CHAPTER 18

Amplifying Adaptation

Selection in the state-determined system

18/1. The origin of selections ceases to be a problem as soon as it is realised that selection, far from being a rarity, is performed to greater or less degree by every isolated state-determined system (I. to C., S. 18/19). In such a system, as two lines of behaviour may become one, but one line cannot become two, so the number of states that it can be in can only decrease.

This selection is well known, but in simple systems it shows only in trivial form. The spring-driven clock, for instance, is selective for the run-down state: start it at any state of partial winding and it will make its way to the run-down state, where it will remain. The often-made observation that machines run to an equilibrium expresses the same property.

In simple systems the property seems trivial, but as the system becomes more complex so does this property become richer and more interesting. The Homeostat, for instance, can be regarded simply as a system, with magnets and uniselectors, that runs to a partial equilibrium, where it sticks. But the equilibrium is only partial, and therefore richer in content than that of the run-down clock. The uniselectors are motionless but the magnets may still move, and the partial equilibrium manifests a dynamic homeostasis that has been selected by the unisector's process of running to equilibrium. Thus the Homeostat begins to show something of the richness of properties that emerge when the system is complex enough, or large enough, to show: (1) a high intensity of selection by running to equilibrium, and also (2) that this selected set of states, though only a small fraction of the whole, is still large enough in itself to give room for a wide range of dynamic activities. Thus, selection for complex equilibria, within which the observer can trace the phenomenon of adaptation, must not be regarded as an exceptional and remarkable event: it is the rule. The chief reason why we have failed to see this fact in the past is that our terrestrial
world is grossly bi-modal in its forms: either the forms in it are extremely simple, like the run-down clock, so that we dismiss them contemptuously, or they are extremely complex, so that we think of them as being quite different, and say they have Life.

18/2. Today we can see that the two forms are simply at the extremes of a single scale. The Homeostat made a start at the provision of intermediate forms, and modern machinery, especially the digital computers, will doubtless enable further forms to be interpolated, until we can see the essential unity of the whole range.

Further examples of intermediate forms are not difficult to invent. Here is one that shows how, in any state-determined dynamic system, some properties will have a greater tendency to persist, or ‘survive’, than others. Suppose a computer has a hundred stores, labelled 00 to 99, each of which initially holds one decimal digit, i.e. one of 0, 1, 2, \ldots, 9, chosen at random, independently and equiprobably. It also has a source of random numbers (drawn, preferably, from molecular, thermal, agitation). It now repeatedly performs the following operation:

Take two random numbers, each of two digits; suppose 82 and 07 come up. In this case multiply together the numbers in stores 82 and 07, and replace the digit in the first store (no. 82) by the right-hand digit of the product.

Now Even $\times$ Even gives Even, and Odd $\times$ Odd gives Odd; but Odd $\times$ Even gives Even, so the number in the first store can change from Odd to Even, but not from Even to Odd. As a result, the stores, which originally contained Odds and Evens in about equal numbers, will change to containing more and more Evens, the Odds gradually disappearing. The biologist might say that in the ‘struggle’ to occupy the stores and survive the Evens have an advantage and will inevitably exterminate the Odds.

In fact, among the Evens themselves there are degrees of ability to survive. For the Zeros have a much better chance than the other Evens, and, as the process goes on, so will the observer see the Zeros spread over the stores. In the end they will exterminate their competitors completely.

18/3. This example is easily followed, but is uncomfortably close to the trivial. More complex examples could easily be set up, but they would tell us nothing of the principles at work (though they would provide most valuable and convincing examples). What all would show is that when a single-valued operation is performed repeatedly on a set of states (this operation being the ‘laws’ of the system), the system tends to such states as are not affected by the operation, or are affected to less than usual degree. In other words, every single-valued operation tends to select forms that are peculiarly able to resist its change-inducing action. In simple systems this fact is almost truistic, in complex systems anything but. And when it occurs on the really grand scale, on a system with millions of variables and over millions of years, then the states selected are likely to be truly remarkable and to show, among their parts, a marked co-ordination tendency to make them immune to the operation.

The development of life on earth must thus not be seen as something remarkable. On the contrary, it was inevitable. It was inevitable in the sense that if a system as large as the surface of the earth, basically polystable, is kept gently simmering dynamically for five thousand million years, then nothing short of a miracle could keep the system away from those states in which the variables are aggregated into intensely self-preserving forms. The amount of selection performed by this system, of which we know only one example, is of an order of size so vastly greater than anything that we experience as individuals, that we not unnaturally have some difficulty in grasping that the process is really the same as that seen so trivially in our everyday systems. Nevertheless it is so; the greater extension in space enables a vastly greater number of forms to be tested, and the greater extension in time enables the forms to be worked up to a vastly greater degree of intricate co-ordination.

We can thus trace, from a perfectly natural origin, the gene-patterns that today inhabit the earth; we are not surprised that the earth has developed forms that show, in conjunction with their environments, the most remarkable power of being resistant to the change-inducing actions of the world around them. They are resistant, not in the static and uninteresting way that a piece of granite, or a run-down clock, is resistant, but in the dynamic and much more interesting way of forming intricate dynamic systems around themselves (their so-called ‘bodies’, with extensions such as nests and tools) so that the whole is homeostatic and self-preserving by active defences.
18/4. What concerns us in this book is the fact that the active defences can be direct or indirect. The direct were considered only in S. 1/8. They include all the regulatory mechanisms that are specified in detail by the gene-pattern. They are adapted because the conditions that insisted on them have been constant over many generations.

The earlier forms of gene-pattern adapted in this way only. The later forms, however, have developed a specialisation that can give them a defence against a class of disturbances to which the earlier were vulnerable. This class consists of those disturbances that, though not constant over a span of many generations (and thus not adaptable to by the gene-pattern, for the change is too rapid) are none the less constant over a span of a single generation. When disturbances of this class are frequent, there is advantage in the development of an adapting mechanism that is (1) controlled in its outlines by the gene-pattern (for the same outlines are wanted over many generations), and (2) controlled in details by the details applicable to that particular generation.

This is the learning mechanism. Its peculiarity is that the gene-pattern delegates part of its control over the organism to the environment. Thus, it does not specify in detail how a kitten shall catch a mouse, but provides a learning mechanism and a tendency to play, so that it is the mouse which teaches the kitten the finer points of how to catch mice.

This is regulation, or adaptation, by the indirect method. The gene-pattern does not, as it were, dictate, but puts the kitten into the way of being able to form its own adaptation, guided in detail by the environment.

18/5. We can now answer the question raised in S. 17/12, and can see how the law of requisite variety is to be applied to the question of how the ancillary regulations are to be achieved, i.e. how the necessary parameters are to be brought to their appropriate values.

Some may be adjusted by the direct action of the gene-pattern, so that the organism is born with the correct values. For this to be possible, the environmental conditions must have been constant for a sufficiently long time, and the processes of natural selection must have been intense enough and endured long enough for the total selection exerted to satisfy the law.

18/6. Some ancillary regulations may be adjusted by the gene-pattern at one remove. In this case the gene-pattern would establish values that would result in the appearance of a mechanism, actually a regulator, that would then proceed, by its own action, to bring the parameters to appropriate values.

Other ancillary regulators might be adjusted by the gene-pattern at two removes; but we need not trace the matter further, as real systems will seldom be arranged neatly in distinct levels (S. 17/9). All we need notice here is that adaptation can be achieved by the gene-pattern either directly or indirectly.

Amplifying adaptation

18/6. The method of adaptation by learning is the only way of achieving adaptation when what is adaptive is constant for too short a time for adaptation of the gene-pattern to be achieved. For this reason alone we would expect the more advanced organisms to show it. The method, however, has also a peculiar advantage that is worth notice, particularly when we consider the limitation implied by the law of requisite variety, and ask how much regulation the gene-pattern can achieve in the two cases.

Direct and indirect regulation occur as follows. Suppose an essential variable X has to be kept between limits x' and x". Whatever acts directly on X to keep it within the limits is regulating directly. It may happen, however, that there is a mechanism M available that affects X, and that will act as a regulator to keep X within the limits x' and x" provided that a certain parameter P (parameter to M) is kept within the limits p' and p". If, now, any selective agent acts on P so as to keep it between p' and p", the end result, after M has acted, will be that X is kept between x' and x".

Now, in general, the quantities of regulation required to keep P in p' and p" and to keep X in x' to x" are independent. The law of requisite variety does not link them. Thus it may happen that a small amount of regulation supplied to P may result in a much larger amount of regulation being shown by X.

When the regulation is direct, the amount of regulation that can be shown by X is absolutely limited to what can be supplied to it (by the law of requisite variety); when it is indirect, however, more regulation may be shown by X than is supplied to P. Indirect
regulation thus permits the possibility of amplifying the amount of regulation; hence its importance.

18/7. Living organisms came across this possibility aeons ago, for the gene-pattern is a channel of communication from parent to offspring: 'Grow a pair of eyes,' it says, 'they'll probably come useful; and better put haemoglobin into your veins—carbon monoxide is rare and oxygen common.' As a channel of communication it has a definite, finite capacity, \( Q \) say. If this capacity is used directly, then, by the law of requisite variety, the amount of regulation that the organism can use as defence against the environment cannot exceed \( Q \). To this limit, the non-learning organisms must conform. If, however, the regulation is done indirectly, then the quantity \( Q \), used appropriately, may enable the organism to achieve, against its environment, an amount of regulation much greater than \( Q \). Thus the learning organisms are no longer restricted by the limit.

The possibility of such 'amplification' is well known in other ways. If a child wanted to discover the meanings of English words, and his father had only ten minutes available for instruction, the father would have two possible modes of action. One is to use the ten minutes in telling the child the meanings of as many words as can be described in that time. Clearly there is a limit to the number of words that can be so explained. This is the direct method. The indirect method is for the father to spend the ten minutes showing the child how to use a dictionary. At the end of the ten minutes the child is, in one sense, no better off; for not a single word has been added to his vocabulary. Nevertheless the second method has a fundamental advantage; for in the future the number of words that the child can understand is no longer bounded by the limit imposed by the ten minutes. The reason is that if the information about meanings has to come through the father directly, it is limited to ten-minutes' worth; in the indirect method the information comes partly through the father and partly through another channel (the dictionary) that the father's ten-minute act has made available.

In the same way the gene-pattern, when it determines the growth of a learning animal, expends part of its resources in forming a brain that is adapted not only by details in the gene-pattern but also by details in the environment. The environment acts as the
Summary

The primary fact is that all isolated state-determined dynamic systems are selective: from whatever state they have initially, they go towards states of equilibrium. The states of equilibrium are always characterised, in their relation to the change-inducing laws of the system, by being exceptionally resistant.

(Specially resistant are those forms whose occurrence leads, by whatever method, to the occurrence of further replicates of the same form—the so-called ‘reproducing’ forms.)

If the system permits the formation of local equilibria, these will take the form of dynamic subsystems, exceptionally resistant to the disruptive effects of events occurring locally.

When such a stable dynamic subsystem is examined internally, it will be found to have parts that are co-ordinated in their defence against disturbance.

If the class of disturbance changes from generation to generation but is constant within each generation, even more resistant are those forms that are born with a mechanism such that the environment will make it act in a regulatory way against the particular environment—the ‘learning’ organisms.

This book has been largely concerned with the last stage of the process. It has shown, by consideration of specially clear and simple cases, how the gene-pattern can provide a mechanism (with both basic and ancillary parts) that, when acted on by any given environment, will inevitably tend to adapt to that particular environment.