Adaptation in Iterated and Serial Systems

15/1. THE last three chapters have been concerned primarily with technique, with the logic of mechanism, when the mechanism shows partial, fluctuating and temporary divisions into sub-systems within the whole; they have considered specially the case when the subsystems are rich in states of equilibrium. We can now take up again the thread left at S. 11/13, and can go on to consider the problem of how a large and complex organism can adapt to a large and complex environment without taking the almost infinite time suggested by S. 11/5.

The remaining chapters will offer evidence that the facts are
. as follows:

(1) The ordinary terrestrial environment has a distribution of properties very different from the distribution assumed when the estimate of S. 11/2 came out so high.

(2) Against the actual distribution of terrestrial environments the process of ultrastability can often give adaptation in a reasonably short time.

(3) When particular environments do get more complex, the time of adaptation goes up, not only in theoretical ultrastable systems but in real living ones.

(4) When the environment is excessively complex and close-knit, the theoretical ultrastable system and the real living fail alike.

In this chapter and the next we will examine environments of gradually increasing complexity. (What is meant by ' complexity ' will appear as we proceed.)

15/2. In S. 11/11 it was suggested that the Homeostat (i.e. the two units or so marked off to represent ' environment ') is not typical of the terrestrial environment because in the Homeostat every variable is joined directly to every other variable, so that

what happens at each variable is conditional, at that moment, on the values of *all* the other variables in the system. What, then, does characterise the ordinary terrestrial environments from this point of view ?

Common observation shows that the ordinary terrestrial environment usually shows several features, which are closely related:

(1) Many of the variables, often the majority, are *constant* over appreciable intervals of time, and thus behave as part-functions. Thus, the mammal stands on ground that is almost always immobile; tree-trunks keep their positions; a cup placed on a table will stay there till a force of more than a certain amount arrives. If one looks around one, only in the most chaotic surroundings will all the variables be changing. This constancy, this commonness of part-functions, must, by S. 12/14, be due to commonness of states of equilibrium in the parts that compose the terrestrial environment. Thus the environment of the living organism tends typically to consist of parts that are rich in states of equilibrium.

(2) Associated with this constancy (naturally enough by S. 12/17) is the fact that most variables of the environment have an immediate effect on only a few of the totality of variables. At the moment, for instance, if I dip my pen in the ink-well, hardly a single other variable in the room is affected. Opening of the door may disturb the positions of a few sheets of paper, but will not affect the chairs, the electric light, the books on the shelves, and a host of others.

We are, in fact, led again to consider the properties of a system whose connexions are fluctuating and conditional—the type encountered before in S. 11/12, and therefore treatable by the same method. I suggest, therefore, that most of the environments encountered on this earth by living organisms contain many part-functions. Conversely, a system of part-functions adequately represents a very wide class of commonly occurring environments.

As a confirmatory example, here is Jennings' description of an hour in the life of *Paramecium*, with the part-functions indicated as they occur.

(It swims upwards and) '. . . thus reaches the surface film.'

The effects of the surface, being constant at zero throughout the

depths of the pond, will vary as part-functions. A discontinuity like a surface will generate part-functions in a variety of ways.

> ' Now there is a strong mechanical jar—someone throws a stone into the water perhaps.'

Intermittent variations of this type will cause variations of part-function form in many variables.

> (The *Paramecium* dives) '. . . this soon brings it into water that is notably lacking in oxygen.'

The content of oxygen will vary sometimes as part-, sometimes as full-, function, depending on what range is considered. Jennings, by not mentioning the oxygen content before, was evidently assuming its constancy.

> '. . . it approaches a region where the sun has been . . . heating the water.'

Temperature of the water will behave sometimes as part-, sometimes as full-, function.

> (It wanders on) '. . . into the region of a fresh plant stem which has lately been crushed. The plant-juice, oozing out, alters markedly the chemical constitution of the water.'

Elsewhere the concentration (at zero) of these substances is constant.

> ' Other *Paramecia* . . . often strike together ' (collide).

The pressure on the *Paramecium's* anterior end varies as a part-function.

> ' The animal may strike against stones.'

Similar part-functions.

> ' Our animal comes against a decayed, softened, leaf.'

More part-functions.

> '. . . till it comes to a region containing more carbon dioxide than usual.'

Concentration of carbon dioxide, being generally uniform with local increases, will vary in space as a part-function.

> ' Finally it comes to the source of the carbon dioxide—a large mass of bacteria, embedded in zoogloea.'

Another part-function due to contact.

It is clear that the ecological world of *Paramecium* contains many part-functions, and so too do the worlds of most living organisms.

A total environment, or universe, that contains many part-functions, will show dispersion, in that the set of variables active at one moment will often be different from the set active at another. The pattern of activity *within the environment* will therefore tend, as in S. 13/18, to be fluctuating and conditional rather than invariant. As an animal interacts with its environment, the observer will see that the activity in the environment is limited now to this set, now to that. If one set persists active for a long time and the rest remains inactive and inconspicuous, the observer may, if he pleases, call the first set ' the ' environment. And if later the activity changes to another set he may, if he pleases, call it a ' second ' environment. It is the presence of part-functions and dispersion that makes this change of view reasonable.

An organism that tries to adapt to an environment composed largely of part-functions will find that the environment is composed of subsystems which sometimes are independent but which from time to time show linkage. The alternation is shown clearly when one learns to drive a car. The beginner has to struggle with several subsystems: he has to learn to control the steering-wheel and the car's relation to road and pedestrian; he has to learn to control the accelerator and its relation to engine-speed, learning neither to race the engine nor to stall it; and he has to learn to change gear, neither burning the clutch nor stripping the cogs. On an open, level, empty road he can ignore accelerator and gear and can study steering as if the other two systems did not exist; and at the bench he can learn to change gear as if steering did not exist. But on an ordinary journey the relations vary. For much of the time the three systems

driver + steering wheel + . . .
driver + accelerator + . . .
driver + gear lever + . . .

could be regarded as independent, each complete in itself. But from time to time they interact. Not only may any two use common variables in the driver (in arms, legs, brain) but some linkage is provided by the machine and the world around. Thus, any attempt to change gear must involve the position of the accelerator and the speed of the engine; and turning sharply

round a corner should be preceded both by a slowing down and by a change of gear. The whole system thus shows that temporary and conditional division into subsystems that is typical of the whole that is composed largely of part-functions.

Thus the terrestrial environment conforms largely to the poly-stable type.

15/3. To study how ultrastability will act when the environment is not fully joined, we shall have to use the strategy of S. 2/17 and pick out certain cases as type-forms. We will therefore consider environments with four degrees of connectedness.

First we will consider (in S. 15/4–7) the ' whole ' in which the connexion between the parts is actually zero—the limiting case as the connexions get less and less.

In S. 15/8–11 we will consider the case in which actual con-nexions exist, but in which the subsystems are connected in a chain, without feedback between subsystems. These two cases will suffice to demonstrate certain basic properties.

In the next chapter we will consider the more realistic case in which the subsystems are joined unrestrictedly in direction, so that feedback occurs between the subsystems. This case will be considered in two stages: first, in S. 16/2–4 we will dispose of the case in which the connexions are rich; and then, from S. 16/5 onwards, we will consider the most interesting case, that in which the connexions are in all directions, so that feedback occurs between the subsystems, but in which the connexions are not rich so that the whole can be regarded as formed from subsystems each of which is richly connected internally, joined by connexions (between the subsystems) that are much poorer—the case, in fact, of the system that is neither richly joined nor unjoined.

Adaptation in iterated systems

15/4. The first case to be considered is that in which the whole system, of organism and environment, is actually divided into subsystems that (at least during the time of observation) do not have any effective action on one another. Thus instead of A in Figure 15/4/1 we are considering B. (For simplicity, the diagram shows lines instead of arrows.) If the whole system consists of organism and environment, the actual division between
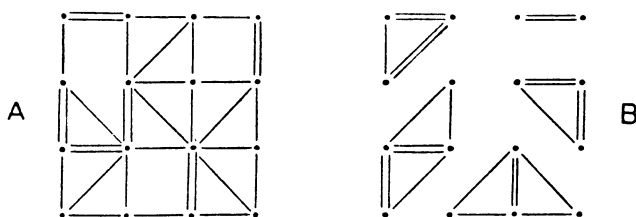
FIGURE 15/4/1.

the two might be that shown in Figure 15/4/2. Such an arrangement would be shown functionally by any organism that deals with its environment by several independent reactions. Such a whole will be said to consist of **iterated** systems.
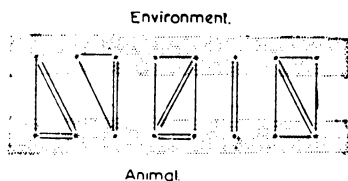

FIGURE 15/4/2 : Diagrammatic representation of an anima of eight variables interacting with its environment as five independent systems.

S. 13/10 exemplified the argument applicable to such a ' whole '. If i is the number of subsystems that are at a state of equilibrium at any particular moment, then in an iterated set i cannot fall, and will usually rise. As subsystem after subsystem reaches equilibrium so will each stay there; and thus the whole will change cumulatively towards total equilibrium.

15/5. Whether the feedbacks in Figure 15/4/2 are first order or second (S. 7/5) is here irrelevant: the whole still moves to equilibrium progressively. Thus, if each subsystem has essential variables and step-mechanisms as in Figure 7/5/1, the stability of the second order will develop as in S. 7/23; and thus the *adaptation* of the whole to this environment will also develop cumulatively and progressively.

In this case, the processes of learning by trial and error will go on in one subsystem independently of what is going on in the others. That such independent, localised learning can occur within one animal was shown by Parker in the following experiment:

' If a sea-anemone is fed from one side of its mouth, it will

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take in, by means of the tentacles on that side, one fragment of food after another. If now bits of food be alternated with bits of filter paper soaked in meat juice, the two materials will be accepted indiscriminately for some eight or ten trials, after which only the meat will be taken and the filter paper will be discharged into the sea water without being brought to the mouth. If, after having developed this state of affairs on one side of the mouth, the experiment is now transferred to the opposite side, both the filter paper and the meat will again be taken in till this side has also been brought to a state of discriminating.'

15/6. What of the time taken by the iterated set to become adapted ? T_3 (of S. 11/5) is applicable here; so the extremeness of T_1 is not to be feared. Thus, however large the whole, if it should actually consist of iterated subsystems, then the time it takes to get adapted may be expected to be of the same order as that taken by one of its subsystems. If this time is fairly short, the whole may be very large and yet become adapted in a fairly short time.

15/7. If Figure 15/4/2 is re-drawn so as to show explicitly its relation to the system of Figure 7/5/1 the result is that shown in Figure 15/7/1 (where the subsystems have been reduced to three for simplicity in the diagram).

At once the reader may be struck by the fact that the three reacting parts in the organism (in its brain usually) are represented as having no connexion between them: is this not a fatal flaw ?

The subject is discussed more thoroughly in S. 17/2; here a partial answer can be given. Let us compare the course of adaptation as it would proceed (1) with the two left-hand subsystems wholly unconnected as shown, and (2) with the reacting part of subsystem A having some immediate effect on subsystem B.

The first case is straightforward: each subsystem is a little ultrastable system, homologous with that of S. 7/5/1, and each would proceed to adaptation in the usual way.

When B is joined so as to be affected by A, however, the whole course is somewhat changed. A is unaffected, so it will proceed to adaptation as before; but B, previously isolated, is now affected by one or more parameters that need no longer be constant. The effect on B will depend on whether the effect comes to B from A's reacting part or from A's step-mechanisms. If from the step-
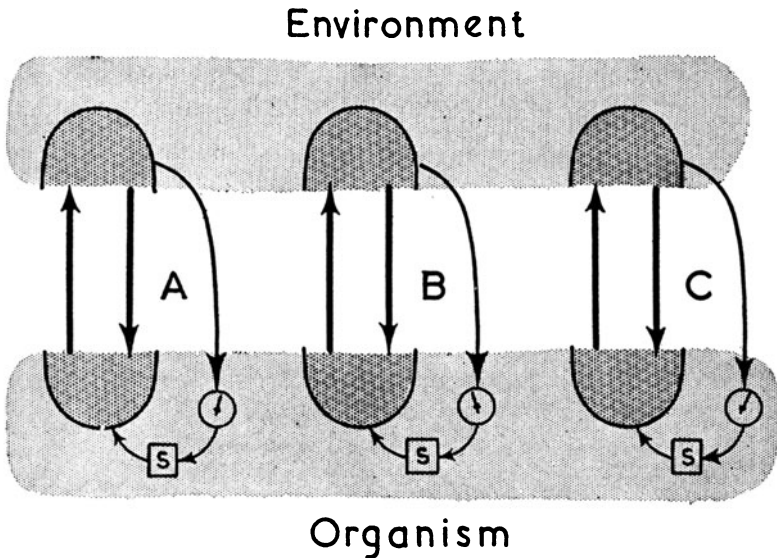
Environment

Organism

FIGURE 15/7/1 : Sketch of the diagram of immediate effects of an organism adapting to an environment as three separate subsystems. (Compare Figures 15/8/1 and 16/6/1.)

mechanisms, B can achieve no permanent adaptation until A has reached adaptation, for their values will keep changing. However, once A's step-mechanisms have reached their terminal values, B's parameters will be constant, and B can *then* commence profitably its own search, undisturbed by further changes. Thus the join from A's step-mechanisms will about double the time taken for the whole to reach adaptation.

If, however, the effect comes to B from A's reacting part, then even after A has reached adaptation, every time that A shows its adaptation (by responding appropriately to a disturbance to its environment), the lines of behaviour that A's reacting part follow will provide B with a varying set of values at its parameters. B is thus in a situation homologous to that of the Homeostat in S. 8/10, except that B may be subject to parameter-values many more than two. The time that B will take to reach adaptation under *all* these values is thus apt to resemble T_1 (S. 11/5), and thus to be excessively long. Thus a joining from the reacting part of A to that of B may have the effect of postponing the whole's adaptation almost indefinitely.

These remarks are probably sufficient for the moment to show that the absence of connexions between organismal subsystems in Figure 15/7/1 does not condemn the representation off-hand. There is more to this matter of joining than is immediately evident. (The topic is resumed in S. 17/2.)

Serial adaptation

15/8. By S. 15/3, our second stage of connectedness in the system occurs when the parts of the environment are joined as a chain. Figure 15/8/1 illustrates the case.
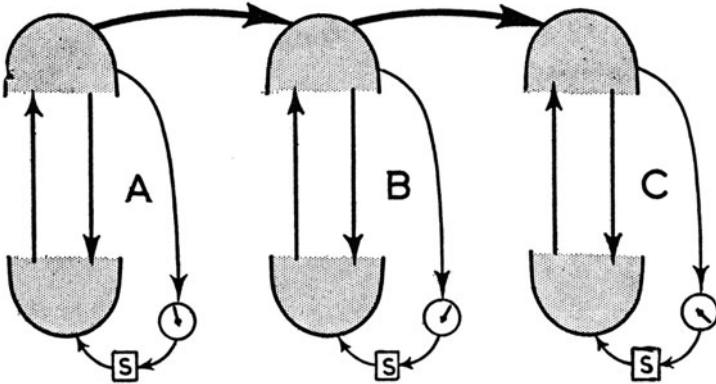

FIGURE 15/8/1.

Without enquiring at the moment into exactly what will happen, it is obvious, by analogy with the previous section, that adaptation must occur in the sequence—*A* first, then *B*, then *C*. Thus we are considering the case of the organism that faces an environment whose parts are so related that the environment can be adapted to only by a process *that respects its natural articulation*.

15/9. Such environments are of common occurrence. A puppy can learn rabbit-catching only after it has learned how to run: the environment does not allow the two reactions to be learned in the opposite order. A great deal of learning occurs in this way. Mathematics, for instance, though too vast and intricate for one all-comprehending flash, can be mastered by stages. The stages have a natural articulation which must be respected if mastery is

to be achieved. Thus, the learner can proceed in the order 'Addition, long multiplication, . . .' but not in the order 'Long multiplication, addition, . . .' Our present knowledge of mathematics has in fact been reached only because the subject contains such stage-by-stage routes.

As a clear illustration of such a process, here is Lloyd Morgan on the training of a falcon:

> 'She is trained to the lure—a dead pigeon . . .—at first with the leash. Later a light string is attached to the leash, and the falcon is unhooded by an assistant, while the falconer, standing at a distance of five to ten yards, calls her by shouting and casting out the lure. Gradually day after day the distance is increased, till the hawk will come thirty yards or so without hesitation; then she may be trusted to fly to the lure at liberty, and by degrees from any distance, say a thousand yards. This accomplished, she should learn to stoop to the lure. . . . This should be done at first only once, and then progressively until she will stoop backwards and forwards at the lure as often as desired. Next she should be entered at her quarry . . .'

The same process has also been demonstrated more formally. Wolfe and Cowles, for instance, taught chimpanzees that tokens could be exchanged for fruit: the chimpanzees would then learn to open problem boxes to get tokens; but this way of getting fruit (the 'adaptive' reaction) was learned only if the procedure for the exchange of tokens had been well learned first. In other words, the environment was beyond their power of adaptation if presented as a complex whole—they could not get the fruit—but if taken as two stages in a particular order, could be adapted to.

'. . . the growing child fashions day by day, year by year, a complex concatenation of acquired knowledge and skills, adding one unit to another in endless sequence', said Culler. I need not further emphasise the importance of serial adaptation.

15/10. To see the process in more detail, consider the following example. A young animal has already learned how to move about the world without colliding with objects. (Though this learning is itself complex, it will serve for illustration, and has the advantage of making the example more vivid.) This learning process was due to ultrastability: it has established a set of values on the step-mechanisms which give a field such that the system composed

of eyes, muscles, skin-receptors, some parts of the brain, and hard external objects is stable and always acts so as to keep within limits the mechanical stresses and pressures caused by objects in contact with the skin-receptors (S. 5/4). The diagram of immediate effects will therefore resemble Figure 15/10/1. This system will be referred to as part A, the ' avoiding ' system.
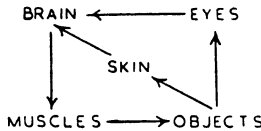

FIGURE 15/10/1 : Diagram of immediate effects of the ' avoiding system. Each word represents many variables.

As the animal must now get its own food, the brain must develop a set of values on step-mechanisms that will give a field in which the brain and the food-supply occur as variables, and which is stable so that it holds the blood-glucose concentration within normal limits. (This system will be referred to as part B, the ' feeding ' system.) This development will also occur by ultrastability; but while this is happening the two systems will interact.

The interaction will occur because, while the animal is making trial-and-error attempts to get food, it will repeatedly meet objects with which it might collide. The interaction is very obvious when a dog chases a rabbit through a wood. Further, there is the possibility that the processes of dispersion within brain and environment may allow the two reactions to use common variables. When the systems interact, the diagram of immediate effects will resemble Figure 15/10/2.
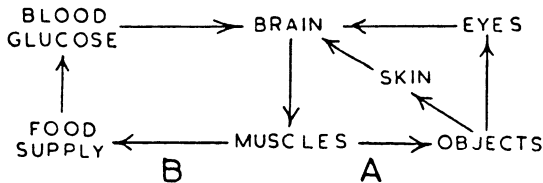

FIGURE 15/10/2.

Let us assume at this point (simply to get a clear discussable case) that the step-mechanisms affecting A are, for whatever reason, not changeable while the adaptation to B is occurring (compare S. 10/8). As the ' avoiding ' system A is not subject

to further step-function changes, its field will not alter, and it will at all times react in its characteristic way. So the whole system is equivalent to an ultrastable system B interacting with an 'environment' A. It would also be equivalent to an ultrastable system interacting with an inborn reflex, as in S. 3/12. B will therefore change its step-mechanism values until the whole has a field which is stable and which holds within limits the variable (blood-glucose concentration) whose extreme deviations cause the step-mechanisms to change. We know from S. 8/11 that, whatever the peculiarities of A, B's terminal field will be adapted *to them*.

It should be noticed that the seven sets of variables (Figure 15/10/2) are grouped in one way when viewed anatomically and in a very different way when viewed functionally. The anatomical point of view sees five sets in the animal's body and two sets in the outside world. The functional point of view sees the whole as composed of two parts: an 'adapting' part B, to which A is 'environment'.

It is now possible to predict how the system will behave after the above processes have occurred. Because part A, the 'avoiding' system, is unchanged, the behaviour of the whole will still be such that collisions do not occur; and the reactions to the food supply will maintain the blood-glucose within normal limits. But, in addition, because B became adapted to A, the getting of food will be modified so that it does not involve collisions, for all such variations will have been eliminated.

15/11. What of the time required for adaptation of all the essential variables when the environment is so joined in a chain ?

The dominating subsystem A will, of course, proceed to adaptation in the ordinary way. B, however, even when A is adapted may still be disturbed to some degree by changes coming to it from A, changes that come ultimately from the disturbances to A that A must adapt against. C also may get upset by some of these disturbances, transmitted through B, and so on. Thus each subsystem down the chain is likely to be disturbed by all the disturbances that come to the subsystems that dominate it, and also by the reactive, adaptive changes made by the same dominating subsystems.

It is now clear how important is the channel-capacity of the

connexions that transmit disturbances down the chain. If their capacity is high, so much disturbance may be transmitted to the lower members of the chain that their adaptations may be postponed indefinitely. If their capacity is low, the attenuation may be so rapid that C, though affected by B, may be practically unaffected by what happens at A; and a further subsystem D may be practically unaffected by those at B; and so on. Thus, as the connexions between the subsystems get weaker, so does adaptation tend to the sequential—first A, then B, then C, and so on. (The limit, of course, is the iterated set.)

If the adaptation is sequential, the behaviour corresponds to that of Case 2 (S. 11/5). The time of adaptation will then be that of the moderate T_2 rather than that of the excessively long T_1. Thus adaptation, even with a large organism facing a large environment, may be achievable in a moderate time if the environment consists of subsystems in a chain, with only channels of small capacity between them.