing "breaks" there is much more happening than usually appears. Breaks have particular properties and principles not hitherto noticed. Usually these properties are ~~[illegible]~~ trifling, as when a cup falls and is broken, but they are still there. It

is only when breaks are used systematically that these latent possibilities become evident.

(Another point we may notice is that sometimes it may be the environment which breaks. By § 52 our scheme covers this possibility equally.)

Summary.

(1) (Preliminary). All behaviour is of two types: fixed and variable. The former consists of reflex action where one stimulus always leads to one action. With this we are not concerned; we merely suppose that some special mechanism exists for each reflex. The second type, variable behaviour, may be divided into two types: (1) reactions to a stimulus which is itself dangerous or painful, and (2)

reactions to stimuli which are themselves harmless but which have meaning or importance from being associated with the first type. Here, I am concerned solely with reactions of the first type, i.e. to stimuli which are themselves dangerous or painful. This is a severe restriction and I can only plead to be allowed to do one thing at a time.

(2) The question I propose to attempt is as follows:— "The reactions of an animal to stimuli depend on the inter-relations of the neurons of the brain, i.e. on their organisation. In the case of variable behaviour, this organisation, particularly in the cerebral cortex, is not

rigidly determined by heredity but is left fluid and must be worked out for the particular situation. A simple example is that the "speech centre" can learn any language. Thus English children born in China can learn to speak Chinese as a native. But our problem is much more extensive than this for we are concerned with all cases where intelligent, adaptive behaviour is developed, not inborn. Our problem is: how is it developed? How do the neurons organise themselves together properly to achieve a combined action which shall be appropriate? The problem is doubly difficult because

the neurons themselves, being creatures of very restricted experience can in many cases form no conception of the whole in which they are playing a part. Thus the speech centre organises itself correctly in spite of the fact that the constituent neurons have no conception of what "speech" means.

Our problem is to show how a collection of ignorant neurones may organise themselves together correctly so that the whole may behave intelligently.

(3) We commence by studying much more closely what is meant by "organisation". We find that it may be specified with

complete precision and conciseness by a substitution-operator. We find that there is a theory of organisation very pertinent to the study of the brain. The book shows amply that there is an abstract science of organisation by which we may develope theorems, make discoveries, etc which are true of the organisation without any regard for what it is that is organised. Chapter 2 particularly deals with this.

(4) In Chapters 3 and 4 we discuss the equilibrium of organisations. The question is investigated and the main problems solved.

(5) In Chapter 5 we

study closely the change of organisation which occurs when an organisation "breaks". It is shown than an exact treatment of the subject is possible. (This, mathematically, is quite new, and we introduce a new mathematical entity, the "step-function", in order to deal with it).

(6) In Chapter 6 we study the question of the animal and the environment in order to show in what way the main ideas must be applied to them.

(7) In Chapter 7 we give the first half of the solution. It is suggested that "finding the correct organisation" is equivalent to "finding an

organisation with a point of stable equilibrium within a specified region." All the main properties of "well-adapted behaviour" appear to be paralleled by the behaviour of any physico-chemical system when it is in a state of stable equilibrium.

If this conclusion is ~~then~~ conceded, then the problem becomes one of discovering how a system can organise itself so as to achieve a stable equilibrium.

(8) In Chapter 8 we show (§ 65) that this feature is not a characteristic of all organisations. But by introducing very simple restrictions which are natural and which correspond

closely with what is known of the brain, then under these conditions the neurons are bound to organise themselves together to form a system with the required properties.

The solution depends on the (hitherto unrecognised) peculiar properties of "breaks". Every break is a change of organisation. Further, breaks are intimately linked with equilibrium because of the basic theorem that:

(§ 68) All dynamic organisations stop breaking when, and only when, they reach a state of stable equilibrium.

(9) According to this theory, "breaking down", as a physical event, instead of being wholly

bad, is given a position of prime physiological importance. "Breaking", apart from its ordinary features, has subtle organisational consequences not immediately obvious in the simpler cases. The brain, in my opinion, is a machine specially constructed to use these "organisational" features of breaking to the fullest extent. It, and the cerebral cortex particularly, owes its extraordinary adaptability to the fact that it provides vast facilities for easy and endless breakings.

Index of definitions

In order to make it clear that every special word used is definable and exact, an index of such words is given, with the page where its definition will be found.