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Introduction

The Programme

Few phenomena in the living world are so immediately evident as the begetting of like by like. A child soon comes to realize that dog is born of dog and corn comes from corn. Mankind early learnt to interpret and exploit the permanence of forms through successive generations. To cultivate plants, to breed animals, to improve them for food or to domesticate them, all require long experience. This already implies a certain notion of heredity and its uses. To obtain good crops, it is not sufficient to wait for the full moon or offer up sacrifices to the gods before sowing; it is also necessary to know how to select the right kind of seed. Farmers of the prehistoric era were somewhat like Voltaire's hero, who undertook to wipe out his enemies with a judicious mixture of prayers, incantations and arsenic. Particularly in the living world, it proved most difficult to separate the arsenic from the incantations. Even when the virtues of the scientific method had become solidly established for the study of the physical world, those who studied the living world continued to think of the origin of living beings in terms of beliefs, anecdotes and superstitions for several generations. Relatively simple experiments suffice to make short work of the notion of spontaneous generations and impossible hybridations. Nevertheless, some aspects of the ancient myths concerning the origin of man, of beasts and of the earth persisted, in one form or another, until the nineteenth century.

Heredity is described today in terms of information, messages and code. The reproduction of an organism has become that of its constituent molecules. This is not because each chemical species has the ability to produce copies of itself, but because the structure of macromolecules is determined down to the last detail by sequences of four chemical radicals contained in the genetic heritage. What are transmitted from generation to generation are the 'instructions' specifying the molecular structures: the architectural plans of the future organism. They are also the means of executing these plans and of coordin-

ating the activities of the system. In the chromosomes received from its parents, each egg therefore contains its entire future: the stages of its development, the shape and the properties of the living being which will emerge. The organism thus becomes the realization of a programme prescribed by its heredity. The intention of a psyche has been replaced by the translation of a message. The living being does indeed represent the execution of a plan, but not one conceived in any mind. It strives towards a goal, but not one chosen by any will. The aim is to prepare an identical programme for the following generation. The aim is to reproduce.

An organism is merely a transition, a stage between what was and what will be. Reproduction represents both the beginning and the end, the cause and the aim. With the application to heredity of the concept of programme, certain biological contradictions formerly summed up in a series of antitheses at last disappear: finality and mechanism, necessity and contingency, stability and variation. The concept of programme blends two notions which had always been intuitively associated with living beings: memory and design. By 'memory' is implied the traits of the parents, which heredity brings out in the child. By 'design' is implied the plan which controls the formation of an organism down to the last detail. Much controversy has surrounded these two themes. First, with respect to the inheritance of acquired characters. The idea that the environment can influence heredity represents a natural confusion between two kinds of memory, genetic and mental. That is an old story going back at least as far as the Old Testament. To avoid further misunderstandings with his father-in-law, Jacob tried to develop flocks of sheep easily distinguishable by their markings. He took rods of green poplar and pilled white strakes in them and set them in the watering troughs... that the animals should conceive when they came to drink. 'And the flocks conceived before the rods and brought forth cattle ringstraked, speckled and spotted.' Throughout the centuries, experiments of this sort were repeated *ad infinitum*, but not always with the same success. For modern biology, the special character of living beings resides in their ability to retain and transmit past experience. The two turning-points in evolution – first the emergence of life, later

the emergence of thought and language – each corresponds to the appearance of a mechanism of memory, that of heredity and that of the mind. There are certain analogies between the two systems: both were selected for accumulating and transmitting past experience, and in both, the recorded information is maintained only as far as it is reproduced at each generation. However, the two systems differ with respect to their nature and to the logic of their performance. The flexibility of mental memory makes it particularly apt for the transmission of acquired characters. The rigidity of genetic memory prevents such transmission.

The genetic programme, indeed, is made up of a combination of essentially invariant elements. By its very structure, the message of heredity does not allow the slightest concerted intervention from without. Whether chemical or mechanical, all the phenomena which contribute to variation in organisms and populations occur without any reference to their effects; they are unconnected with the organism's need to adapt. In a mutation, there are 'causes' which modify a chemical radical, break a chromosome, invert a segment of nucleic acid. But in no case can there be correlation between the cause and the effect of the mutation. Nor is this contingency limited to mutations alone. It applies to each stage in the formation of an individual's genetic heredity, the segregation of the chromosomes, their recombination, the choice of the gametes which play a role in fertilization and even, to a large extent, to the choice of sexual partners. There is not the slightest connection between a particular fact and its consequences in any of these phenomena. Each individual programme is the result of a cascade of contingent events. The very nature of the genetic code prevents any deliberate change in programme whether through its own action or as an effect of its environment. It prohibits any influence on the message by the products of its expression. The programme does not learn from experience.

Design is another notion which has always been intuitively associated with the organism. As long as the living world appeared as a system regulated from without, as long as it was presumed to be administered externally by a supreme power, neither the origin nor the finality of living beings raised any difficulties; they remained

merged with those of the universe itself. However, after the establishment of physics as a science at the beginning of the seventeenth century, the study of living beings found itself faced with a contradiction. Since that time there has been increasing opposition between the mechanistic interpretation of the organism on one hand, and the evident finality* of certain phenomena, such as the development of the egg into an adult, or animal behaviour, on the other. Claude Bernard summed up the paradox in these words:

> Even if we assume that vital phenomena are linked to physico-chemical manifestations, which is true, this does not solve the question as a whole, since it is not a casual encounter between physico-chemical phenomena which creates each being according to a predetermined plan and design ... Vital phenomena certainly have strictly defined physico-chemical conditions, but at the same time they are subordinated and succeed each other in sequence according to a law laid down in advance; they are repeated over and over again in ordered, regular and constant manner, harmonizing with each other, with a view to achieving the organization and growth of the individual, animal or plant. There is a kind of pre-established design for each being and each organ, so that, considered in isolation, each phenomenon of the harmonious arrangement depends on the general forces of nature, but taken in relationship with the others, it reveals a special bond: some invisible guide seems to direct it along the path it follows, leading it to the place which it occupies.[1]

Not a word of these lines needs to be changed today: they contain nothing which modern biology cannot endorse. However, when heredity is described as a coded programme in a sequence of chemical radicals, the paradox disappears.

Everything in a living being is centred on reproduction. A bacterium, an amoeba, a fern – what destiny can they dream of other than forming two bacteria, two amoebae or several more ferns? If there are living beings on earth today, it is because other beings have reproduced with desperate eagerness for two thousand million years or more. Let us imagine an uninhabited world. We can conceive the establishment of systems possessing certain properties of life, such as the ability to react to certain stimuli, to assimilate, to breathe, or even

* Translation of the French word '*finalité*' used to describe both a finalistic or purposeful behaviour and the principle of final causes viewed as operative in the universe.

to grow – but not to reproduce. Can they be called living systems? Each represents the fruit of long and laborious elaboration. Each birth is a unique event, without a morrow. Each occasion is an eternal recommencement. Always at the mercy of some local cataclysm, such organizations can have only an ephemeral existence. Moreover, their structure is rigidly fixed at the outset, incapable of change. If, on the contrary, there emerges a system capable of reproduction, even if only badly, slowly, and at great cost, that is a living system without any doubt. It will spread wherever conditions permit. The more it spreads, the greater its protection from catastrophe. Once the long period of incubation is over, the system becomes established by the repetition of identical events. The first step is taken once and for all. In such a system, however, reproduction, which is the very cause of existence, also becomes its purpose. It is doomed to reproduce or disappear. Some beings have succeeded each other throughout a vast number of generations without changing. Some annual plants have remained unchanged for millions of years, and therefore through at least as many successive cycles. *Limulus*, the king crab of the sea-shore, is still identical with its ancestor found in the fossils of the Secondary geological era: during all this time the programme has not varied, each generation punctually fulfilling its task of exactly reproducing the programme for the following generation.

If, however, an event occurs in the system which happens to 'improve' the programme and facilitate in some way the reproduction of certain descendants, the latter naturally inherit the ability to multiply more effectively. The very finality of the programme thus transforms certain changes in programme into adaptation factors. For variability is an inherent quality in the very nature of living systems, in the structure of the programme, in the manner in which it is recopied by each generation. Modifications in the programme occur at random. It is only afterwards that a sorting operation takes place, by the very fact that every organism which appears is immediately put to the test of reproduction. The famous 'struggle for survival' merely represents a contest for progeny – an endless competition recommencing with each generation. In this eternal contest there is only one criterion – fecundity. The most prolific automatically win through the subtle

interplay between populations and environment. By dint of always inclining towards those with the most offspring, reproduction ends by diverting populations along extremely precise paths. Natural selection represents only the regulation imposed on the multiplication of organisms by their environment. If the living world is evolving in the opposite direction to the inanimate world, steering not towards disorder but towards increasing order, it is thanks to this requirement imposed on living beings to reproduce, always more, always better. The necessity for reproduction, the very fact which would inevitably lead an inert system to disintegration, becomes a source of novelty and variety in the living world.

The notion of programme enables a clear distinction to be drawn between the two domains of order which biology tries to establish. Contrary to what is often imagined, biology is not a unified science. The heterogeneity of its objects, the variety of its techniques and the divergent interests of its practitioners, all lead to intellectual diversity. At the extremes are two great tendencies, two attitudes in fundamental opposition. The first may be called integrationist or evolutionist. Not only does it claim that the organism cannot be separated into its components, but also that it is often useful to consider it as an element of a system of higher order – group, species, population or ecological family. Evolutionary biology is concerned with communities, behaviour, the relationships which organisms set up with one another or with their environment. In fossils it looks for traces of present-day living forms. Impressed by the incredible diversity of beings, it analyses the structure of the living world, seeks the cause of existing characteristics and describes the mechanism of adaptations. Its aim is to define the forces and factors which have made the fauna and flora of today. For the integrationist, the organ and the function are interesting only as part of a whole that comprises not simply the organism, but the species, with its impedimenta of sexuality, prey, enemies, communication and rites. The integrationist refuses to believe that *all* the properties, behaviour and performances of a living being can be explained by its molecular structures alone. For him, biology cannot be reduced to physics and chemistry, not because he desires to invoke mystically a vital force, but because integration

confers on systems at all levels properties which their elements do not possess. The whole is not just the sum of its parts.

The opposing attitude may be called tomist or reductionist. For the reductionist, the organism is indeed a whole, but a whole which must be explained by the properties of its parts alone. He is interested in organs, tissues, cells and molecules. Reductionism seeks to explain functions by means of structures alone. Conscious of the unity of composition and functioning found behind the diversity of living beings, it sees the organism's performances as the expression of its chemical reactions. The reductionist believes that the components of a living being must be isolated and studied under controlled conditions. By varying these conditions, repeating the experiments, defining each parameter, this biologist attempts to master the system and eliminate the variables. His aim is to break up the complexity as far as possible and to study the components with that degree of purity and precision characteristic of experiments in physics and chemistry. For him, there is no property of the organism which cannot ultimately be described in terms of molecules and their interactions. Certainly there is no question of denying the phenomena of integration and emergence. Without doubt the whole may have properties which its components lack, but these properties always result from the structure of the components themselves and their arrangement.

The wide disparity between these two attitudes is obvious. There are differences not only in method and objective, but also in language, concepts and thus even in causal explanations of the living world. The integrationist is interested in remote causes that involve the history of the earth and of living beings for millions of generations. The reductionist, in contrast, is concerned with proximate causes that affect the components of the organism, its functions and its reactions to environment. Much of the controversy and misunderstanding, particularly with regard to the finality of living beings, is caused by a confusion between these two attitudes. Each tries to establish a system of order in the living world. For one, it is the order which links beings to one another, sets up relationships and defines speciations. For the other, it is the order between the structures by which functions are determined, activities coordinated and the organism integrated. One

considers living beings as the elements of a vast system embracing the whole earth. The other considers the system formed by each living being. One seeks to establish order between organisms; the other within each organism. The two kinds of order meet at the level of heredity, which constitutes the order of biological order, so to speak. If the species are stable, it is because the programme is scrupulously recopied, sign by sign, from one generation to another. If they vary, it is because from time to time the programme changes. On the one hand, it is necessary to analyse the structure of the programme, its logic and its execution; on the other, to examine the history of programmes, their drift and the laws governing their changes throughout generations in terms of ecological systems. In all cases, however, the finality of their reproduction justifies both the structure of the present-day living systems and their history. The smallest organism, the smallest cell, the minutest molecule of protein is the result of endless experimentation unremittingly pursued through geological time. What significance could there be in a mechanism regulating the production of a metabolite by a cell, if not an economy of synthesis and energy? Or in the effect of a hormone on the behaviour of a fish, if not the protection of its offspring? There is a definite purpose in the fact that a haemoglobin molecule changes shape according to oxygen pressure; in the production of cortisone by a cell of the suprarenal gland; in the registration by a frog's eye of the forms moving in front of it; in the mouse fleeing from the cat; in the male bird parading in front of the female. In each case there is a property which confers an advantage on the organism in the competition for descendants. To adjust a response with reference to a potential enemy or to an eventual sexual partner is to adapt, in the most precise sense of the word. In evolution, a genetic programme which makes such reactions automatic is certain to prevail over one which does not. The same is true of a programme which allows learning and adaptation of behaviour by various regulatory systems. In each case, reproduction acts as the main operative factor: on one hand, it provides an aim for each organism; on the other it gives a direction to the aimless history of organisms. For a long time, the biologist treated teleology as he would a woman he could not do without, but did not care to be seen

with in public. The concept of programme has made an honest woman of teleology.

The aim of modern biology is to interpret the properties of the organism by the structure of its constituent molecules. In this sense, modern biology belongs to the new age of mechanism. The programme is a model borrowed from electronic computers. It equates the genetic material of an egg with the magnetic tape of a computer. It evokes a series of operations to be carried out, the rigidity of their sequence and their underlying purpose. In fact, these two kinds of programme differ in many ways. First in their properties: one can change at will, the other cannot. In a computer programme, information is added or deleted according to the results obtained; the nucleic-acid structure, on the contrary, is inaccessible to acquired experience and remains unchanged throughout generations. The two programmes also differ in the role they play and in their relationships with the executive organs. The machine's instructions do not deal with physical structure or component parts. The organism, on the contrary, determines the production of its own components, that is, the organs which are to execute the programme. Even if a machine capable of self-reproduction could be built, it could only make copies of what it actually is. Since all machines wear out in time, little by little the offspring would necessarily become less perfect than the parents. In a few generations, the system would drift further and further towards statistical disorder. Descendants would be doomed to die out. The reproduction of a living being, on the contrary, does not simply involve making a copy of the parent at the time of procreation. A new object is created, starting a series of events which lead from an initial state to the state of the parents. Each generation begins from a vital minimum, that is, a cell. The programme contains all the operations which the cycle accomplishes, leading the individual from youth to death. Furthermore, the genetic programme is not rigidly laid down. Very often it only sets the limits of action by environment, or merely gives the organism the ability to react, the power to acquire some extra information which is not inborn. Phenomena such as regeneration or modifications produced in the individual by environment certainly indicate some degree of flexibility in the expression of the

programme. As organisms become more complex, as their nervous system increases in importance, genetic instructions provide them with new potentialities, such as the ability to remember or to learn. However, the programme plays a role even in these phenomena – in learning, for example, it determines what may be learnt and at what stage in life learning should take place – in memory, it limits the nature, number and permanence of recollections. The rigidity of the programme thus varies according to the operations. Certain instructions are carried out literally. Others are expressed by capacities or potentialities. However, in the end the programme itself determines its degree of flexibility and the range of possible variations.

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This book deals with the history of heredity and reproduction. It deals with the changes in the way man has looked at the nature of living beings, their structure and their continuity. For a biologist, there are two different ways of examining the history of his science. Firstly, it may be considered as a succession of ideas, thus involving a search for the thread which guided thought along the path to current theories. This is reverse history, so to speak, which moves back from the present towards the past. Step by step, the forerunner of the current hypothesis is chosen, then the forerunner of the forerunner, and so on. This view of history permits ideas to acquire independence: they behave somewhat like living organisms, being born, reproducing and dying. Endowed with an explanatory value, they can spread and invade. Such a view presupposes a sort of evolution of ideas, for which the selective forces are either a constantly improving series of hypotheses and their applications or some kind of rational finalism. Considered in this fashion, spontaneous generation, for example, was weakened by Francisco Redi's experiments. It lost more ground with those of Spallanzani and finally disappeared with those of Pasteur. However this does not explain why Spallanzani's experiments failed to carry conviction when a century later Pasteur's repetition of these experiments with only slight extensions quickly settled the issue in a conclusive fashion. The same is true of the theory of evolution. Lamarck can be seen as a predecessor of Darwin, Buffon of Lamarck,

Benoît de Maillet of Buffon, and so on. But this fails to explain why Lamarck's ideas were almost totally neglected at the beginning of the nineteenth century by men such as Goethe, Erasmus Darwin and Geoffroy Saint-Hilaire, the very people who were seeking arguments in favour of transformism.

The alternative approach to the history of biology involves the attempt to discover how objects become accessible to investigation thus permitting new fields of science to be developed. It requires analysis of the nature of these objects, and of the attitude of the investigators, their methods of observation, and the obstacles raised by their cultural background. The importance of a concept is defined operationally in terms of its role in directing observation and experience. There is no longer a more or less linear sequence of ideas, each produced from its predecessor, but instead a domain which thought strives to explore, where it seeks to establish order and attempts to construct a world of abstract relationships in harmony not only with observations and techniques, but also with current practices, values and interpretations. Ideas repudiated in time gone by often assume as much significance as those recognized by present-day science, and obstacles are as important as open pathways. Here knowledge works on two levels. Each period is characterized by a range of possibilities defined not only by current theories or beliefs, but also by the very nature of the objects accessible to investigation, the equipment available for studying them and the way of observing and discussing them. It is only within this range that reason can manoeuvre. It is within these fixed limits that ideas operate, are tested and come into conflict. Among all the possible terms, the one which best integrates the results of investigations must be singled out. This is where individual choice comes in. However, in this endless discussion between what is and what might be, in the quest for a chink revealing another possibility, the margin of freedom of the individual investigator is sometimes very narrow. The importance of the individual decreases as the number of practitioners increases: if an observation is not made here today, it will most frequently be made somewhere else tomorrow. For a long time, men have wondered what would have become of scientific thought if Newton had been an apple-gatherer, Darwin a

sea-captain or Einstein a plumber (as he said he would have preferred to be). At worst, there might have been a few years' delay in the development of the theories of gravity or relativity, and even less in the development of the theory of evolution, which Wallace put forward at the same time as Darwin. When a theory appears too soon, as in the case of Mendel's laws of inheritance, no one pays attention to it. When it becomes timely for a small group of specialists, it may come to light in several places at the same time. On the contrary, once they are accepted, scientific theories contribute more than anything else to reorganizing the domain of the possible, modifying ways of looking at things, bringing to light new relationships or objects; in short, changing the existing order.

This way of considering the evolution of a science such as biology is completely different from the preceding one. There is no longer any question of finding the royal road of ideas, retracing the confident march of progress towards what now appears to be a solution, using present-day rational values to interpret the past and examine it for pointers to the present. On the contrary, it means specifying the various stages of knowledge, defining the transformations and revealing the conditions which enable objects and interpretations to enter the field of the possible. The elimination of the doctrine of spontaneous generation then no longer appears an almost linear process, leading from Redi to Pasteur by way of Spallanzani. Darwin is no longer merely Lamarck's son and Buffon's grandson. The disappearance of the doctrine of spontaneous generation and the appearance of a theory of evolution become the products of mid-nineteenth-century thought as a whole. The development of concepts of life and of the history of nature were preconditions. Before these changes could occur, there had to be a delimitation of the species, a discrimination between the organic and the inorganic and an elimination of the series of transitions leading imperceptibly from the simplest organisms to the most complex. In the end, by their rigidity and their dogmatism, their obstinacy in considering only the fixity of species, Linnaeus and Cuvier contributed at least as much to the eradication of spontaneous generation as did Redi and Spallanzani by their experiments. And by shattering the old myth of a chain of living beings, Cuvier perhaps

did more to make a theory of evolution possible than did Lamarck, with his generalization of eighteenth-century transformism.

There are many generalizations in biology, but precious few theories. Among these, the theory of evolution is by far the most important, because it draws together from the most varied sources a mass of observations which would otherwise have remained isolated; it unites all the disciplines concerned with living beings; it establishes order among the extraordinary variety of organisms and closely binds them to the rest of the earth; in short, it provides a causal explanation of the living world and its heterogeneity. The theory of evolution may be summed up essentially in two propositions. First, that all organisms, past, present or future, descend from one or several rare living systems which arose spontaneously. Second, that species are derived from one another by natural selection of the best procreators. Considered as a scientific theory, the theory of evolution has the worst failing of all: founded on history, it cannot be directly verified in any way. Nevertheless, it has a scientific character, unlike magic and religion, because it remains open to contradiction by experimental evidence. Formulating this theory means running the risk of being contradicted one day by some scientific observation. However, up till now, most biological generalizations only reflect and confirm certain aspects of the theory of evolution. This is particularly true of a whole series of propositions, such as: all living beings are made up of cells; all living beings utilize the same optical isomers; the genetic information of an organism is contained in deoxyribonucleic acid (DNA); the energy a living being requires is provided by reactions in which phosphorylations are coupled with the utilization either of a chemical compound or of light. What physiology and biochemistry have shown during the present century is principally the unity of composition and functioning in the living world. Over and above the diversity of forms and the variety of performances, all organisms use the same materials for carrying out similar reactions, as if the living world as a whole always used the same ingredients and the same recipes, originality being introduced only in the cooking and the seasoning. It must be admitted that once she had found the best recipe, nature abided by it throughout evolution. Whatever his speciality, whether he deals

with organisms, cells or molecules, every biologist today sooner or later has to interpret the results of his investigations in the light of the theory of evolution. Other biological theories, such as the theories of nervous conduction and of heredity, are generally extremely simple and involve only a very minor degree of abstraction. Even when an abstract entity such as the gene appears, the biologist will not rest until he has replaced it by material components, particles or molecules, as if, in order to last, a biological theory had to be based on a concrete model.

Perhaps what brought about the greatest transformation in the study of living beings is the fact that new objects have become accessible to investigation – not always as a result of a new technique for increasing sensorial powers, but often as the result of new ways of looking at the organism, examining it and formulating questions to be answered by observation. Indeed, a mere change of lighting often makes an obstacle disappear, or brings into view some aspect of an object, some hitherto invisible relationship. No new instrument was required, at the end of the eighteenth century, in order to compare a horse's leg with a man's leg, and to reach conclusions about their similarities of structure and function. Between the hand of Fernel, who coined the word physiology, and that of Harvey, who made possible experiments on the circulation of blood, the scalpel did not change in shape or quality. From all those who studied heredity during the nineteenth century up to Mendel, there was no more than a slight difference in the choice of experimental objects, in what was examined and, above all, in what was disregarded. If Mendel's work remained neglected for more than thirty years, it was because neither professional biologists, stockraisers nor horticulturists were yet in a position to adopt his attitude. 'Those who seek God, find him,' said Pascal – but they find only the God they are looking for.

Even the sudden appearance of an instrument which increases the discriminatory powers of the senses is never more than the practical application of an abstract concept. The microscope is the reutilization of physical theories of light. Moreover, it is not enough to 'see' a hitherto invisible body to turn it into an object for investigation. When Leeuwenhoek first contemplated a drop of water under a

microscope, he discovered an unknown world: swarming forms, living beings, a whole unpredictable fauna which the instrument suddenly made accessible to observation. Yet thought of that period did not know what to make of this world: it had no use for these microscopic beings, no way of relating them to the rest of the living world. This discovery merely provided a topic of conversation. That they can live and move about, these beings so small that the eye cannot discern them – there was yet another demonstration (if one were needed) of the power and generosity of Nature. A subject of entertainment as well for the courts and salons given up to scientific gossip. A subject of scandal, finally, for men like Buffon, who saw a flagrant insult to the whole living world in these microscopic beings. It was an insult to all creatures, and particularly to the noblest of them all, that a drop of water could contain thousands of living beings. When, in the same period, Robert Hooke looked at a piece of cork under a microscope, he discerned honeycomb shapes which he baptized cells. Malpighi and others found similar shapes in sections of certain plant organs. However, they were unable to draw the slightest conclusion as to the structure of plants. At the end of the seventeenth century, it was still a question of investigating the visible structure of living beings, not breaking them down into sub-units. The only field in which thought was prepared to welcome the revelations of the microscope was that of generation. Hitherto, the events which accompany the mixing of seeds and the development of the egg had remained hidden through lack of adequate sensorial equipment. Thus when Leeuwenhoek and Hartsoeker observed 'animalcules' frantically swimming around in the spermatic fluid of many different types of male animals, they immediately found a use for them – but not the right one. For many decades, naturalists tried either to turn these animalcules into the sole artisans of generation, or to reduce their role to that of mere bystanders. For an object to be accessible to investigation, it is not sufficient just to perceive it. A theory prepared to accommodate it must also exist. In the dialogue between theory and experience, theory always has the first word. It determines the form of the question and thus sets limits to the answer. 'Chance favours only the prepared mind,' said Pasteur. Chance, here, means

that the observation was made by accident and not in order to verify the theory. Yet the theory which enabled the accident to be interpreted already existed.

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Like other sciences, biology today has lost many of its illusions. It is no longer seeking for truth. It is building its own truth. Reality is seen as an ever-unstable equilibrium. In the study of living beings, history displays a pendulum movement, swinging to and fro between the continuous and the discontinuous, between structure and function, between the identity of phenomena and the diversity of beings. From these oscillations, the architecture of the living gradually emerges, revealed in ever deeper layers. In the living world as elsewhere, the question is always to 'explain the complicated and visible by the simple and invisible', according to Jean Perrin's expression. However, with living beings as with inanimate objects, there are wheels within wheels. There is not one single organization of the living, but a series of organizations fitted into one another like nests of boxes or Russian dolls. Within each, another is hidden. Beyond each structure accessible to investigation, another structure of a higher order is revealed, integrating the first and giving it its properties. The second can only be reached by upsetting the first, by decomposing the organism and recomposing it according to other laws. Each level of organization thus brought to light leads to a new way of considering the formation of living beings. After the sixteenth century, a new organization is seen to have appeared on four separate occasions, each time a structure of a higher order: first, at the beginning of the seventeenth century, the arrangement of visible surfaces, which might be called the first-order structure; then at the end of the eighteenth century, the 'organization', the second-order structure which underlies organs and functions and was finally broken down into cells; next at the beginning of the twentieth century, chromosomes and genes, the third-order structure hidden in the heart of the cell; finally, in the middle of the present century, the nucleic acid molecule, the fourth-order structure, which is considered today to be the basis of each organism, of its properties and its permanence

throughout generations. Each of these structures became in turn the focus of investigations.

What this book attempts to describe are the conditions which, since the sixteenth century, have enabled the successive disclosure of these structures: it is the way in which 'generation', a new creation each time and always requiring the intervention of some external force, has become 'reproduction', the intrinsic property of all living systems; it is the access to such increasingly concealed objects as cells, genes, nucleic-acid molecules. The discovery of each 'Russian doll', the demonstration of these consecutive levels are not the result of a mere accumulation of observations and experiments. More often they express a deeper change, a new way of considering objects, a transformation in the very nature of knowledge.

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Figures in *bold type* indicate whole chapters or sections; '*p*' means *passim* (here and there) – scattered references.

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