I Newtonian and Bergsonian Time

There is a little hymn or song familiar to every German child.

It goes:

“Weisst du, wieviel Sternlein stehen
An dem blauen Himmelszelt?
Weisst du, wieviel Wolken gehen
Weithin über alle Welt?
Gott, der Herr, hat sie gezählet
Dass ihm auch nicht eines fehlet
An der ganzen, grossen Zahl.”

W. Hey

In English this says: “Knowest thou how many stars stand in the blue tent of heaven? Knowest thou how many clouds pass far over the whole world? The Lord God hath counted them, that not one of the whole great number be lacking.”

This little song is an interesting theme for the philosopher and the historian of science, in that it puts side by side two sciences which have the one similarity of dealing with the heavens above us, but which in almost every other respect offer an extreme contrast. Astronomy is the oldest of the sciences, while meteorology is among the youngest to begin to deserve the name. The more familiar astronomical phenomena can be predicted for many centuries, while a precise prediction of tomorrow's weather is generally not easy and in many places very crude indeed.

To go back to the poem, the answer to the first question is that, within limits, we do know how many stars there are. In the first place, apart from minor uncertainties concerning some of the double and variable stars, a star is a definite object, eminently suitable for counting and cataloguing; and if a human *Durchmusterung* of the stars—as we call these catalogues—stops short for stars less intense than a certain magnitude, there is nothing too repugnant to us in the idea of a divine *Durchmusterung* going much further.

On the other hand, if you were to ask the meteorologist to give you a similar *Durchmusterung* of the clouds, he might laugh in your face, or he might patiently explain that in all the language of meteorology there is no such thing as a cloud, defined as an object with a quasi-permanent identity; and that if there were, he neither possesses the facilities to count them, nor is he in fact interested in counting them. A topologically inclined meteorologist might perhaps define a cloud as a connected region of space in which the density of the part of the water content in the solid or liquid state exceeds a certain amount, but this definition would not be of the slightest value to anyone, and would at most represent an extremely transitory state. What really concerns the meteorologist is some such statistical statement as, "Boston: January 17, 1950: Sky 38% overcast: Cirrocumulus."

There is of course a branch of astronomy which deals with what may be called cosmic meteorology: the study of galaxies and nebulae and star clusters and their statistics, as pursued for example by Chandrasekhar, but this is a very young branch of astronomy, younger than meteorology itself, and is something outside the tradition of classical astronomy. This tradition, apart from its purely classificatory, *Durchmusterung* aspects, was originally concerned rather with the solar system than with the world of the fixed stars. It is the astronomy of the solar system which is that chiefly associated with the names of Copernicus, Kepler, Galileo, and Newton, and which was the wet nurse of modern physics.

It is indeed an ideally simple science. Even before the existence of any adequate dynamical theory, even as far back as the Babylonians, it was realized that eclipses occurred in regular predictable cycles, extending backward and forward over time. It was realized that time itself could better be measured by the motion of the stars in their courses than in any other way. The pattern for all events in the solar system was the revolution of a wheel or a series of wheels, whether in the form of the Ptolemaic theory of epicycles or the Copernican theory of orbits, and in any such theory the future after a fashion repeats the past. The music of the spheres is a palindrome, and the book of astronomy reads the same backward as forward. There is no difference save of initial positions and directions between the motion of an orrery turned forward and one run in reverse. Finally, when all this was reduced by Newton to a formal set of postulates and a closed mechanics, the fundamental laws of this mechanics were unaltered by the transformation of the time variable t into its negative.

Thus if we were to take a motion picture of the planets, speeded up to show a perceptible picture of activity, and were to run the film backward, it would still be a possible picture of planets conforming to the Newtonian mechanics. On the other hand, if we were to take a motion-picture photograph of the turbulence of the clouds in a thunderhead and reverse it, it would look altogether wrong. We should see downdrafts where we expect updrafts, turbulence growing coarser in texture, lightning preceding instead of following the changes of cloud which usually precede it, and so on indefinitely.

What is the difference between the astronomical and the meteorological situation which brings about all these differences, and in particular the difference between the apparent reversibility of astronomical time and the apparent irreversibility of meteorological time? In the first place, the meteorological system is one involving a vast number of approximately equal particles, some of them very closely coupled to one another, while the astronomical system of the solar universe contains only a relatively small number of particles, greatly diverse in size and coupled with one another in a sufficiently loose way that the second-order coupling effects do not change the general aspect of the picture we observe, and the very high order coupling effects are completely negligible. The planets move under conditions more favorable to the isolation of a certain limited set of forces than those of any physical experiment we can set up in the laboratory. Compared with the distances between them, the planets, and even the sun, are very nearly points. Compared with the elastic and plastic deformations they suffer, the planets are either very nearly rigid bodies, or, where they are not, their internal forces are at any rate of a relatively slight, significance where the relative motion of their centers is concerned. The space in which they move is almost perfectly free from impeding matter; and in their mutual attraction, their masses may be considered to lie very nearly at their centers and to be constant. The departure of the law of gravity from the inverse square law is most minute. The positions, velocities, and masses of the bodies of the solar system are extremely well known at any time, and the computation of their future and past positions, while not easy in detail, is easy and precise in principle. On the other hand, in meteorology, the number of particles concerned is so enormous that an accurate record of their initial positions and velocities is utterly impossible; and if this record were actually made and their future positions and velocities computed, we should have nothing but an impenetrable mass of figures which would need a radical reinterpretation before it could be of any service to us. The terms “cloud,” “temperature,” “turbulence,” etc., are all terms referring not to one single physical situation but to a distribution of possible situations of which only one actual case is realized. If all the readings of all the meteorological stations on earth were simultaneously taken, they would not give a billionth part of the data necessary to characterize the actual state of the atmosphere from a Newtonian point of view. They would only give certain constants consistent with an infinity of different atmospheres, and at most, together with certain *a priori* assumptions, capable of giving, as a probability distribution, a measure over the set of possible atmospheres. Using the Newtonian laws, or any other system of causal laws whatever, all that we can predict at any future time is a probability distribution of the constants of the system, and even this predictability fades out with the increase of time.

Now, even in a Newtonian system, in which time is perfectly reversible, questions of probability and prediction lead to answers asymmetrical as between past and future, because the questions to which they are answers are asymmetrical. If I set up a physical experiment, I bring the system I am considering from the past into the present in such a way that I fix certain quantities and have a reasonable right to assume that certain other quantities have known statistical distributions. I then observe the statistical distribution of results after a given time. This is not a process which I can reverse. In order to do so, it would be necessary to pick out a fair distribution of systems which, without intervention on our part, would end up within certain statistical limits, and find out what the antecedent conditions were a given time ago. However, for a system starting from an unknown position to end up in any tightly defined statistical range is so rare an occurrence that we may regard it as a miracle, and we cannot base our experimental technique on awaiting and counting miracles. In short, we are directed in time, and our relation to the future is different from our relation to the past. All our questions are conditioned by this asymmetry, and all our answers to these questions are equally conditioned by it.

A very interesting astronomical question concerning the direction of time comes up in connection with the time of astrophysics, in which we are observing remote heavenly bodies in a single observation, and in which there seems to be no unidirectionalness in the nature of our experiment. Why then does the unidirectional thermodynamics which is based on experimental terrestrial observations stand us in such good stead in astrophysics? The answer is interesting and not too obvious. Our observations of the stars are through the agency of light, of rays or particles emerging from the observed object and perceived by us. We can perceive incoming light, but cannot perceive outgoing light, or at least the perception of outgoing light is not achieved by an experiment as simple and direct as that of incoming light. In the perception of incoming light, we end up with the eye or a photographic plate. We condition these for the reception of images by putting them in a state of insulation for some time past: we dark-condition the eye to avoid after-images, and we wrap our plates in black paper to prevent halation. It is clear that only such an eye and only such plates are any use to us: if we were given to pre-images, we might as well be blind; and if we had to put our plates in black paper after we use them and develop them before using, photography would be a very difficult art indeed. This being the case, we can see those stars radiating to us and to the whole world; while if there are any stars whose evolution is in the reverse direction, they will attract radiation from the whole heavens, and even this attraction from us will not be perceptible in any way, in view of the fact that we already know our own past but not our future. Thus the part of the universe which we see must have its past-future relations, as far as the emission of radiation is concerned, concordant with our own. The very fact that we see a star means that its thermodynamics is like our own.

Indeed, it is a very interesting intellectual experiment to make the fantasy of an intelligent being whose time should run the other way to our own. To such a being, all communication with us would be impossible. Any signal he might send would reach us with a logical stream of consequents from his point of view, antecedents from ours. These antecedents would already be in our experience, and would have served to us as the natural explanation of his signal, without presupposing an intelligent being to have sent it. If he drew us a square, we should see the remains of his figure as its precursors, and it would seem to be the curious crystallization—always perfectly explainable—of these remains. Its meaning would seem to be as fortuitous as the faces we read into mountains and cliffs. The drawing of the square would appear to us as a catastrophe—sudden indeed, but explainable by natural laws—by which that square would cease to exist. Our counterpart would have exactly similar ideas concerning us. *Within any world with which we can communicate, the direction of time is uniform.*

To return to the contrast between Newtonian astronomy and meteorology: most sciences lie in an intermediate position, but most are rather nearer to meteorology than to astronomy. Even astronomy, as we have seen, contains a cosmic meteorology. It contains as well that extremely interesting field studied by Sir George Darwin, and known as the theory of tidal evolution. We have said that we can treat the relative movements of the sun and the planets as the movements of rigid bodies, but this is not quite the case. The earth, for example, is nearly surrounded by oceans. The water nearer the moon than the center of the earth is more strongly attracted to the moon than the solid part of the earth, and the water on the other side is less strongly attracted. This relatively slight effect pulls the water into two hills, one under the moon and one opposite to the moon. In a perfectly liquid sphere, these hills could follow the moon around the earth with no great dispersal of energy, and consequently would remain almost precisely under the moon and opposite to the moon. They would consequently have a pull on the moon which would not greatly influence the angular position of the moon in the heavens. However, the tidal wave they produce on the earth gets tangled up and delayed on coasts and in shallow seas such as the Bering Sea and the Irish Sea. It consequently lags behind the position of the moon, and the forces producing this are largely turbulent, dissipative forces, of a character much like the forces met in meteorology, and need a statistical treatment. Indeed, oceanography may be called the meteorology of the hydrosphere rather than of the atmosphere.

These frictional forces drag the moon back in its course about the earth and accelerate the rotation of the earth forward. They tend to bring the lengths of the month and of the day ever closer to one another. Indeed, the day of the moon is the month, and the moon always presents nearly the same face to the earth. It has been suggested that this is the result of an ancient tidal evolution, when the moon contained some liquid or gas or plastic material which could give under the earth's attraction, and in so giving could dissipate large amounts of energy. This phenomenon of tidal evolution is not confined to the earth and the moon but may be observed to some degree throughout all gravitating systems. In ages past it has seriously modified the face of the solar system, though in anything like historic times this modification is slight compared with the "rigid-body" motion of the planets of the solar system.

Thus even gravitational astronomy involves frictional processes that run down. There is not a single science which conforms precisely to the strict Newtonian pattern. The biological sciences certainly have their full share of one-way phenomena. Birth is not the exact reverse of death, nor is anabolism—the building up of tissues—the exact reverse of catabolism—their breaking down. The division of cells does not follow a pattern symmetrical in time, nor does the union of the germ cells to form the fertilized ovum. The individual is an arrow pointed through time in one way, and the race is equally directed from the past into the future.

The record of paleontology indicates a definite long-time trend, interrupted and complicated though it might be, from the simple to the complex. By the middle of the last century this trend had become apparent to all scientists with an honestly open mind, and it is no accident that the problem of discovering its mechanisms was carried ahead through the same great step by two men working at about the same time: Charles Darwin and Alfred Wallace. This step was the realization that a mere fortuitous variation of the individuals of a species might be carved into the form of a more or less one-directional or few-directional progress for each line by the varying degrees of viability of the several variations, either from the point of view of the individual or of the race. A mutant dog without legs will certainly starve, while a long thin lizard that has developed the mechanism of crawling on its ribs may have a better chance for survival if it has clean lines and is freed from the impeding projections of limbs. An aquatic animal, whether fish, lizard, or mammal, will swim better with a fusiform shape, powerful body muscles, and a posterior appendage which will catch the water; and if it is dependent for its food on the pursuit of swift prey, its chances of survival may depend on its assuming this form.

Darwinian evolution is thus a mechanism by which a more or less fortuitous variability is combined into a rather definite pattern. Darwin's principle still holds today, though we have a much better knowledge of the mechanism on which it depends. The work of Mendel has given us a far more precise and discontinuous view of heredity than that held by Darwin, while the notion of mutation, from the time of de Vries on, has completely altered our conception of the statistical basis of mutation. We have studied the fine anatomy of the chromosome and have localized the gene on it. The list of modern geneticists is long and distinguished. Several of these, such as Haldane, have made the statistical study of Mendelianism an effective tool for the study of evolution.

We have already spoken of the tidal evolution of Sir George Darwin, Charles Darwin's son. Neither the connection of the idea of the son with that of the father nor the choice of the name "evolution" is fortuitous. In tidal evolution as well as in the origin of species, we have a mechanism by means of which a fortuitous variability, that of the random motions of the waves in a tidal sea and of the molecules of the water, is converted by a dynamical process into a pattern of development which reads in one direction. The theory of tidal evolution is quite definitely an astronomical application of the elder Darwin.

The third of the dynasty of Darwins, Sir Charles, is one of the authorities on modern quantum mechanics. This fact may be fortuitous, but it nevertheless represents an even further invasion of Newtonian ideas by ideas of statistics. The succession of names Maxwell-Boltzmann-Gibbs represents a progressive reduction of thermodynamics to statistical mechanics: that is, a reduction of the phenomena concerning heat and temperature to phenomena in which a Newtonian mechanics is applied to a situation in which we deal not with a single dynamical system but with a statistical distribution of dynamical systems; and in which our conclusions concern not all such systems but an overwhelming majority of them. About the year 1900, it became apparent that there was something seriously wrong with thermodynamics, particularly where it concerned radiation. The ether showed much less power to absorb radiations of high frequency—as shown by the law of Planck—than any existing mechanization of radiation theory had allowed. Planck gave a quasi-atomic theory of radiation—the quantum theory—which accounted satisfactorily enough for these phenomena, but which was at odds with the whole remainder of physics; and Niels Bohr followed this up with a similarly *ad hoc* theory of the atom. Thus Newton and Planck-Bohr formed, respectively, the thesis and antithesis of a Hegelian antinomy. The synthesis is the statistical theory discovered by Heisenberg in 1925, in which the statistical Newtonian dynamics of Gibbs is replaced by a statistical theory very similar to that of Newton and Gibbs for large-scale phenomena, but in which the complete collection of data for the present and the past is not sufficient to predict the future more than statistically. It is thus not too much to say that not only the Newtonian astronomy but even the Newtonian physics has become a picture of the average results of a statistical situation, and hence an account of an evolutionary process.

This transition from a Newtonian, reversible time to a Gibbsian, irreversible time has had its philosophical echoes. Bergson emphasized the difference between the reversible time of physics, in which nothing new happens, and the irreversible time of evolution and biology, in which there is always something new. The realization that the Newtonian physics was not the proper frame for biology was perhaps the central point in the old controversy between vitalism and mechanism; although this was complicated by the desire to conserve in some form or other at least the shadows of the soul and of God against the inroads of materialism. In the end, as we have seen, the vitalist proved too much. Instead of building a wall between the claims of life and those of physics, the wall has been erected to surround so wide a compass that both matter and life find themselves inside it. It is true that the matter of the newer physics is not the matter of Newton, but it is something quite as remote from the anthropomorphizing desires of the vitalists. The chance of the quantum theoretician is not the ethical freedom of the Augustinian, and Tyche is as relentless a mistress as Ananke.

The thought of every age is reflected in its technique. The civil engineers of ancient days were land surveyors, astronomers, and navigators; those of the seventeenth and early eighteenth centuries were clockmakers and grinders of lenses. As in ancient times, the craftsmen made their tools in the image of the heavens. A watch is nothing but a pocket orrery, moving by necessity as do the celestial spheres; and if friction and the dissipation of energy play a role in it, they are effects to be overcome, so that the resulting motion of the hands may be as periodic and regular as possible. The chief technical result of this engineering after the model of Huyghens and Newton was the age of navigation, in which for the first time it was possible to compute longitudes with a respectable precision, and to convert the commerce of the great oceans from a thing of chance and adventure to a regular understood business. It is the engineering of the mercantilists.

To the merchant succeeded the manufacturer, and to the chronometer, the steam engine. From the Newcomen engine almost to the present time, the central field of engineering has been the study of prime movers. Heat has been converted into usable energy of rotation and translation, and the physics of Newton has been supplemented by that of Rumford, Carnot, and Joule. Thermodynamics makes its appearance, a science in which time is eminently irreversible; and although the earlier stages of this science seem to represent a region of thought almost without contact with the Newtonian dynamics, the theory of the conservation of energy and the later statistical explanation of the Carnot principle or second law of thermodynamics or principle of the degradation of energy—that principle which makes the maximum efficiency obtainable by a steam engine depend on the working temperatures of the boiler and the condenser—all these have fused thermodynamics and the Newtonian dynamics into the statistical and the non-statistical aspects of the same science.

If the seventeenth and early eighteenth centuries are the age of clocks, and the later eighteenth and the nineteenth centuries constitute the age of steam engines, the present time is the age of communication and control. There is in electrical engineering a split which is known in Germany as the split between the technique of strong currents and the technique of weak currents, and which we know as the distinction between power and communication engineering. It is this split which separates the age just past from that in which we are now living. Actually, communication engineering can deal with currents of any size whatever and with the movement of engines powerful enough to swing massive gun turrets; what distinguishes it from power engineering is that its main interest is not economy of energy but the accurate reproduction of a signal. This signal may be the tap of a key, to be reproduced as the tap of a telegraph receiver at the other end; or it may be a sound transmitted and received through the apparatus of a telephone; or it may be the turn of a ship's wheel, received as the angular position of the rudder. Thus communication engineering began with Gauss, Wheatstone, and the first telegraphers. It received its first reasonably scientific treatment at the hands of Lord Kelvin, after the failure of the first transatlantic cable in the middle of the last century; and from the eighties on, it was perhaps Heaviside who did the most to bring it into a modern shape. The discovery of radar and its use in the Second World War, together with the exigencies of the control of anti-aircraft fire, have brought to the field a large number of well-trained mathematicians and physicists. The wonders of the automatic computing machine belong to the same realm of ideas, which was certainly never so actively pursued in the past as it is at the present day.

At every stage of technique since Daedalus or Hero of Alexandria, the ability of the artificer to produce a working simulacrum of a living organism has always intrigued people. This desire to produce and to study automata has always been expressed in terms of the living technique of the age. In the days of magic, we have the bizarre and sinister concept of the Golem, that figure of clay into which the Rabbi of Prague breathed life with the blasphemy of the Ineffable Name of God. In the time of Newton, the automaton becomes the clockwork music box, with the little effigies pirouetting stiffly on top. In the nineteenth century, the automaton is a glorified heat engine, burning some combustible fuel instead of the glycogen of the human muscles. Finally, the present automaton opens doors by means of photocells, or points guns to the place at which a radar beam picks up an airplane, or computes the solution of a differential equation.

Neither the Greek nor the magical automaton lies along the main lines of the direction of development of the modern machine, nor do they seem to have had much of an influence on serious philosophic thought. It is far different with the clockwork automaton. This idea has played a very genuine and important role in the early history of modern philosophy, although we are rather prone to ignore it.

To begin with, Descartes considers the lower animals as automata. This is done to avoid questioning the orthodox Christian attitude that animals have no souls to be saved or damned. Just how these living automata function is something that Descartes, so far as I know, never discusses. However, the important allied question of the mode of coupling of the human soul, both in sensation and in will, with its material environment is one which Descartes does discuss, although in a very unsatisfactory manner. He places this coupling in the one median part of the brain known to him, the pineal gland. As to the nature of his coupling—whether or not it represents a direct action of mind on matter and of matter on mind—he is none too clear.

He probably does regard it as a direct action in both ways, but he attributes the validity of human experience in its action on the outside world to the goodness and honesty of God.

The role attributed to God in this matter is unstable. Either God is entirely passive, in which case it is hard to see how Descartes' explanation really explains anything, or He is an active participant, in which case it is hard to see how the guarantee given by His honesty can be anything but an active participation in the act of sensation. Thus the causal chain of material phenomena is paralleled by a causal chain starting with the act of God, by which He produces in us the experiences corresponding to a given material situation. Once this is assumed, it is entirely natural to attribute the correspondence between our will and the effects it seems to produce in the external world to a similar divine intervention. This is the path followed by the Occasionalists, Geulincx and Malebranche: In Spinoza, who is in many ways the continuator of this school, the doctrine of Occasionalism assumes the more reasonable form of asserting that the correspondence between mind and matter is that of two self-contained attributes of God; but Spinoza is not dynamically minded, and gives little or no attention to the mechanism of this correspondence.

This is the situation from which Leibniz starts, but Leibniz is as dynamically minded as Spinoza is geometrically minded. First, he replaces the pair of corresponding elements, mind and matter, by a continuum of corresponding elements: the monads. While these are conceived after the pattern of the soul, they include many instances which do not rise to the degree of self-consciousness of full souls, and which form part of that world which Descartes would have attributed to matter. Each of them lives in its own closed universe, with a perfect causal chain from the creation or from minus infinity in time to the indefinitely remote future; but closed though they are, they correspond one to the other through the pre-established harmony of God. Leibniz compares them to clocks which have so been wound up as to keep time together from the creation for all eternity. Unlike humanly made clocks, they do not drift into asynchronism; but this is due to the miraculously perfect workmanship of the Creator.

Thus Leibniz considers a world of automata, which, as is natural in a disciple of Huyghens, he constructs after the model of clockwork. Though the monads reflect one another, the reflection does not consist in a transfer of the causal chain from one to another. They are actually as self-contained as, or rather more self-contained than, the passively dancing figures on top of a music box. They have no real influence on the outside world, nor are they effectively influenced by it. As he says, they have no windows. The apparent organization of the world we see is something between a figment and a miracle. The monad is a Newtonian solar system writ small.

In the nineteenth century, the automata which are humanly constructed and those other natural automata, the animals and plants of the materialist, are studied from a very different aspect. The conservation and the degradation of energy are the ruling principles of the day. The living organism is above all a heat engine, burning glucose or glycogen or starch, fats, and proteins into carbon dioxide, water, and urea. It is the metabolic balance which is the center of attention; and if the low working temperatures of animal muscle attract attention as opposed to the high working temperatures of a heat engine of similar efficiency, this fact is pushed into a corner and glibly explained by a contrast between the chemical energy of the living organism and the thermal energy of the heat engine. All the fundamental notions are those associated with energy, and the chief of these is that of potential. The engineering of the body is a branch of power-engineering. Even today, this is the predominating point of view of the more classically minded, conservative physiologists; and the whole trend of thought of such biophysicists as Rashevsky and his school bears witness to its continued potency.

Today we are coming to realize that the body is very far from a conservative system, and that its component parts work in an environment where the available power is much less limited than we have taken it to be. The electronic tube has shown us that a system with an outside source of energy, almost all of which is wasted, may be a very effective agency for performing desired operations, especially if it is worked at a low energy level. We are beginning to see that such important elements as the neurons, the atoms of the nervous complex of our body, do their work under much the same conditions as vacuum tubes, with their relatively small power supplied from outside by the circulation, and that the bookkeeping which is most essential to describe their function is not one of energy. In short, the newer study of automata, whether in the metal or in the flesh, is a branch of communication engineering, and its cardinal notions are those of message, amount of disturbance or "noise"—a term taken over from the telephone engineer—quantity of information, coding technique, and so on.

In such a theory, we deal with automata effectively coupled to the external world, not merely by their energy flow, their metabolism, but also by a flow of impressions, of incoming messages, and of the actions of outgoing messages. The organs by which impressions are received are the equivalents of the human and animal sense organs. They comprise photoelectric cells and other receptors for light; radar systems, receiving their own short Hertzian waves; hydrogen-ion-potential recorders, which may be said to taste; thermometers; pressure gauges of various sorts; microphones; and so on. The effectors may be electrical motors or solenoids or heating coils or other instruments of very diverse sorts. Between the receptor or sense organ and the effector stands an intermediate set of elements, whose function is to recombine the incoming impressions into such form as to produce a desired type of response in the effectors. The information fed into this central control system will very often contain information concerning the functioning of the effectors themselves. These correspond among other things to the kinesthetic organs and other proprioceptors of the human system, for we too have organs which record the position of a joint or the rate of contraction of a muscle, etc. Moreover, the information received by the automaton need not be used at once but may be delayed or stored so as to become available at some future time. This is the analogue of memory. Finally, as long as the automaton is running, its very rules of operation are susceptible to some change on the basis of the data which have passed through its receptors in the past, and this is not unlike the process of learning.

The machines of which we are now speaking are not the dream of the sensationalist nor the hope of some future time. They already exist as thermostats, automatic gyrocompass ship-steering systems, self-propelled missiles—especially such as seek their target—anti-aircraft fire-control systems, automatically controlled oil-cracking stills, ultra-rapid computing machines, and the like. They had begun to be used long before the war—indeed, the very old steam-engine governor belongs among them—but the great mechanization of the Second World War brought them into their own, and the need of handling the extremely dangerous energy of the atom will probably bring them to a still higher point of development. Scarcely a month passes but a new book appears on these so-called control mechanisms, or servomechanisms, and the present age is as truly the age of servomechanisms as the nineteenth century was the age of the steam engine or the eighteenth century the age of the clock.

To sum up: the many automata of the present age are coupled to the outside world both for the reception of impressions and for the performance of actions. They contain sense organs, effectors, and the equivalent of a nervous system to integrate the transfer of information from the one to the other. They lend themselves very well to description in physiological terms. It is scarcely a miracle that they can be subsumed under one theory with the mechanisms of physiology.

The relation of these mechanisms to time demands careful study. It is clear, of course, that the relation input-output is a consecutive one in time and involves a definite past-future order. What is perhaps not so clear is that the theory of the sensitive automata is a statistical one. We are scarcely ever interested in the performance of a communication-engineering machine for a single input. To function adequately, it must give a satisfactory performance for a whole class of inputs, and this means a statistically satisfactory performance for the class of input which it is statistically expected to receive. Thus its theory belongs to the Gibbsian statistical mechanics rather than to the classical Newtonian mechanics. We shall study this in much more detail in the chapter devoted to the theory of communication.

Thus the modern automaton exists in the same sort of Bergsonian time as the living organism; and hence there is no reason in Bergson's considerations why the essential mode of functioning of the living organism should not be the same as that of the automaton of this type. Vitalism has won to the extent that even mechanisms correspond to the time-structure of vitalism; but as we have said, this victory is a complete defeat, for from every point of view which has the slightest relation to morality or religion, the new mechanics is fully as mechanistic as the old. Whether we should call the new point of view materialistic is largely a question of words: the ascendancy of matter characterizes a phase of nineteenth-century physics far more than the present age, and “materialism” has come to be but little more than a loose synonym for “mechanism.” In fact, the whole mechanist-vitalist controversy has been relegated to the limbo of badly posed questions.

Cybernetics or Control and Communication in the Animal and the Machine

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