CHAPTER 2

Dynamic Systems

2/1. IN the previous chapter we have repeatedly used the concepts of a system, of parts in a whole, of the system's behaviour, and of its changes of behaviour. These concepts are fundamental and must be properly defined. Accurate definition at this stage is of the highest importance, for any vagueness here will infect all the subsequent discussion; and as we shall have to enter the realm where the physical and the psychological meet, a realm where the experience of centuries has found innumerable possibilities of confusion, we shall have to proceed with unusual caution.

That some caution is necessary can be readily shown. We have, for instance, repeatedly used the concept of a ' change of behaviour ', as when the kitten stopped dabbing at the red-hot coal and avoided it. Yet behaviour is itself a sequence of changes (e.g. as the paw moves from point to point). Can we distinguish clearly those changes that constitute behaviour from those changes that are from behaviour to behaviour ? It is questions such as these which emphasize the necessity for clarity and a secure foundation. (The subject has been considered more extensively in *I. to C,* Part I; the shorter version given here should be sufficient for our purpose in this book.)

We start by assuming that we have before us some dynamic system, i.e. something that may change with time. We wish to study it. It will be referred to as the ' machine ', but the word must be understood in the widest possible sense, for no restriction is implied at the moment other than that it should be objective.

2/2. As we shall be more concerned in this chapter with principles than with practice, we shall be concerned chiefly with constructing a method for the study of this unknown machine. When the method is constructed, it must satisfy the demands implied by the axioms of S. 1/10-15:

(1) The method must be precisely defined, and in operational form;

(2) it must be applicable equally readily (at least in principle) to all material 'machines', whether animate or inanimate;

(3) its procedure for obtaining information from the ' machine ' must be wholly objective (i.e. accessible or demonstrable to all observers);

(4) it must obtain its information solely from the ' machine ' itself, no other source being permitted.

The actual form developed may appear to the practical worker to be clumsy and inferior to methods already in use; it probably is. But it is not intended to compete with the many specialised methods already in use. Such methods are usually adapted to a particular class of dynamic systems: one method is specially suited to electronic circuits, another to rats in mazes, another to solutions of reacting chemicals, another to automatic pilots, another to heart-lung preparations. The method proposed here must have the peculiarity that it is applicable to all; it must, so to speak, specialise in generality.

Variable and system

2/3. In *I. to C*, Chapter 2, is shown how the basic theory can be founded on the concept of unanalysed states, as a mother might distinguish, and react adequately to, three expressions on her baby's face, without analysing them into so much opening of the mouth, so much wrinkling of the nose, etc. In this book, however, we shall be chiefly concerned with the relations between parts, so we will assume that the observer proceeds to record the behaviour of the machine's individual parts. To do this he identifies any number of suitable variables. A variable is *a measurable quantity which at every instant has a definite numerical value.* A ' grandfather ' clock, for instance, might provide the following variables:—the angular deviation of the pendulum from the vertical; the angular velocity with which the pendulum is moving; the angular position of a particular cog-wheel; the height of a driving weight; the reading of the minute-hand on the scale; and the length of the pendulum. If there is any doubt whether a particular quantity may be admitted as a ' variable ' I shall use the criterion whether it can be represented by a pointer on a dial.

All the quantities used in physics, chemistry, biology, physiology, and objective psychology, are variables in the defined sense.

Thus, the position of a limb can be specified numerically by coordinates of position, and movement of the limb can move a pointer on a dial. Temperature at a point can be specified numerically and can be recorded on a dial. Pressure, angle, electric potential, volume, velocity, torque, power, mass, viscosity, humidity, surface tension, osmotic pressure, specific gravity, and time itself, to mention only a few, can all be specified numerically and recorded on dials. (Eddington's statement on the subject is explicit: ' The whole subject matter of exact science consists of pointer readings and similar indications.') ' Whatever quantity we say we are " observing ", the actual procedure nearly always ends in reading the position of some kind of indicator on a graduated scale or its equivalent.'

Whether the restriction to dial-readings is justifiable with living subjects will be discussed in the next chapter.

One minor point should be noticed as it will be needed later. The absence of an entity can always be converted to a reading on a scale simply by considering the entity to be present but in zero degree. Thus, ' still air ' can be treated as a wind blowing at 0 m.p.h.; ' darkness ' can be treated as an illumination of 0 foot-candles ; and the giving of a drug can be represented by indicating that its concentration in the tissues has risen from its usual value of 0 per cent.

2/4. It will be appreciated that *every real ' machine ' embodies no less than an infinite number of variables,* all but a few of which must of necessity be ignored. Thus if we were studying the swing of a pendulum in relation to its length we would be interested in its angular deviation at various times, but we would often ignore the chemical composition of the bob, the reflecting power of its surface, the electric conductivity of the suspending string, the specific gravity of the bob, its shape, the age of the alloy, its degree of bacterial contamination, and so on. The list of what might be ignored could be extended indefinitely. Faced with this infinite number of variables, the experimenter must, and of course does, select a definite number for examination—in other words, he defines an abstracted system. Thus, an experimenter once drew up Table 2/4/1. He thereby selected his variables, of time and three others, ready for testing. This experiment being finished, he later drew up other tables which included new

Time (mins.)	Distance of secondary coil (em.)	Part of skin stimulated	Secretion of saliva during 30 secs, (drops)
			. . .

TABLF. 2/4/1

variables or omitted old. These new combinations were new systems.

2/5. Because any real ' machine ' has an infinity of variables, from which different observers (with different aims) may reasonably make an infinity of different selections, there must first be given an observer (or experimenter); a system is then defined as *any set of variables* that he selects from those available on the real ' machine '. It is thus a list, nominated by the observer, and is quite different in nature from the real' machine '. Throughout the book, ' the system ' will always refer to this abstraction, not to the real material ' machine '.

Among the variables recorded will almost always be ' time ', so one might think that this variable should be included in the list that specifies the system. Nevertheless, time comes into the theory in a way fundamentally different from that of all the others. (The difference is shown most clearly in the canonical equations of S. 19/9.) Experience has shown that a more convenient classification is to let the set of variables be divided into ' system ' and ' time '. Time is thus not to be included in the variables of the system. In Table 2/4/1 for instance, ' the system ' is *defined* to be the three variables on the right.

2/6. The state of a system at a given instant is the set of numerical values which its variables have at that instant.

Thus, the six-variable system of S. 2/3 might at some instant have the state: —4°, 0.3 radians/sec., 128°, 52 cm., 42.8 minutes, 88.4 em.

Two states are equal if and only if the two numerical values in each pair are equal, all pairs showing equality,

The operational method

2/7. The variables being decided on, the recording apparatus is now assumed to be connected and the experimenter ready to start observing. We must now make clear what is assumed about his powers of control over the system.

Throughout the book we shall consider only the case in which he has access to all states of the system. It is postulated that the experimenter can control any variable he pleases: that he can make any variable take any arbitrary value at any arbitrary lime. The postulate specifies nothing about the methods: it demands only that certain end-results are to be available, In most cases the means to be used are obvious enough. Take the example of S. 2/3: an arbitrary angular deviation of the pendulum can be enforced at any time by direct manipulation; an arbitrary angular momentum can be enforced at any time by an appropriate impulse; the cog can be disconnected and shifted, the driving-weight wound up, the hand moved, and the pendulum-bob lowered.

By repeating the control from instant to instant, the experimenter can force a variable to take any prescribed series of values. The postulate, therefore, implies that any variable can be forced to follow a prescribed course.

Some systems cannot be forced, for instance the astronomical, the meteorological, and those biological systems that are accessible to observation but not to experiment. Yet no change is necessary in principle: the experimenter simply waits until the desired set of values occurs during the natural changes of the system, and he counts that instant as if it were the instant at which the system were started. Thus, though he cannot create a thunderstorm, he can observe how swallows react to one simply by waiting till one occurs ' spontaneously '.

It will also be assumed (except where explicitly mentioned) that he has similarly complete control over those variables that are not in the system yet which have an effect on it. In the experiment of Table 2/4/1 for instance, Pavlov had control not only of the variables mentioned but also of the many variables that might have affected the system's behaviour, such as the lights that might have flashed, the odours that might have been applied, and tin: noises that might have come from outside.

The assumption that the control is complete is made because,