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BIOLOGY AND COGNITION

This article is a summary of the conclusions of a work in progress on "Biology and Cognition;" from this stems the rather general character of the following observations. In order to compare cognitive and biological mechanisms, we must first state that the former are an extension and utilization of organic auto-regulations, of which they are a form of end-product. To demonstrate this, one can begin by noting the close parallels between the major problems faced by biologists and those faced by theoreticians of the intelligence or of cognition. Secondly, one can analyze the functional analogies and especially the structural isomorphisms between organic life and the means of cognition: "nested" structures, structures of order, multiplicative correspondence, etc. One can also attempt a sort of comparative epistemology of the different levels of behavior (the "logic" of the instincts or of the learning processes, etc.). Finally, one can examine the explanations current among biologists to account for the formation of intelligence. But if these various analyses bring into relief the continuity between organic life and cognitive mechanisms, on the other hand it still remains to be seen that the latter constitute

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differentiated and specialized organs for reacting physiologically to the external world. Or in other words, that at the same time that they are an elaboration of organic structures in general, they fulfill particular functions, although still of a biological nature. The following pages are based on this premise, but it should be understood that it is not a question of contrasting cognition with organic behavior but rather of placing the functions of the former within the framework of the latter.

A. THE FUNCTIONS SPECIFIC TO COGNITION

In studying the functional relationships and the partial structural isomorphisms between cognitive and organic functions, one notes the existence of a remarkable number of similarities but also a certain number of differences which show that cognition also has specific functions. Moreover the contrary would be unthinkable since if organisms were self-sufficient—without instincts, acquired ability, or intelligence—it would indicate a radical duality of kind between life and cognition, since cognitive mechanisms do in fact exist. This in turn would raise inextricable difficulties for an epistemology simply trying to explain how science is able to arrive at objective knowledge.

I. *Behavior, the extension of the environment and the closing of the "open system."* To begin with the basic facts of ethology, the majority of perceptions characteristic of animals are of a utilitarian and practical kind. Instinct is always at the service of the three fundamental needs of nutrition, self-defense, and reproduction. If with migrations or different types of social organization it seems to pursue derivative ends, they are derivative only in the sense that these interests, grafted onto the three principal ones, are still based on them and are ultimately subordinate to the survival of the species and to the possible survival of the individual.

The elementary forms of perceptual or sensory-motor learning fall within a similar functional structure, and it is the same for a very large part of routine or sensory-motor intelligence. Nevertheless, in this latter area one must admit that with mammals and especially Anthropoids there is some development of activity which remains functional but involves comprehension for its own sake: we know that young mammals play and that this, despite K. Groos, is not just an exercise of the instincts, but a general exercise of the activities possible at a given level, without present utility or without being put into use. Now, play is but one pole of the functional processes operating in the course of individual development, the other pole being non-playful exercise, where the young subject "learns to learn" (Harlow) in a context of cognitive adaptation and not solely of play. One of our children, aged about one year, chanced to pass through the bars of his play-pen a toy which he wanted but which, being too long, had to be placed vertically in order to make the passage possible. He was not satisfied by his chance success, but he put it outside again and repeated his efforts until he "understood." This beginning of disinterested knowledge is without doubt equally accessible to chimpanzees.

But whether exclusively utilitarian or involved in this transition from "know-how" to "understanding," animal cognition thus already quite clearly demonstrates a specific function, in comparison with survival, nutrition, or reproduction in their purely organic aspects: this is the function of extension of the environment. To search for food instead of drawing it from the earth or from the atmosphere like a plant, is already to enlarge the environment. To search for the female and to care for offspring is to assure to reproduction more spatial-temporal control than that of the purely physiological function. And to explore for the sake of exploration (like the rats described by Blodgett), without immediate utility, to the point of learning for its own sake, as this already appears within the realm of sensory-motor intelligence, is to extend even further the part of the environment that is actually put to use.

It is clear that during later development the mere existence of instruments for intelligent cognition, even if it pursued only utilitarian ends at the start, creates a new functional situation, since every organ tends to develop and maintain itself for its own sake: from this stem the fundamental cognitive needs of comprehension and invention; but they in turn lead to an ever-growing extension of the environment, this time as an object of consciousness.

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One can express biologically this slow extension, later to become more and more accelerated with man, of the accessible environment to needs at first biological and later more specifically cognitive, by relating it to the fundamental traits of the living system. An organism, according to Bertalanffy, is an "open system" precisely in the sense that it retains its form only through a continuous flow of exchanges with the environment. Now, an open system is a constantly threatened system, and it is not for nothing that the basic concerns of survival, food and reproduction lead to behavior which results in the extension of the usable environment. This extension must then be translated into terms which express its actual function: it is essentially an attempt to close the system and this precisely because it is too "open." From the point of view of probability (and it is the only one suitable here) the particular risk to the open system is that its immediate environment or its frontiers will not supply the necessary elements for its survival. To close the system would instead be to circumscribe an area capable of ensuring survival.

One sees at once that the closing of the system is a goal constantly pursued but never achieved. It is not that the initial needs of food, protection, or reproduction are infinite, far from it. Rather it is that, as soon as various actions serving to satisfy these needs are developed, thanks to a slight enlargement of the initial environment, the cognitive controls of these actions lead sooner or later to an unlimited extension of the system, and this for two reasons.

The first is related to the probability of encounter with desired elements (food and sex) or feared ones (protection). So long as a living creature does not have differentiated sensory organs, exterior events affect it only through immediate contacts and cease to exist as soon as the immediacy disappears. There exist then only momentary needs which disappear as soon as they are satisfied and reappear later, according to a periodic cycle of varying length. However, as soon as a cognitive control develops and olfactory or visual organs indicate food or danger some distance away, the needs are modified by this extension itself: even if the appetite is momentarily satisfied, the absence of visible nourishment or its odor becomes a disturbing modification of the possibilities of recurrence and creates a new need in the form of the need to search, although there may be no immediate desire to be satisfied. Similary, awareness of enemies, even a safe distance away, engenders a new need for vigilance and watchfulness. In other words, the appearance of a cognitive control leads to its alteration as a consequence of function, and this change involves an enlargement of the environment without the possibility, on this elementary level, of ever closing the "open system." Moreover we should note that a similar general extension of the environment begins already on an organic scale previous to sensory controls. This is the dissemination of seed in the sexual reproduction of plants, a good example of spontaneous extension without cognitive control. What would happen if a cognitive control permitted the plant to be informed by feedback of the relative insuccess of this manner of propagation?

II. *Behavior and cognitive controls.* The second reason for the enlarging of the environment which aims at closing the "open system" but which constantly pushes back the limits of this closure is progress in the internal mechanisms of cognitive regulation. Here we reach an essential point about the nature of the cognitive process and the way it develops.

Let us take an ordinary physiological cycle $(A \times A') \rightarrow (B \times B') \rightarrow \ldots (Z \times Z') \rightarrow (A \times A') \rightarrow$, where $A, B \ldots Z$ are the elements of the organism and $A', B' \ldots Z'$ the elements of the milieu with which they are in basic interaction. One can then schematize the intervention of a developing cognitive mechanism as a control which reacts to the presence of some external element or other, A', informs the relevant organs, A, and thus participates in the process $A\,B$, facilitating its development.

From the beginning therefore, cognitive response has a role of control and leads to compromise, intensification, change, compensation or other regulation of the physiological process. But it goes without saying that this elementary response, which can take the form of tropisms or of only slightly differentiated reflexes, precisely because it is a regulating mechanism involves the possibility of, and even requires, indefinite development, for it is in the nature of a regulating agency to be able to correct itself through the control of controls. In the case of our elementary scheme the chain or feedback leading from A' to A, which comprises a signal from A', or afference, and an effect on A, or effection, results in two kinds of possible improvements or controls of behavior to the second power, while internal or physiological regulation affect the process $A \rightarrow B$: (1) there can be refinements in the recording of A' in the form of various conditionings which assimilate new signals or cues within the initial set of perceptive schemata and thus constantly enrich the perceptive keyboard with controls differentiating the initial total stimulus; (2) above all there will be refinements in the reactive systems affecting A, and it is here that new controls show their possibilities in an uninterrupted sequence, of which sensory-motor development in man's growth pattern gives a particularly striking example: on the basic reflex schemata such as suction, grasping, or oculary-motor reflexes a succession of more and more complex behaviors is built, whose two general principles are the accommodation of assimilatory schemata leading to their differentiation, and above all the reciprocal assimilation of schemata (vision and touch, etc.), leading to their coordination. Now from the point of view which concerns us here, the double basic significance of this development, which produces sensory-motor intelligence, is (a) that the progress we have observed is due to a control of controls which results in the exercise of cognitive functions for their own sake, independently of utilitarian or strictly biological basic needs (nutrition, etc.), and (b) that consequently this pushes further and further back the "closure" of a system open to the environment.

That this progress is due to a control of controls is evident, to begin with, in the differentiation by accommodation of the assimilatory systems. For on one hand this accommodation is carried out by trial and error, and this is typical of feedback systems where the action is corrected according to its results. But on the other hand, this trial and error control does not develop from nothing, but from within a previous framework of reflexes or acquired assimilatory schemata, and these initial schemata are the basic controls whose differentiation is elicited by a superimposed regulation.

The coordination of schemata by reciprocal assimilation also involves the control of previous regulations by new ones, and these secondary regulations are especially important since they are related to actions. For the coordination of schemata is a process which simultaneously moves forwards and backwards, since it arrives at a new synthesis which modifies in its turn the schemata thus coordinated.

The internal progression of the mechanism of cognitive control then implies its exercise, that is to say, the formation of a series of new interests no longer subject to the initial interests which are activated by the functioning *per se* of the system. These interests are the functional expression of the mechanism of cognitive assimilation itself but, again we see, as a direct extension of the initial sensory process. The resulting enlarged environment is therefore both the environment, in the biological sense of all the stimuli which affect the organism in its physiological cycle, and the cognitive milieu, considered as all the objects of interest to the consciousness.

But this new extension of the environment is unable to close the "open system" since it remains subject to probabilities of occurrence or, in other words, to the chance experiences of the subject. It is only with imagination or thought, which multiplies at an accelerating rate the spatial-temporal distances characterizing the field of action and comprehension of the subject, that the closing of the open system becomes a possibility. But this requires inter-individual or social exchanges as well as individual exchanges with the environment, and we shall return to this problem later.

III. *Organic equilibrium and cognitive equilibrium.* If the first essential function of cognitive mechanisms is thus the progressive closing of the "open system" of the organism thanks to an indefinite extension of the environment (and this function is indeed an essential part of the process even if, or above all if, it never reaches complete stability), this function leads to a series of others.

The second one to remember is of equally fundamental importance, for it relates to the system's mechanisms of equilibrium. Living systems are essentially self-regulating. If what we have discussed is correct, the development of cognitive functions is clearly, in accordance with our hypothesis, the creation of specialized organs of control for the regulation of exchanges with the exterior, at first of a physiological type, directed at materials and forces, and later purely functional, that is to say, bearing essentially on the functioning of actions and of behavior. But once differentiated organs come into being, are their controls identical to those of the organism? Or in other words, are the forms of equilibrium the same?

The body of known facts leads to the reply, yes and no. They are the same regulations or the same forms of equilibrium in the sense that cognitive organization is an extension of living organization and therefore introduces an equilibrium in the sectors where the organic equilibrium is inadequate—in its particular sphere (as we have seen) and in its accomplishments. But the controls and the cognitive equilibrium differ from the organic equilibrium precisely in that they succeed where the latter is incomplete.

The evolution of organized life appears as an uninterrupted sequence of assimilations of the environment to more and more complex forms, but the very diversity of these forms shows that none of them has been able to put this assimilation in a state of lasting equilibrium. If each group or species is in equilibrium, their succession demonstrates a perpetual beginning anew. It is therefore first of all in the relationship between assimilation and adjustment that the cognitive functions introduce something new.

To begin with the development of knowledge, it seems at first sight that we are in the presence of a completely comparable phenomenon. Not to mention the diversity of instincts or of elementary learning processes, the evolution of the human sciences does not always give us a picture of coherent development easily able to introduce new adjustments required by experience into a permanent assimilatory framework by enlarging or simply differentiating it. But there is an exception, and this is the major one of logico-mathematical structures, important enough by itself but notably increased in significance by the fact that these structures provide the principal assimilatory schemes used by the experimental sciences. In effect, logico-mathematical structures present the unique example of a continuously evolving development, such that no new structurization has had to eliminate its predecessors. Of course these can be poorly adapted to an unforeseen situation but only in the sense that they are unable to resolve a new problem and not that they are contradicted by the very terms of this problem, as it can happen in physics.

Thus, in the relationship between assimilation and accommodation, logico-mathematical structures involve a *sui generis* type of equilibrium. On one hand they can be viewed as the continuous construction of new schemes of assimilation—the assimilation of previous structures in a new, integrated one, and the assimilation of experimental data in the structures thus created. But on the other hand, they show a permanent accommodation in the sense that they are not modified by the newly created structures (except to be amplified) or by the experimental data which the latter are capable of assimilating. Certainly, new data on physical experience can pose unexpected problems for mathematicians and lead to the creation of theories which can absorb them; but the creation in this case is not drawn from an accommodation in the manner of the concepts of physics. On the contrary it is derived from previous structures or schemata at the same time that it is adapted to the new reality.

One can then propose an interpretation which might appear to be rash but which seems to have a true biological foundation if one agrees, as everything seems to suggest, that the primary source for the coordination of actions, out of which come mathematics, can be found in the general laws of the system: it is that the equilibrium between assimilation and accommodation reached by logico-mathematical structures constitutes the simultaneously flexible, or dynamic, and stable state vainly sought after by the succession of forms, at least in the realm of behavior, during the evolution of organized life. While this evolution is marked by a continuous series of disequilibriums and equilibriums, logico-mathematical structures achieve a permanent equilibrium despite the new additions which characterize their evolution.

This brings us to the problem of "vection" or of "progress" raised by many present-day biologists. Vection, which seems to be proved by organic evolution, is characterized by the remarkable union of two apparently antithetical qualities, whose cooperation is necessary for the major accomplishments of adaptation. One has been especially stressed by Schmalhausen: this is an increasing integration which makes the processes of development more and more autonomous with regard to the environment. The other, stressed by Rensch and by J. Huxley, is the increasing "widening" of possibilities for influencing the environment, and by consequence penetration into environments which become more and more extended.

It goes without saying that these two aspects in combination can be found in the development of the sciences. It is to the extent that human intelligence has found in logico-mathematical structures an instrument of integration increasingly independent of experience that it has made a greater conquest of the experienced environment. But once again, because of the very nature of their equilibrium, the cognitive structures develop from the organic ones through extension. They have a similar nature but, as we have seen, in the case of cognition it has developed into forms which are inaccessible to the organic equilibrium. With regard to vection, the difference appears in the following way. The process of integration pointed out by Schmalhausen involves only a certain type of integration, which can be described as current or synchronous, and it therefore has to reconstitute itself in every new group without being able to integrate the entire phyletic past as a sub-system both retained and developed (to put it concretely, mammals have lost some of the characteristics of reptiles by becoming mammals, etc.). The unique character of the integration characteristic of cognitive evolution is, on the contrary, as we have seen, that it is more than temporary and integrates previous structures as sub-systems of the current integration. This integration, surprisingly both diachronic and synchronous, occurs without conflict in mathematics (whose "crises" are only those of growth with but momentary contradictions); however, in the experimental sciences a new theory can contradict previous ones. It remains notable though that a new theory always aims at a *maximum* of integration of the past, so that the best theory is the one which integrates previous results, adding necessary retroactive corrections.

IV. *The dissociation and conservation of forms.* But this achievement is due to another specific character of the cognitive functions in contrast with organic life: this is the possible dissoci-

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ation of form and content. An organic form is inseparable from the matter which it organizes, and in any particular case it is suited only to a limited and well-defined group of substances, whose modification necessitates a change in form. Once again we find a similar situation (given the continuity between the living system and the cognitive one) in elementary forms of consciousness such as sensory-motor or perceptual schemes, although they are already more generalized than the innumerable forms of biological organization. But with the development of intelligence, operative systems become still more generalized, although at the level of concrete operations (classes and relations) they may still be related to their contents, just as structurization is to the structured matter when it can proceed only step by step without sufficient deductive mobility. Finally, with the hypothesizing-deductive activity which proportional combination permits, it becomes possible to elaborate a formal logic, in the sense of an organizing structure applicable to any kind of content whatever. This is what makes it possible to create "pure" mathematics, viewed as an assemblage of organized forms prepared to organize anything, but ceasing temporarily to act according as it is dissociated from application. Once again we find a biological situation impossible on an organic level, where micro-organisms are capable of "transduction" of genetic messages from one species to another, but only as content or matter, and where genetic "transduction" of an organization understood as a form dissociated from all substance has not yet been observed!

But on the cognitive level, this refining of form leads to accomplishments constantly sought after, one might say, in the organic domain but never fully achieved. It is possible to establish certain analogies between the conservation of biological forms (so evident in the regulatory self-conservation of the chromosome) and the exigencies of conservation characteristic of different forms of intelligence, from sensory-motor intelligence (a system for the permanency of objects) to operative conservation. In this respect it might seem that an artificial comparison is being made between quasi-physical systems on the one hand and normative or ideating ones on the other. But once one is aware of the basic nature of regulation characteristic of elementary cognitive functions and the sequence from regulation to action, the comparison becomes more natural, for organic conservation is in fact the outcome of regulatory mechanisms. But the analogies thus touched upon nonetheless run into an important difference, and this is what concerns us here: organic conservation is never more than approached. Moreover, this is also true for preliminary cognitive forms (perceptual constants), while only the operative conservations of intelligence are rigorous and "necessary," on account of the dissociation of form and content.

Conservation is closely related to operative reversibility, which is its source and which, in addition, demonstrates the particular form of equilibrium reached by logico-mathematical structures. We must then be at the very heart of the difference which, deep within their similarity, distinguishes the constructive work of intelligence from that of organic transformations. The basic analogy is that both have to struggle incessantly against the irreversibility of events and the deterioration of energy and information. And both systems deal with the problem by elaborating organized and balanced systems whose principle is to compensate for deviation and error. Thus, beginning with controls of a homeostatic[1] nature—genetically as well as physiologically—there is a fundamental tendency towards reversibility of which the attempted conservation of the system is the result. Whatever may be the eventual explanations, still to be worked out, used to resolve the problem of the anti-chance function necessary to the organization and evolution of life (exceptions to Carnot's principle or various forms of conciliation) there remains however that an auto-regulatory system involves actions oriented in two opposed directions and that it is this partial reversibility whose progress we can follow in the development of cognitive controls. But as we have pointed out above, the result of the general interplay of reflective abstractions and of reconstructions converging with this evolution, is that the evolution which marks the progress of each level with respect to the preceding one is based more on the regulation of regulations, and so on a reflexive refining of the

[1] According to Cannon, homeostasis means the regulatory mechanism which maintains equilibrium as a physiological system, plus, as we have since discovered, the organic function which ensures hereditary transmission (genetic homeostasis).

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system or on superimposed controls, rather than on a simple horizontal extension. This is why the mechanism of the "operations" of thought represents more than an extension of previous controls and constitutes a sort of limiting process towards the point where strict reversibility establishes itself as soon as the retroactive action of feedback becomes an "inverse operation," thus ensuring the exact functional equivalence of the two possible directions of the construction.

V. *Social life and the general coordination of action.* But the most remarkable aspect of human knowledge in its mode of formation, as compared with the evolutionary transformations of organisms and the forms of knowledge achieved by animals, is its collective as well as individual nature. One can of course observe the outlines of a similar characteristic in a number of animal species, especially the chimpanzee. Nevertheless, the novelty with man is that external or educative transmission (as opposed to the hereditary or internal transmission of the instincts) has led to an organization capable of fathering civilizations.

We should first note that, if it is necessary to distinguish between two types of development, one organic (characteristic of a single organism) and the other genealogical (comprising lines of descent, whether social or genetic), the history of human science combines these two developments in a single whole: ideas, theories, and schools of thought develop genealogically, and one can construct for them genealogical trees representing the relationship of structures. But they are so well integrated into a single intellectual organism that the succession of thinkers is comparable, to quote Pascal, to a single man endlessly learning.

Now, human societies have been described, in turn, as the result of individual initiative propagating itself by imitation, as totalities acting from the outside on individuals, or as systems of complex interactions producing individual action, which is always in conjunction with a more or less important part of the group, as well as producing the entire group defined as the system of these interactions. In the area of cognition, it seems evident that the individual operations of intelligence and the operations that ensure the actual exchange in cognitive cooperation are one and the same thing, since the "general coordination of the actions," which is the source of logic, is an inter-individual as well as intra-individual coordination, inasmuch as these "actions" are collective as well as individual. It is therefore a meaningless question to ask if logic or mathematics are essentially individual or social. The epistemic subject which creates them is both an individual, placed off-center with respect to his specific "me," and the sector of the social group, off-centered with respect to the constraining idols of the tribe; and these two types of displacement show the same intellectual interactions or general coordination of action which is constitutive of cognition.

The result is thus (and this is the final basic difference which we shall point out between biological and cognitive organization) that the most general forms of thought, since they are capable of being dissociated from their content, are because of this the medium for cognitive exchange or inter-individual regulation, at the same time that they arise out of common functions characteristic of all living systems. Certainly, from a psychogenetic point of view, these inter-individual or social (and not hereditary) regulations form a new element with respect to individual thought, which if deprived of them is exposed to all kinds of egocentric deformation, and they are a necessary condition for the constitution of a decentralized, epistemic subject. But from a logical point of view, these higher controls are still dependent on the conditions of all general coordination of action and so have the same biological origins.

B. ORGANIC REGULATION AND COGNITIVE REGULATION

This collective re-elaboration of forms already built out of elements pertaining to biological organization also helps to locate the remaining observations within their true framework. Our hypothesis is thus that cognitive functions are a specialized organ for the regulation of exchanges with the external world, although they derive their instruments from biological organization in its general forms.

I. *Life and truth.* It might seem that the necessary existence of a differentiated organ is self-evident, since the specific character of knowledge is to attain truth, while it is specific of life only

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to seek its persistence. But if we do not know exactly what life consists of, we know even less about cognitive "truth." There is general agreement that it is something other than a faithful copy of reality, for the good reason that such a copy is impossible, since only the copy could provide the knowledge of the model to be copied and since this knowledge, on the other hand, is necessary for the copy! To attempt it leads to a simple phenomenism, where subjectivity constantly interferes with the perceived datum, which itself demonstrates an inextricable connection between subject and object.

If truth is not a copy, it is then an organization of reality. But organized by what subject? If we take the human subject, the risk in this case is expanding egocentrism intro anthropocentrism—which will also be sociocentrism—and the gain is minimal. Consequently philosophers concerned with the absolute have had recourse to a transcendental subject which goes beyond man and especially "nature" so as to place truth outside spatial-temporal and physical contingencies and to make nature intelligible in a non-temporal or eternal perspective. But the question then is whether it is possible to leap over one's shadow and to reach the "Subject" *in se*, without his remaining, in spite of all, "human, too human," to quote Nietzsche. For the trouble is that from Plato to Husserl the transcendental subject has constantly changed shape, with no improvements other than those due to the progress of the sciences themselves, hence of the real model and not the transcendental one.

Our intention then is not to run away from nature, since no one escapes nature, but to investigate it step in step with the effort of science because, whatever the philosophers may think, it has still not given up all its secrets and because, before putting the absolute in the clouds, it may be useful to look at the inside of things. Consequently, if truth is an organization of reality, the first question is to understand how one organizes an organization, and this is a question for biology. In other words, since the epistemological problem is to know how science is possible, we should exhaust the possibilities of immanent organization before having recourse to the transcendental.

But if truth is not egocentric and should no longer be anthropocentric, is it then necessary to reduce it to a biocentric organization? If truth is more than man, is it necessary to look for it in protozoa, termites, or chimpanzees? If one defined it as a vision of the world shared in common by all living creatures, including man, the result would be a meager one. But the character of life is to surpass itself constantly, and if one seeks the secret of rational organization in the living system, *including its own mechanisms of progress*, the method then consists of trying to understand knowledge by its very construction, which is not the least bit absurd, since it is *essentially construction.*

II. *The deficiencies of the organism.* From a cognitive point of view, these progressive evolutions, which are just as essential as the initial state, seem inherent to the living system itself. Its organization is that of the system of all exchanges with the environment; it tends then to spread out into the envire environment but it never completely succeeds. This is where cognition comes in to assimilate functionally the whole universe without being limited to material physiological assimilation. The living system creates forms and it tends to conserve them in as much stability as possible, but without success. And this again is where cognition comes in to extend material forms into forms of action or of operation which are then capable of conservation under their applications to the various contents from which they are dissociated. This living system is a source of homeostasis at every step; its regulations ensure equilibrium by the evolution of quasi-reversible mechanisms. However, this equilibrium remains fragile and resists the surrounding irreversibility during but transient stages, so that evolution appears to be a series of disequilibriums and of returns to equilibrium, partially giving way to a mode of structuring that comprises the integrations and reversible mobility which cognitive mechanisms only are able to accomplish completely by integrating control into the construction itself in the form of "operations."

In short, the need for differentiated organs to regulate exchanges with the external world results from the inability of the living system to carry out its own program, implicit in the very laws of its organization. For on one hand, it involves genetic mechanisms which are formative and not merely transmittive;

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but their method of formation (as it is now understood) founded on the recombination of genes, ensures only a limited construction, bounded by the needs of hereditary programming which is necessarily restricted, as it is unable to conciliate construction and conservation within a single coherent dynamic (as cognition will do), and as it lacks sufficiently flexible information on the environment. On the other hand, phenotypes,[2] that achieve a certain amount of interaction with the environment, fall within a norm of reactions in itself bounded; but above all their individual achievements remain both limited and without influence on the whole (for want of the social or external interactions which are made possible for man by cognitive exchanges) except through genetic recombinations, with their afore-mentioned limitations.

This double deficiency of organisms in their material exchanges with the environment is partly compensated by the constitution of structured behaviors, created by the system as an extension of its internal program. For behavior is nothing more than the very organization of life, but applied or generalized to a larger sector of material and energy exchanges than those which are already ensured by the physiological organization. And functional implies that the emphasis is on the actions and forms or schemes of action that extend organic forms. Nonetheless, these new exchanges, like all the others, consist in adaptations to the environment, that take into account its events and their sequence; but above all they consist of assimilations which use the environment and often even impose shapes upon it through constructions or arrangements of objects satisfying the needs of the organism.

Like all organization, this behavior involves regulations, whose function is to control constructive adaptations and assimilations by acting on information on the results received in the course of action or by the elaboration of anticipations which allow the forecasting of favorable events or of obstacles and the preparation of the necessary compensations. These regulations, which are differentiated with regard to the internal control of the organism (since we are concerned here with behavior) constitute the cognitive functions. And the problem then is to understand

[2] By phenotypes we mean the form which individual organisms take with relation to the milieu, as opposed to the "genotype" or hereditary form.

how they widen the scope of organic regulation to the point where they can carry out the internal program of the system without being subject to the deficiencies we mentioned.

III. *Instinct, learning, and logico-mathematical structures.* The basic facts here are in the first place, that cognitive controls begin by using only the instruments of organic adaptation in general, that is to say, heredity with its limited variations and phenotypic accommodation: from these stem the hereditary modes of cognition such as those that appear in instinctive behavior. But subsequently the deficiencies of the initial system that are corrected only slightly on the new behavioral level turn up at the level of this innate cognition. This is what causes, but only during the later stages of evolution, the final break-up of instinct and the separation of its two components, internal organization and phenotypic adaptation. What results then (and this is not immediately upon dissociation, but as an effect of complementary reconstructions in two opposite directions), is the double emergence of logico-mathematical structures and of experimental science, still undifferentiated in the practical intelligence of Anthropoids, who are geometers[3] as much as they are technicians, and in the technical intelligence of the beginnings of humanity.

The three fundamental types of knowledge are innate skill, whose prototype is instinct, knowledge of the physical world, which extends the learning process as a function of the environment, and logico-mathematical knowledge; and the connection between the first and the latter two seems essential to an understanding of the way in which higher forms are indeed an organ for controlling interchanges. We shall return to this point in conclusion.

Instinct indeed already includes some cognitive controls as may be observed, for example, in the feedback system formed by Grassé's "stigmergies."[4] But these controls remain limited and rigid, precisely because they develop within a framework of

[3] See the interesting experiments of I. Meyerson and P. Guillaume.

[4] Grassé calls "stigmergies" certain hereditary behavioral regulations of termites. They form small pellets of matter in building their homes, and when these reach a specific volume, the pellets then become used as supports, floors, etc., in accordance with a new set of laws, but without a particular order of succession.

hereditary programming, and programmed controls are not capable of invention. Certainly it happens that animals are able to deal with unforeseen situations through readjustments which foretoken intelligence. The coordination of schemata that occurs on this occasion can be compared with the innate coordinations of the instinctual, trans-individual cycle, which gives an important indication of the possible functional relationship between instinct and intelligence, despite the difference of epigenotypic[5] and phenotypic levels which characterizes them. But the phenotypic developments of instinct remain very limited and its deficiency thus remains tied to its nature, which demonstrates that a form of cognition that remains linked to the simple mechanisms of organic adaptation, despite some traces of cognitive regulation, scarcely approaches the achievements of intelligence.

Though the area of learning *stricto sensu*, that which lies beyond the innate, begins with protozoa, it grows only very slowly until the cerebralization of the higher vertebrates, and however remarkable the exceptions that begin to appear with insects, it shows no systematic development until the primates.

IV. *The break-up of instinct.* The fundamental phenomenon of this scission, or in other words, the almost total disappearance in the Anthropoids and man, of a cognitive organization which remained dominant throughout the entire evolution of animal behavior, is thus highly significant. This is not, as it is generally said, because a new mode of cognition, that is to say, intelligence considered en bloc, replaces a superseded one. More deeply, it is because a still quasi-organic form of cognition develops into new forms of control which take the place of the preceding form but do not replace it. Properly speaking, they inherit it, dissociating it and using its components in two complementary directions.

What disappears with the dismemberment of instinct is hereditary programming, and this benefits two new types of cognitive self-regulation, that are both flexible and constructive. One might then say that this is in fact a replacement, and indeed a complete one. But one then forgets two essential factors. Instinct does

[5] The epigenotype is a structure (using the definition suggested by the work of Waddington) which includes both genotypic and epigenotypic structures, that is, related to an embryonic development interacting with the environment.

not consist exclusively of hereditary mechanisms—such a concept is an extreme one, as Viaud has properly pointed out. On the one hand, instinct derives its programs and above all its "logic" from an organized activity which originates in the most general forms of the living system. On the other hand, it extends this programming by individual or phenotypic actions that contain an important element of adaptation and even of assimilation, in part learned and in certain cases almost intelligent.

Now, what vanishes with the disappearance of instinct is only the central or median part, that is to say, programmed control, while the other two components—the origins of organization and the results of individual or phenotypic adjustment—remain. Intelligence therefore inherits instinct while it rejects the methods of programmed regulation in favor of constructive self-regulation. What it retains allows it to follow the two complementary directions of interiorization, towards sources, and of exteriorization, towards learned or experienced adjustments.

The condition for this double evolution is naturally the construction of a new mode of control, and this must be remembered to begin with. These controls, which are no longer programmed but from now on are flexible, begin with the usual corrective activity, carried out as a function of the results of actions and of anticipations. But as participants in the construction of schemes of assimilation and in their coordination, under the combined influence of progressive and retroactive effects they end up moving in the direction taken by operations themselves, inasmuch as these are viewed as controls for precorrection and not just correction, and as the inverse operation is viewed as an action ensuring complete and not simply approximate reversibility.

It is thanks to this new kind of control, that constitutes a differentiated organ for deductive verification as well as for construction, that intelligence can evolve simultaneously in the two directions of reflexive interiorization and experimental exteriorization we have just discussed. It is clear that this double orientation does not involve, and in fact has nothing in common with a sharing of the spoils of instinctual cognition. On the contrary, what remains of instinct is only its sources of organization and its end-products such as exploration and individual

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research. For intelligence to use the former and extend the latter, it must therefore turn to new constructions, of which some release the pre-conditions for general coordination of action through the use of reflective abstraction, and others absorb the experimental data into the operatory systems thus constructed. But it remains no less true that these two directions carry on the functions of two of the previous components of instinct.

After the break-up of instinct, a new cognitive evolution begins and in fact it starts from scratch since the innate mechanisms of instinct have disappeared and, no matter how hereditary the cerebral nervous system and intelligence, seen as an ability to learn and invent, may be, the work to be done henceforth is phenotypic. Moreover, it is because this intellectual evolution starts from scratch that one generally finds it so difficult to relate it to the living system or above all to the structures, remarkable in their own right, of instinct.

This is a good example of what one might call "convergent evolving reconstructions." In the case of human intelligence, this reconstruction is in fact so complete that hardly any theoreticians of logico-mathematical knowledge have thought to explain it in the clearly necessary framework of biological organization. This was true at least before mechanophysiology showed the connection between logic, cybernetic models and the neurophysiological activity of the brain, or before McCulloch described the logic of neurons.

V. *Knowledge and society.* But if such complete reconstruction is possible, it is because intelligence, by discarding the prop provided by hereditary structures and moving towards constructed and phenotypic controls, turns away from the trans-individual cycles of instinct only in order to engage in inter-individual and social interaction. There does not seem to be any discontinuity here, since we already find group action in chimpanzees.

One might say in this connection that from a cognitive point of view the social group plays the same role that "population" does from the point of view of genetics and therefore from that of instinct. In this sense society is the supreme unit, and the individual succeeds in inventing or in creating intellectual structures only to the degree that he is the seat of collective interactions whose level and value naturally depend on that of the society in general. The great man who seems to initiate new trends is only a point of intersection or of synthesis, of ideas elaborated by continuous co-operation, and even when he dissents from majority opinion he is responding to underlying needs of which he is not the source. This is why the social environment actually does for intelligence what genetic recombinations in the entire population did for evolutionary variation or the trans-individual cycle of the instincts.

But society, however external and educative its methods of transmission and interaction may be in comparison with those of hereditary transmission or combination, is no less than the latter a product of life. And "collective representations," as Durkheim called them, still presuppose the existence of a nervous system in the members of the group. This is why the important question is not to weigh the merits of the individual versus the group (like asking which came first, the chicken or the egg): it is to distinguish between logic, whether in the course of solitary reflection or co-operation, and errors or insanities in collective opinion or in the individual consciousness. For, despite Tarde, there are not two logics, one serving the group and the other, the individual. There is only one way of coordinating actions *A* and *B* in a nested relationship or in one of order, etc., regardless of whether these are the actions of various individuals, one or some for *A* and another or others for *B*, or the actions of the same person (who did not after all invent them alone, since he is a member of the whole society). It is in this sense that cognitive controls or operations are the same whether in a single brain or in a system of co-operations (which is the meaning in French of the word *coopération*).

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In sum, and however banal the thesis might seem, it is worth stressing that cognitive functions are extensions of organic controls and that they constitute a differentiated organ for regulating exchanges with the external world, for this hypothesis implies far more than these few pages can suggest.