ADAPTIVENESS AND EQUILIBRIUM.

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The behaviour of animals and man may be approached from many points of view, but there is one feature of their behaviour which is outstanding in its importance and in its difficulty. I refer to the peculiar "adaptiveness" of animals' behaviour. The concept is vague, but everyone knows, roughly at least, what is meant by it. It is certainly one of the most remarkable features of animal behaviour. In psychiatry its importance is central, for it is precisely the loss of this " adaptiveness " which is the reason for certification.

We may demonstrate the phenomenon very clearly by writing, not " the burnt child dreads the fire," but " the burnt child seeks the fire." In this latter statement we see at once that the adaptiveness has disappeared.

But the concept of " adaptiveness," though important, has several marked disadvantages. Firstly it is vague. It is very difficult to define exactly what we mean by the word. Secondly it is not quantitative; and although one can recognize, roughly, degrees of adaptation yet there is, at present, no means of expressing this quantitatively. Its third disadvantage is that it is apt to involve subjective elements from the mind of the observer. Instead of the question of " adaptiveness " being decided purely by an objective examination of the animal and its circumstances, it is apt to be a judgment on the part of the observer, and there is no guarantee that different observers will all come to the same conclusion.

It would clearly be better if this concept could be changed for another which would be equivalent to it as far as its essential features are concerned but which would be free from these objections.

It is suggested in this paper that the concept of " stable equilibrium " may perhaps be equivalent to it.

In order to discuss the question adequately, however, we must first study the question of " equilibrium " in more detail, for there is more in the subject than meets the eye.

The Nature of "Equilibrium."

We may start with the classic example of physics. We have three objects on the table before us: one is a cube resting on one face, the second is a sphere, and the third is an inverted cone exactly balanced on its point. They correspond to the usual "stable," "neutral" and "unstable" equilibria respectively. The criterion used to distinguish the types of equilibria is that we apply a small disturbance to the object and see what happens. We find that the cube tilts and then returns to its original position; that the sphere starts rolling slowly; while the cone topples over. But we can make our test much more general and more precise. We apply a force to the body to be tested, tending to make it move a little. This movement changes the distribution of forces acting on the body, and we then notice how the resultant force compares with the original disturbing force. We find that in the case of the sphere there is no resultant force (ignoring simple inertia). In the case of the cube, or any body in stable equilibrium, we find that the resultant force always acts ***against*** the original disturbing force, while in the case of the cone the resultant force acts ***with*** the disturbing force. Consequently, by comparing the resultant force with the original disturbing force we may decide the question of the type of equilibrium in a purely objective and quantitative manner. (The word "equilibrium" is used to include unstable as well as stable equilibrium.)

We must notice some minor points at this stage. Firstly, we notice that "stable equilibrium" does *not* mean immobility. A body, e.g. a pendulum swinging, may vary considerably and yet be in stable equilibrium the whole time. Secondly, we note that the concept of "equilibrium" is essentially a dynamic one. If we just look at the three bodies on our table and do nothing with them the concept of equilibrium can hardly be said to have any particular meaning. It is only when we disturb the bodies and observe their subsequent reactions that the concept develops its full meaning.

But our definition so far is not quite precise. Equilibrium belongs properly to a single variable and not to an entire physical body. This may be demonstrated most clearly by an example. Consider a square card exactly balanced on one edge. For displacements at right angles to the plane of the card it is in unstable equilibrium, while for displacements parallel with the plane of the card it is, theoretically at least, in stable equilibrium. The point is that there are two separate variables to be considered (two angles of deviation), and either may be stable or unstable independently of the other.

We may now define stable equilibrium more precisely: a variable is in stable equilibrium if, when it is disturbed, reactive forces are set up which act back on the variable so as to *oppose* the initial disturbance. If they go with it then the variable is in unstable equilibrium.

Since the reactive forces are set up by the change in the variable and then come back to the variable to affect it, we are clearly dealing with a functional circuit. A straightforward example is given by an incubator with gas-flame and capsule as regulator. We will trace the functional circuit. We may start with the temperature of the air in the incubator. (It is to be noted that every variable mentioned is capable of direct measurement.) We have :

Temperature of incubator	controls	temperature of capsule.
,, of capsule	,,	diameter of capsule.
Diameter of capsule	,,	volume of gas flowing per minute.
Volume of gas flowing	,,	output of heat per minute.
Output of heat	,,	temperature of incubator.

So we have arrived back at the beginning and have demonstrated the real physical existence of the circuit.

We see therefore that the concept of "equilibrium" necessarily involves the existence of a functional circuit. We may symbolize this by writing $x_1 \rightleftarrows x_2$, where x_1 and x_2 are variables and the arrow $(x_1 \rightarrow x_2)$ means that the value of x_1 determines the value of x_2.

Next we have the inverse problem : Does the existence of a circuit necessarily involve an equilibrium? The answer is certainly "Yes," for if we have $a_1 \rightleftarrows a_2$, then by the upper arrow, a disturbance of a_1 will necessarily disturb a_2 and, by the lower arrow, this will disturb a_1. This latter disturbance, being a change of the variable a_1, will be comparable (or dimensionally similar) to the initial disturbance of a_1 and must therefore compound with it. This means that it will reinforce it or counteract it, thus giving the conditions of equilibrium (unstable or stable respectively). (The precise after-effect will depend on the particular hypothesis we may make about the compounding of the first and the second disturbance.)

The next point is that all systems in equilibrium have a "neutral point." In general, if we have variables $x_1, x_2, \ldots x_n$, the change of a particular variable x_i will be given by equations of the type.

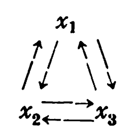
$$\Delta x_i = f_i(x_1, x_2, \ldots x_n) \qquad (i = 1, 2, \ldots n).$$

If we put all $f_i = 0$ we have n equations involving n variables and the equations may, in general, be solved for the variables. We thus obtain a particular set of values of the variables, $X_1, X_2, \ldots X_n$. If all $x_i = X_i$ then all Δx_i are 0, and the system will tend to undergo no change. This multi-dimensional point $X_1, X_2, \ldots X_n$ may properly be called the "neutral point" of the equilibrium. If the system is stable it will tend to come to rest at this point, while if it is unstable the system, if at this point, will undergo no immediate change (e.g. a cone exactly balanced on its point). The importance of this is that in talking of a stable system we are implicitly assuming that we are dealing with deviations from this neutral point. Thus in the case of a stable thermostat the neutral point is the temperature about which the thermostat is continually oscillating and to which it is continually tending.

This leads to the next concept of a " range " of stability. If we consider stable systems we find that they are stable for small deviations from the neutral point but that, if pushed too far from their neutral point, they ultimately become unstable. Thus a cube resting on one face is stable for tilts up to 45°. If it passes this deviation, however, it becomes unstable and falls over. Similarly a thermostat is stable for fairly large deviations of temperature from its neutral point, but if the temperature becomes too high the metal, etc., will eventually melt and the system will lose its stability. The maximal deviation from the neutral point which still allows the system to remain stable may be called the " range of stability."

An interesting example of " range of stability " is given by explosives. Commercial explosives must be stable substances. Were they in unstable equilibrium the minutest disturbance would cause them to break down. For this reason a useful explosive must have a fairly large range of stability in order that it may stand up to the processes of manufacturing and subsequent handling. It is only when it is driven outside this range of stability that it should demonstrate its marked instability.

So far the discussion of equilibrium has been simple, and it may be objected that so simple a concept is quite incapable of dealing with the enormous complexity of function of known living organisms. This objection, however, does not appear to be valid, for the subject of equilibrium soon leads into much greater complexities. Thus instead of a single circuit we may have two circuits joined by a common variable: $x_1 \rightleftarrows x_2 \rightleftarrows x_3$. We may have three variables influencing one another to form a compound circuit:



and so on. In such cases the properties of the system from the point of view of equilibrium soon become much more complicated. We will give an example of the curious and interesting properties of such compound systems. If we take our incubator again and consider the variable " temperature in the incubator " to be the main variable (x_1), and regard the variable " diameter of the capsule " as a stabilizing variable (x_2) acting on x_1, and if we join x_2 on to a new circuit with a variable x_3 which has the effect of stabilizing x_2, then the effect of "stabilizing the stabilizer" is to render x_1 *less* stable. It will be seen, therefore, that there is no lack of complexity when we come to deal with compound systems of circuits.

Another point to be noticed in compound systems is that the behaviour of a given variable is now a function of the whole system, and this, again, leads to an endlessly increasing complexity.

Finally, there is one point of fundamental importance which must be grasped. It is that stable equilibrium is necessary for *existence*, and that systems in unstable equilibrium inevitably destroy themselves. Consequently, if we find that a system *persists*, in spite of the usual small disturbances which affect every physical body, then we may draw the conclusion with absolute certainty that the system must be in stable equilibrium. This may sound dogmatic, but I can see no escape from this deduction.

To give an example, it is well known that there are stable and unstable chemical substances. And it is a fact that if we look round any laboratory's stock of chemicals we shall find only stable chemicals on the shelves. Not only is this a fact: it is a logical necessity. Again, while it is common to find bricks resting on one face, it is rare to find bricks exactly balanced on one edge. And it is clear that this must be so.

Having given this preliminary survey of the nature of "equilibrium" we may now proceed to the discussion.

It is clear that the adaptiveness of animal behaviour is not its only feature. There are other aspects and problems such as that of memory, etc. With such we are not concerned.

There are certainly many examples, in animal organization, of variables which are known definitely to be in stable equilibrium. Thus the *p*H of the blood is stabilized by the circuit: *p*H of blood $\rightarrow$ activity of the medulla $\rightarrow$ rate and depth of breathing $\rightarrow$ rate of removal of CO_2 $\rightarrow$ concentration of CO_2 in the blood $\rightarrow$ *p*H of the blood. It should be noted that this is not quite as simple as it looks, for were any one of the linkages reversed in its effect the system would then be in *unstable* equilibrium, and this would quickly result in the death of the animal.

Pupil diameter is similarly in stable equilibrium through its optical effect on the intensity of the light on the retina and the subsequent changes through the nervous system. This is a slightly more complex circuit, since the neutral point is no longer absolutely fixed but depends on the intensity of the illumination outside the eye.

The blood sugar of an animal is also usually in stable equilibrium, for it is well known that if the blood sugar drops, through lack of food, complex behaviour is set up which results eventually in the blood sugar *rising*.

There is no necessity to give many examples. Reflection soon shows that vast numbers of variables associated with the animal are all in stable equilibrium. Not only is this so as an observed fact, but it is clear that it *must* be so because any variable or system in unstable equilibrium inevitably destroys itself.

The question of whether adaptiveness is *always* equivalent to "stable equilibrium" is difficult. First we must study the nature of "adaptiveness" a little closer.

We note that in all cases adaptiveness is shown only in relation to some specific situation: an animal in a void can show neither good nor bad adaptation. Further, it is clear that this situation or environment must affect the animal in some manner, i.e. must disturb it, for if it has no effect on the animal it does not exist as far as the animal is concerned. Further, for adaptive behaviour, the animal must affect the environment in some manner, i.e. must change it, since otherwise the animal is just receiving the stimulus without responding to it. This means that we are dealing with a circuit, for we have, first: environment has an effect on the animal, and then: the animal has some effect on the environment. The concept of adaptive behaviour deals with the relationship between the two effects. It becomes meaningless if we try to remove one of the effects. Uexküll (1926) recognized this clearly and insisted that the animal and its environment must be thought of as a series of "function circles." He did not, however, reach the next deduction, which is that every reacting circuit must involve some state of equilibrium, either stable, neutral or unstable. The moment we see that "adaptiveness" implies a circuit and that a circuit implies an equilibrium, we can see at once that this equilibrium must be of the stable type, for any unstable variable destroys itself. And it is precisely the main feature of adaptive behaviour that it enables the animal to continue to exist.

Whether "adaptiveness" is always interchangeable with "stable equilibrium" must remain an open question, for the subject is a large one. It is clear, however, that there is a striking similarity between the two concepts as far as their objective features are concerned, and it seems reasonable, as a working hypothesis, to explore the possibilities that they may prove to be identical.

Summary.

Animal and human behaviour shows many features. Among them is the peculiar phenomenon of "adaptiveness." Although this fact is easily recognized in any given case, yet it is difficult to define with precision.

It is suggested here that adaptive behaviour may be identical with the behaviour of a system in stable equilibrium, and that this latter concept may, with advantage, be substituted for the former.

The advantages of this latter concept are that (1) it is purely objective, (2) it avoids all metaphysical complications of "purpose," (3) it is precise in its definition, and (4) it lends itself immediately to quantitative studies.

Reference.

Uexküll, J. von (1926), *Theoretical Biology*. London.