Biology of Cognition

Humberto R. Maturana

(1970)

Biological Computer Laboratory Research Report BCL 9.0. Urbana IL: University of Illinois, 1970. As Reprinted in: *Autopoiesis and Cognition: The Realization of the Living* Dordecht: D. Reidel Publishing Co., 1980, pp. 5–58.

I. Introduction

Man knows and his capacity to know depends on his biological integrity; furthermore, he knows that he knows. As a basic psychological and, hence, biological function *cognition* guides his handling of the universe and *knowledge* gives certainty to his acts; *objective knowledge* seems possible and through *objective knowledge* the universe appears systematic and predictable. Yet *knowledge* as an experience is something personal and private that cannot be transferred, and that which one believes to be transferable, objective knowledge, must always be created by the listener: the listener understands, and *objective knowledge* appears transferred, only if he is prepared to understand. Thus *cognition* as a biological function is such that the answer to the question, *"What is cognition?"* must arise from understanding knowledge and the knower through the latter's capacity to know.

Such is my endeavor.

Epistemology

The basic claim of science is objectivity: it attempts, through the application of a well defined methodology, to make statements about the universe. At the very root of this claim, however, lies its weakness: the *a priori* assumption that objective knowledge constitutes a description of that which is known. Such assumption begs the questions, *"What is it to know?"* and *"How do we know?"*.

Biology

(a) The greatest hindrance in the understanding of the living organization lies in the impossibility of accounting for it by the enumeration of its properties; it must be understood as a unity. But if the organism is a unity, in what sense are its component properties it parts? The organismic approach does not answer this question, it merely restates it by insisting that there are elements of organization that subordinate each part to the whole and make the organism a unity [Cf. Bertalanffy, 1960]. The questions *"How does this unity arise?"* and *"To what extent must it be considered a property of the organization of the organism, as opposed to a property emerging from its mode of life?"* remain open. A similar difficulty exists for the understanding of the functional organization of the nervous system, particularly if one considers the higher functions of man. Enumeration of the transfer functions of all nerve cells would leave us with a list, but not with a system capable of abstract thinking, description, and self-description. Such an approach would beg the question, *"How does the living organization give rise to cognition in general and to self-cognition in particular?"*

(b) Organisms are adapted to their environments, and it has appeared adequate to say of them that their organization represents the 'environment' in which they live, and that through evolution they have accumulated information about it, coded in their nervous systems. Similarly it has been said that the sense organs gather information about the 'environment', and through learning this information is coded in the nervous system [Cf. Young, 1967]. Yet this general view begs the questions, *"What does it mean to "gather information"?"* and *"What is coded in the genetic and nervous systems?"*.

A successful theory of cognition would answer both the epistemological and the biological questions. This I propose to do, and the purpose of this essay is to put forward a theory of cognition that should provide an epistemological insight into the phenomenon of cognition, and an adequate view of the functional organization of the cognizant organism that gives rise to such phenomena as conceptual thinking, language, and self-consciousness.

In what follows I shall not offer any formal definitions for the various terms used, such as "cognition", "life", or "interaction", but I shall let their meaning appear through their usage. This I shall do because I am confident that the internal consistency of the theory will show that these terms indeed adequately refer to the phenomena I am trying to account for, and because I speak as an *observer*, and the validity of what I say at any moment has its foundation in the validity of the whole theory, which, I assert, explains why I can say it. Accordingly, I expect the complete work to give foundation to each of its parts, which thus appear justified only in the perspective of the whole.

Note: I shall be speaking of the organism as a unity, but when I wrote this essay I was not aware that the word unit did not always quite mean unity. Since I cannot now correct this. I beg the reader to bear this in mind.

II. The Problem

(1) Cognition is a biological phenomenon and can only be understood as such; any epistemological insight into the domain of knowledge requires this understanding.

(2) If such an insight is to be attained, two questions must be considered:

What is cognition as a function?

What is cognition as a process?

III. Cognitive Function in General

The Observer

(1) Anything said is said by an observer. In his discourse the observer speaks to another observer, who could be himself; whatever applies to the one applies to the other as well. The observer is a human being, that is, a living system, and whatever applies to living systems applies also to him.

(2) The observer beholds simultaneously the entity that he considers (an organism, in our case) and the universe in which it lies (the organism's environment). This allows him to interact independently with both and to have interactions that are necessarily outside the domain of interactions of the observed entity.

(3) It is an attribute of the observer to be able to interact independently with the observed entity and with its relations; for him both are units of interaction (entities).

(4) For the observer an entity is an entity when he can describe it. To describe is to enumerate the actual or potential interactions and relations of the described entity. Accordingly, the observer can describe an entity only if there is at least one other entity from which he can distinguish it and with which he can observe it to interact or relate. This second entity that serves as a reference for the description can be any entity, but the ultimate reference for any description is the observer himself.

(5) The set of all interactions into which an entity can enter is its domain of interactions. The set of all relations (interactions through the observer) in which an entity can be observed is its domain of relations. This latter domain lies within the cognitive domain of the observer. An entity is an entity if it has a domain of interactions, and if this domain includes interactions with the observer who can specify for it a domain of relations. The observer can define an entity by specifying its domain of interactions; thus part of an entity, a group of entities, or their relations, can be made units of interactions (entities) by the observer.

(6) The observer can define himself as an entity by specifying his own domain of interactions; he can always remain an observer of these interactions, which he can treat as independent entities.

(7) *The observer is a living system and an understanding of cognition as a biological phenomenon must account for the observer and his role in it.*

The Living System

(1) Living systems are units of interactions; they exist in an ambience. From a purely biological point of view they cannot be understood independently of that part of the ambience with which they interact: the niche; nor can the niche be defined independently of the living system that specifies it.

(2) Living systems as they exist on earth today are characterized by exergonic metabolism, growth and internal molecular reproduction, all organized in a closed causal circular process that allows for evolutionary change in the way the circularity is maintained, but not for the loss of the circularity itself. Exergonic metabolism is required to provide energy for the endergonic synthesis of specific polymers (proteins, nucleic acids, lipids, polysaccharides) from the corresponding monomers, that is, for growth and replication; special replication procedures secure that the polymers synthesized be specific, that they should have the monomer sequence proper to their class; specific polymers (enzymes) are required for the exergonic metabolism and the synthesis of specific polymers (proteins, nucleic acids, lipids, polysaccharides) [Cf. Commoner, 19651.]

This circular organization constitutes a homeostatic system whose function is to produce and maintain this very same circular organization by determining that the *components* that specify it be those whose synthesis or maintenance it secures. Furthermore, this circular organization defines a living system as a unit of interactions and is essential for its maintenance as a unit; that which is not in it is external to it or does not exist. The circular organization in which the *components* that specify it are those whose synthesis or maintenance it secures in a manner such that the product of their functioning is the same functioning organization that produces them, is the living organization.

(3) It is the circularity of its organization that makes a living system a unit of interactions, and it is this circularity that it must maintain in order to remain a living system and to retain its identity through different interactions. All the peculiar aspects of the different kinds of organisms are superimposed on this basic circularity and are subsequent to it, securing its continuance through successive interactions in an always changing environment. A living system defines through its organization the domain of all interactions into which it can possibly enter without losing its identity, and it maintains its identity only as long as the basic circularity that defines it as a unit of interactions remains unbroken. Strictly, the identity of a unit of interactions that otherwise changes continuously is maintained only with respect to the observer, for whom its character as a unit of interactions remains unchanged.

(4) Due to the circular nature of its organization a living system has a self-referring domain of interactions (it is a self-referring system), and its condition of being a unit of interactions is maintained because its organization has functional significance only in relation to the maintenance of its circularity and defines its domain of interactions accordingly.

(5) Living systems as units of interactions specified by their condition of being living systems cannot enter into interactions that are not specified by their organization. The circularity of their organization continuously brings them back to the same internal state (same with respect to the cyclic process). Each internal state requires that certain conditions (interactions with the environment be satisfied in order to proceed to the next state. Thus, the circular organization implies the prediction that an interaction that took place once will take place again. If this does not happen the system disintegrates; if the predicted interaction does take place, the system maintains its integrity (identity with respect to the observer) and enters into a new prediction. In a continuously changing environment these predictions can only be successful if the environment does not change in that which is predicted. Accordingly, the predictions implied in the organization of the living system are not predictions of particular events, but of classes of interactions. Every interaction is a particular interaction, but every prediction is a prediction of a class of interactions that is defined by those features of its elements that will allow the living system to retain its circular organization after the interaction, and thus, to interact again. This makes living systems inferential systems, and their domain of interactions a cognitive domain.

(6) The niche is defined by the classes of interactions into which an organism cam enter. The environment is defined by the classes of interactions into which the observer can enter and which he treats as a context for his interactions with the observed organism. The observer beholds organism and environment simultaneously and he considers as the niche of the organism that part of the environment which he *observes* to lie in its domain of interactions. Accordingly, as for the observer the niche *appears* as part of the environment, for the observed organism the niche constitutes its entire domain of interactions, and as such it cannot be *part* of the environment that lies exclusively in the cognitive domain of the observer. Niche and environment, then, intersect only to the extent that the observer (including instruments) and the organism have comparable organizations, but even then there are always parts of the environment that lie beyond any possibility of intersection with the domain of interactions of the organism, and there are parts of the niche that lie beyond any possibility of intersection with the domain of interactions of the observer. Thus for every living system its organization implies a prediction of a niche, and the niche thus predicted as a domain of classes of interactions constitutes its entire cognitive reality. If an organism interacts in a manner not prescribed by its organization, it does so as something different from the unit of interactions defined by its basic circularity, and this interaction remains outside its cognitive domain, although it may well lie within the cognitive domain of the observer.

(7) Every unit of interactions can participate in interactions relevant to other, more encompassing units of interactions. If in doing this a living system does not lose its identity, its niche may evolve to be contained by the larger unit of interactions and thus be subservient to it. If this larger unit of interactions is (or becomes) in turn also a self-referring system in which its components (themselves self-referring systems) are subservient to its maintenance as a unit of interactions, then it must itself be (or become) subservient to the maintenance of the circular organization of its components. Thus, a particular self-referring system may have the circular organization of a living system or partake functionally of the circular organization of its components, or both. The society of bees (the honey producing bees) is an example of a third order self-referring system of this kind; it has a circular organization superimposed on the second order self-referring systems that are the bees, which in turn have a circular organization superimposed on the first order living systems that are the cells; all three systems with their domains of interactions are subordinated both to the maintenance of themselves and to the maintenance of the others.

Evolution

(1) Evolutionary change in living systems is the result of that aspect of their circular organization which secures the maintenance of their basic circularity, allowing in each reproductive step for changes in the way this circularity is maintained. Reproduction and evolution are not essential for the living organization, but they have been essential for the historical transformation of the cognitive domains of the living systems on earth.

(2) For a change to occur in the domain of interactions of a unit of interactions without its losing its identity with respect to the observer it must suffer an internal change. Conversely, if an internal change occurs in a unit of interactions, without its losing its identity, its domain of interactions changes. A living system suffers an internal change without loss of identity if the predictions brought forth by the internal change are predictions which do not interfere with its fundamental circular organization. A system changes only if its domain of interactions changes.

(3) After reproduction the new unit of interactions has the same domain of interactions as the parental one only if it has the same organization. Conversely, the new unit of interactions has a different domain of interactions only if its organization is different, and hence, implies different predictions about the niche.

(4) Predictions about the niche are inferences about classes of interactions. Consequently, particular interactions which are indistinguishable for an organism may be different for an observer if he has a different cognitive domain and can describe them as different elements of a class defined by the conduct of the organism. The same applies to interactions that are identical for the organism but different for (have different effects) its different internal parts. Such interactions may result in different modifications of the internal states of the organism and, hence, determine different paths of change in its domain of interactions without loss of identity. These changes may bring about the production of offspring having domains of interactions different from the parental ones. If this is the case and a new system thus produced predicts a niche that cannot be actualized, it disintegrates; otherwise it maintains its identity and a new cycle begins.

(5) What changes from generation to generation in the evolution of living systems are those aspects of their organization which are subservient to the maintenance of their basic circularity but do not determine it, and which allow them to retain their identity through interactions; that is, what changes is the way in which the basic circularity is maintained, and not this basic circularity in itself. The manner in which a living system is compounded as a unit of interactions, whether by a single basic unit, or through the aggregation of numerous such units (themselves living systems) that together constitute a larger one (multicellular organisms), or still through the aggregation of their compound units that form self-referring systems of even higher order (insect societies, nations) is of no significance; what evolves is always a unit of interactions defined by the way in which it maintains its identity. The evolution of the living systems is the evolution of the niches of the units of interactions defined by their self-referring circular organization, hence, the evolution of the cognitive domains.

The Cognitive Process

(1) A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself, and the process of cognition is the actual (inductive) acting or behaving in this domain. *Living systems are cognitive systems, and living as a process is a process of cognition.* This statement is valid for all organisms, with and without a nervous system.

(2) If a living system enters into a cognitive interaction, its internal state is changed in a manner relevant to its maintenance, and it enters into a new interaction without loss of its identity. In an organism without a nervous system (or its functional equivalent) its interactions are of a chemical or physical nature (a molecule is absorbed and an enzymatic process is initiated; a photon is captured and a step in photosynthesis is carried out). For such an organism the relations holding between the physical events remain outside its domain of interactions. The nervous system enlarges the domain of interactions of the organism by making its internal states also modifiable in a relevant manner by "pure relations", not only by physical events; the observer sees that the sensors of an animal (say, a cat) are modified by light, and that the animal (the cat) is modified by a visible entity (say, a bird). The sensors change through physical interactions: the absorption of light quanta; the animal is modified through its interactions with the relations that hold between the activated sensors that absorbed the light quanta at the sensory surface. *The nervous system expands the cognitive domain of the living system by making possible interactions with "pure relations"; it does not create cognition.*

(3) Although the nervous system expands the domain of interactions of the organism by bringing into this domain interactions with "pure relations", the function of the nervous system is subservient to the necessary circularity of the living organization.

(4) The nervous system, by expanding the domain of interactions of the organism, has transformed the unit of interactions and has subjected acting and interacting in the domain of "pure relations" to the process of evolution. As a consequence, there are organisms that include as a subset of their possible interactions, interactions with their own internal states (as states resulting from external and internal interactions) as if they were independent entities, generating the apparent paradox of including their cognitive domain within their cognitive domain. In us this paradox is resolved by what we call "abstract thinking", another expansion of the cognitive domain.

(5) Furthermore, the expansion of the cognitive domain into the domain of "pure relations" by means of a nervous system allows for non-physical interactions between organisms such that the interacting organisms orient each other toward interactions within their respective cognitive domains. Herein lies the basis for communication: the orienting behavior becomes a representation of the interactions toward which it orients, and a unit of interactions in its own terms. But this very process generates another apparent paradox: there are organisms that generate representations of their *own* interactions by specifying entities with which they interact as if they belonged to an independent domain, while as representations they only map their own interactions. In us this paradox is resolved simultaneously in two ways:

(*a*) We become *observers* through recursively generating representations of our interactions, and by interacting with several representations simultaneously we generate relations with the representations of which we can then interact and repeat this process recursively, thus remaining in a domain of interactions always larger than that of the representations.

(*b*) We become *self-conscious* through self-observation; by making descriptions of ourselves (representations), and by interacting with our descriptions we can describe ourselves describing ourselves, in an endless recursive process.

IV. Cognitive Function in Particular

Nerve Cells

(1) The neuron is the anatomical unit of the nervous system because it is a cell, and as such it is an independent integrated self-referring metabolic and genetic unit (a living system indeed).

(2) Anatomically and functionally a neuron is formed by a collector area (dendrites, and in some cases, also the cell body and part of the axon) united via a distributive element (the axon, and in some cases, also the cell body and main dendrites), capable of conducting propagated spikes to an effector area formed by the terminal branching of the axon. The functional state of the collector area depends on both its internal state (reference state) and on the state of activity of the effector areas synapsing on it. Correspondingly, the state of activity of the effector area depends on both the train of impulses generated at the corresponding collector area and on the pre-synaptic and non-synaptic interactions with distributive elements and other effector areas that may take place in the neuropil and in the immediate vicinity of the next collector areas. This is true even in the case of amacrine cells, in which the collector and effector areas may be intermingled. The distributive element determines where the effector exerts its influence.

(3) Whether one or two branches of a bifurcating axon are invaded by a nerve impulse propagating along it depends on their relative diameter and on the state of polarization of their membranes at their origin in the bifurcation zone. As a result, the pattern of effector activity, that is, the pattern of branch invasion which a train of impulses determines in the branches of the distribution element and effector area of a neuron, depends on the spike internal distribution of the train of impulses, which determines the time that the axonal membrane at the branching zone has for recovery before the arrival of the next spike, and (ii) on the non synaptic influences which, in the form of local water and ion movements caused by the electric activity of neighboring elements, may produce diameter and polarization changes at the branching zones, and thus modify the invisibility of the branches by the arriving spikes.

(4) At any moment the state of activity of a nerve cell, as represented by the pattern of impulses traveling along its distributive element, is a function of the spatio-temporal configuration of its input, as determined by the relative activity holding between the afferent neurons, that modulates the reference state proper of the collector area. It is known that in many neurons the recurrence of a given afferent spatio-temporal configuration results in the recurrence of the same state of activity, independently of the way in which such a spatio-temporal configuration is generated [Cf. Maturana and Frenk, 1963; Morrell, 1967]. [This is so in the understanding that two states of activity in a given cell are the "same" (equivalent) if they belong to the same class, as defined by the pattern of impulses that they generate, and not because they are a one-to-one mapping of each other.] Also, the spatio-temporal configuration of the input to a neuron that causes in it the recurrence of a given state of activity is a class of afferent influences defined by a pattern in the relations holding between the active afferents and the collector; a given class of responses is elicited by a given class of afferent influences.

(5) For every nerve cell, at any moment, its transfer function at its collector area is a well-defined deterministic process [Cf. Segundo and Perkel, 1969]. Many neurons have several transfer functions, and different classes of afferent influences change their activity differently, causing them to generate different classes of activity in their effector areas. Because every nerve cell participates in the generation of the spatio-temporal configuration of afferent influences on the other nerve cells, all their states of activity must be considered as significant for their next states of activity. Thus there are two aspects to consider with respect to the activity of any given neuron: its genesis, which must be considered in reference to the neuron itself and to the afferents to it; (ii) its participation in the generation of activity in other neurons for which it is an afferent influence, which must be considered in reference to those other neurons. In both cases the interactions between the neurons involved are strictly deterministic, although what is cause in one is not necessarily cause in another.

(6) The nerve impulses that travel along the distributive element originate at the point where this element emerges from the collector area. Each nerve impulse is the result of the state of excitation of the collector area at a given moment (as determined by the spatio-temporal configuration of the afferent excitatory and inhibitory influences acting upon it, and on its own internal generating mechanisms, if any) that spreads reaching a given threshold at the point of emergence of the distributor. Excitatory and inhibitory influences, however, do not superimpose linearly; their relative participation in determining the production of nerve impulses, and hence, the state of activity of the neuron, depends on their relative spatial distribution on the collector area. Inhibition works by shunting off the spreading excitatory processes; as a result the relative contributions of a point of excitation and a point of inhibition in the generation of a nerve impulse depend on where, on the collector, they stand with respect to each other and with respect to the point of emergence of the distributive element. Excitation and inhibition must be seen as integral parts in the definition of the spatio-temporal configuration of afferent influences, not as independent processes. The shape of the collector area (its geometry) determines the class or classes of spatio-temporal configurations of afferent influences to which the cell responds.

(7) The neuropil is the site where the distributive elements and effector areas of many different neurons intermingle with each other and with the collector areas of the post-synaptic cells. Here non-synaptic interactions take place between neighboring elements which may cause in each other, as a result of the local movements of water and ions produced by their independent electrical activity, changes in diameter and polarization at their branching points. Depending on the time constant of these local changes, and on the capacity of the axons to homeostatically maintain their diameter at the new values, the pattern of branch invasion produced in a given effector area by a given train of impulses may be modified in a more or less permanent manner by these non-synaptic interactions. Something singular may happen during synaptic concomitances at the collector areas if synapses also affect each other non-synaptically, due to their spatial contiguity, causing each other more or less permanent changes in size (increase or decrease) and polarization (with the corresponding changes in effectiveness) as a result of their independent electrical activities. Thus, the neuropil may have to be seen as constituting a plastic system through which acquired self-addressing states of activity attain their functional significance as they become specified by the non-synaptic and synaptic concomitances generated by the interactions of the organism. It is not the repetition of the same state of activity which can cause neuronal changes of behavioral significance subordinated to the evolving domain of interactions of an organism, but rather it is the occurrence of local concomitant states of activity produced by seemingly unrelated interactions which can cause such subordinated changes in the reactive capacity of neurons.

(8) It follows that one should expect in a significant number of neurons, which may vary in different classes of animals according to the organization of their different neuropils, a continuous change in their transfer functions (from collector to effector area), or in the circumstances under which they are activated, as a result of the past history of the organism. However, for the understanding of the functional organization of the nervous system it is necessary to consider that nerve cells respond at any moment with definite transfer functions to classes of afferent spatio-temporal configurations in their input, generating definite states of effector activity, and not to particular afferent states. Furthermore:

(*a*) Any interaction is represented in the nervous system by the sequence of states of relative neuronal activity leading to the conduct which it generates; this conduct should be repeatable to the extent that the interaction (sequence of states of relative activity) is reproducible, that is, as long as the historical transformation of the nervous system (learning) does not make it impossible.

(*b*) The nervous system always functions in the present, and it can only be understood as a system functioning in the present. The present is the time interval necessary for an interaction to take place; past, future and time exist only for the observer. Although many nerve cells may change continuously, their mode of operation and their past history can explain to the observer how their present mode of operation was reached, but not how it is realized now, or what their present participation in the determination of behavior is.

(*c*) Any behavior is defined through a sequence of states in the receptor surfaces (external and internal) that satisfy its direct or indirect subordination to the maintenance of the basic circularity of the living system. Since the nervous system is continuously changing through experience, what occurs when the observer sees a given behavior reenacted is a sequence of interactions that satisfy this subordination independently of the neuronal process which generated them. The more complex the domain of interactions of an organism, the more indirect is this subordination (an adequate mode of behavior subordinated to another), but not the less strict.

(*d*) An organism is a unit to the extent that its conduct results in the maintenance of its basic circularity (and hence identity), and two modes of conduct are equivalent if they satisfy the same class of requirements for this maintenance. For this reason an organism, as a self-regulated homeostatic organization, does not require a constant behavior in its deterministic component elements (in this case, neurons) if their changes become specified through the generation of conduct, and sameness of conduct is defined with respect to an observer or a function that must be satisfied.

Thus although at any moment every neuron functions deterministically with a definite transfer function, and generates a definite pattern of activity in its effector area, the transfer functions and the patterns of effector activity in many of them may change from one moment to another and the organism still will give rise to what the observer would call “the same behavior”. The converse is also the case, and through what the observer would call “different behaviors” the organism may satisfy its subordination to the same aspect of the maintenance of its basic circularity.

(9) From these notions it is apparent that the neuron cannot be considered as the functional unit of the nervous system; no neuron can have a fixed functional role in the generation of conduct if it must be continuously changing its participation in it. For the same reason a fixed collection of cells also cannot be considered as a functional unit of the nervous system. Only conduct itself can be considered as the functional unit of the nervous system.

(10) If nerve cells respond to classes of afferent configurations and not to particular afferent states, they must necessarily treat as equivalent particular afferent configurations that arise through interactions which for the observer are otherwise unrelated.

Architecture

(1) In any given nervous system the great majority (and perhaps the totality) of its neurons can be assigned to well-defined morphological classes, each characterized by a given pattern of distribution of the collector and effector areas of its elements. As a result, the elements of the same class hold similar relations with each other and with other classes of neurons; the shapes of the nerve cells (collector area, distributive element, and effector area) specify their connectivity. These shapes are genetically determined and have been attained through evolution; the whole architecture of the brain is genetically determined and has been attained through evolution. The following implications are significant for the understanding of the nervous system:

(*a*) There is a necessary genetic variability in the shape of nerve cells as well as a variability that results from interactions of the organism with independent events during its development. The functional organization of the nervous system must be such as to tolerate this double variability.

(*b*) Due to the genetic and somatic variability no two nervous systems of animals of the same species (particularly if they have many cells) are identical, and they resemble each other only to the extent that they are organized according to the same general pattern. It is the organization defining the class, and not any particular connectivity, which determines the mode of functioning of any given kind of nervous system.

(2) The shapes of nerve cells and their packing are such that there is in general a great overlapping in the collector and effector areas of neurons of the same class. Also, the spatial distribution and the interconnections between different classes of neurons is such that any particular part of the nervous system is in general simultaneously related to many other parts; the parts interconnected, however, differ in different species, and as a result these have different interacting capabilities.

(3) The organism ends at the boundary that its self-referring organization defines in the maintenance of its identity. At this boundary there are sensors (the sensory surfaces) through which the organism interacts in the domain of relations and effectors (the effector surfaces) through which the nervous system modifies the posture of the organism in this domain. The sensory surfaces are in general constituted by collections of sensory elements (cells) with similar, though not identical, properties (classes of properties) which in their mode of interaction with the nervous system share the characteristics of neurons in general. As a result whenever the organism enters into an interaction within the physical domain of interactions of the sensors, as a rule not one but many sensory elements are excited. The effectors are also multifarious and differ from each other in the manner in which they change the receptor surfaces of the organism during the interactions: action always leads to a change in the state of activity of the receptor surfaces.

(4) The architectural organization of the nervous system is subordinated to the order of the sensory and effector surfaces. This subordination has two aspects: the receptor and effector surfaces project to the central nervous system retaining their proper topological relations; (ii) the topological relations specified by the receptor and effector surfaces in their projection constitute the basis for all the architectural order of the central nervous system. As a consequence, this architectural organization constitutes a system that interconnects these surfaces in a manner that permits the occurrence of certain concomitances of activity and not others in the different neuropils, and thus secures well-defined functional relations between these surfaces, specifying how they modify each other. *Truism*: the nervous system cannot give rise to a conduct that implies the concomitance of states of activity for which there is no anatomical basis. As a result of its architectural organization every point in the central nervous system constitutes an anatomical localization with respect to the possibility of establishing certain functional concomitances. From this it follows that any localized lesion in the nervous system must necessarily interfere in a localized manner with the possibility of synthesizing some specific conduct (state of neural activity).

Function

(1) The way the nervous system functions is bound to its anatomical organization. The functioning of the nervous system has two aspects: one which refers to the domain of interactions defined by the nervous system (relations in general); the other which refers to the particular part of that domain used by a given species (particular classes of relations): Different species interact with different sets of relations (have different niches).

(2) The nervous system only interacts with relations. However, since the functioning of the nervous system is anatomy bound, these interactions are necessarily mediated by physical interactions; for an animal to discriminate objects visually the receptors in its eyes must absorb light quanta and be activated; yet, the objects that the animal sees are determined not by the quantity of light absorbed, but by the relations holding between the receptor-induced states of activity within the retina, in a manner determined by the connectivity of its various types of cells. Therefore, the nervous system defines through the relative weights of the patterns of interactions of its various components, both innate and acquired through experience, which relations will modify it at any given interaction [Cf. Maturana, 1965]. Or, in general, the organization and structure of a living system (its nervous system included) define in it a "point of view", a bias or posture from the perspective of which it interacts determining at any instant the possible relations accessible to its nervous system. Moreover, since the domain of interactions of the organism is defined by its structure, and since this structure implies a prediction of a niche, the relations with which the nervous system interacts are defined by this prediction and arise in the domain of interactions of the organism.

(3) Due to the properties of neurons, and due to the architecture of the nervous system, interactions within the nervous system give rise to activity in aggregates of cells. Also, for the same reasons, any given cell may assume the same state of activity under many different circumstances of interactions of the organism. Thus, under no circumstances is it possible to associate the activity of any particular cell with any particular interaction of the living system. When any particular interaction takes place at the level of the sensors, the relations accessible to the nervous system are given at this level in a certain state of relative activity of the sensing elements and not in the state of activity of any particular one [Cf. Maturana, Uribe, and Frenk, 1968]. At the same time, although operational localizations can be established in the nervous system [Cf. Geschwind, 1965], these localizations are to be viewed in terms of areas where certain modalities of interactions converge, and not as localizations of faculties or functions. As a result of the mode of organization of the nervous system that I have emphasized, localized lesions should produce discrete functional deficiencies by impeding the convergence of activities necessary for the synthesis of a particular conduct (state of activity). The anatomical and functional organization of the nervous system secures the synthesis of behavior, not a representation of the world; hence, it is only with the synthesis of behavior that one cam interfere. The nervous system is localized in terms of the organism's surfaces of interaction but not in terms of representations of the interactions it can generate.

Representation

(1) The fundamental anatomical and functional organization of the nervous system is basically uniform; the same functions and operations (excitation, inhibition, lateral interaction, recursive inhibition, etc.) are performed in its various parts, although in different contexts, and integrated in different manners. A partial destruction of the nervous system does not alter this basic uniformity, and, although the parts left untouched cannot do the same things that the whole did, they appear in their mode of operations identical to the untouched whole. To the observer, once the boundary of the sensors is passed, the nervous system, as a mode of organization, seems to begin at any arbitrary point that he may choose to consider; the answer to the question, *"What is the input to the nervous system?"* depends entirely on the chosen point of observation. This basic uniformity of organization can best be expressed by saying: all that is accessible to the nervous system at any point are states of relative activity holding between nerve cells, and all that to which any given state of relative activity can give rise are further states of relative activity in other nerve cells by *forming* those states of relative activity to which they respond. The effector neurons are not an exception to this since they, by causing an effector activity and generating an interaction, cause a change in the state of relative activity of the receptor elements at the receptor surfaces. This has a fundamental consequence: *unless they imply their origin (through concomitant events, their locations, or through the consequences of the new interactions which they originate) there is no possible distinction between internally and externally generated states of nervous activity.*

(2) The relations with which the nervous system interacts are relations given by the physical interactions of the organism, and, hence, depend on its anatomical organization. For the observer the organism interacts with a given entity that he can describe in his cognitive domain. Yet, what modifies the nervous system of the observed organism are the changes in activity of the nerve cells associated with the sensing elements, changes that henceforth constitute an embodiment of the relations that arise through the interaction. These relations are not those that the observer can describe as holding between component properties of the entity in his cognitive domain; they are relations generated in the interaction itself and depend on both the structural organization of the organism and the properties of the universe that match the domain of interactions that this organization defines. Whenever such a relation recurs at the sensory surface, the same state of relative activity arises among the neurons in contact with the sensing elements. Two interactions that produce the same state of relative activity are identical for the nervous system, no matter how different they may be in the cognitive domain of the observer.

(3) Every relation is embodied in a state of relative activity of nerve cells, but also every state of relative activity acts to modify the relative activity of other nerve cells. Thus, relations through their embodiment in states of relative activity become units of internal interactions and generate additional relations, again embodied in states of relative activity which in turn may also become units of internal interactions, and so on, recursively.

(4) If an external interaction takes place, the state of activity of the nervous system is modified by the change in relative activity of the neurons, which in close association with the sensing elements embody the relations given in the interaction. Accordingly, that which the different states of activity thus generated can be said to represent are the relations given at the sensory surfaces by the interaction of the organism, and not an independent medium, least of all a description of an environment necessarily made in terms of entities that lie exclusively in the cognitive domain of the observer.

If an internal interaction takes place, the state of activity of the nervous system is modified by one of its own substates of relative activity that embodies one set of relations. However, that which the new state of relative activity represents is the relations given in the internal interaction and not an independent set of relations or their description, in terms of some kind of entities, such as thoughts, that lie only within the cognitive domain of the observer.

(5) The classes of relations that can be embodied have been defined through the evolution of the general structural organization of the organism, and particularly, of the sensors, that has defined the classes of relation that are accessible to the nervous system; and (ii) through the evolution of a particular organization of the nervous system that defines for each class of animals (species) the specific mode of how these relations generate a behavior relevant to their maintenance.

(6) For any class of relations, the particular relations given as a result of a present interaction are embodied in a set of particular states of activity occurring in the present. This is the case independently of the history of the system. However, the relevance of the behavior generated by those states of activity for the maintenance of the living system is a function of history, and may depend both on the evolutionary history of the species and on the past experiences of the organism as an individual. In the first case I would speak of instinctive behavior, and in the second case of learned behavior. The description of learning in terms of past and present behavior lies in the cognitive domain of the observer; the organism always behaves in the present. The observer, however, by interacting with descriptions that he generates can treat interactions which do not recur as if they were in the present. This apparent paradox is resolved by generating the notion of time, past, present, and future, as a new expansion of the domain of interactions. Whenever an interaction takes place which is an element of a class experienced for the first time, it is sufficient that the state of activity which it generates be followed by the suppression of a peculiar concomitant internal state of activity (that is apparent in what the observer calls the emotion of anxiety or uncertainty) for the organism to experience the recurrence of an interaction of the same class, which takes place without such a concomitant state, as not new (in the sense that it can generate an established conduct as is apparent in the absence of anxiety) and, hence *known*. Any experience without anxiety can be described as known, and thus serve as a basis for the functional notion of time.

(7) There is no difference in the nature of the embodiment of the relations generated through either external or internal interactions; both are sets of states of neuronal activity that can be said to represent the interactions. In a nervous system capable of interacting with some of its own internal states as if they were independent entities, there are two consequences:

- (*a*) The distinction between externally and internally generated inter-actions can only arise through a concomitance of events that indicates the source (sensory surface or not) of the state of activity caused by them, or through the outcome of new interactions which they initiate. A nervous system that is capable of treating its internally generated states of activity as different from its externally generated states, that is, of distinguishing their origin, is capable of abstract thinking.
- (*b*) The nervous system can interact with the representations of its interactions (and hence, of the organism) in an endless recursive manner.

(8) Four comments:

- (*a*) Notions such as embodiment of representation express the correspondence that the observer sees between relations, or sets of relations, and different states of activity of the nervous system, and, as such, lie in his cognitive domain. They describe the functional organization of the nervous system in the cognitive domain of the observer, and point to the ability of the nervous system to treat some of its own states as independent entities with which it can interact, but they do not characterize the nature of the functional subordination of the nervous system to its own states. This subordination is that of a functionally closed, state determined, ultrastable system, modulated by interactions [Cf. Ashby, 1960].

(*b*) The closed nature of the functional organization of the nervous system is a consequence of the self-referring domain of interactions of the living organization; every change of state of the organism must bring forth another change of state, and so on, recursively, always maintaining its basic circularity. Anatomically and functionally the nervous system is organized to maintain constant certain relations between the receptor and effector surfaces of the organism, which can only in that way retain its identity as it moves through its domain of interactions. Thus all conduct, as controlled through the nervous system, must (necessarily, due to the latter's architectural organization) lead through changes in the effector surfaces to specific changes in the receptor surfaces that in turn must generate changes in the effector surfaces that again ... and so on, recursively. Conduct is thus a functional continuum that gives unity to the life of the organism through its transformations in the latter's self-referring domain of interactions. The evolutionary subordination of the architecture of the central nervous system to the topology of the sensory and effector surfaces appears as an obvious necessity.

(*c*) The ability of the nervous system to interact with its own internal states, as if these were independent entities, enters these internal states as modulating factors in the continuum of behavior. This requires an anatomical and functional internal reflection so that the internal organization of the nervous system can project itself onto itself retaining its morphological and functional topological relations, as the receptor and effector surfaces do in their own projection. This seems to have acquired an autonomous evolutionary course with the development of the neo-cortex in mammals, which arises as a center of internal anatomical projection, and whose evolution in this line is accompanied by an increased dependency of the organism on its own states of nervous activity.

(*d*) The closed nature of the functional organization of the nervous system (open only to modulations through interactions) is particularly evident in systematic observations that explicitly show the subordination of conduct to the correlation of activity between the receptor and effector surfaces [Cf. Held and Hein, 1963] . Experiments such as those of Held and Hein show that a cat does not learn to control its environment visually if raised in darkness and carried about only passively, by another cat, when under light. From these observations, it is apparent that the "visual handling" of an environment is no handling of an environment, but the establishment of a set of correlations between effector (muscular) and receptor (proprioceptor and visual) surfaces, such that a particular state in the receptor surfaces may cause a particular state in the effector surfaces that brings forth a new state in the receptor surfaces ... and so on. Behavior is like an instrumental flight in which the effectors (engines, flaps, etc.) vary their state to maintain constant, or to change, the readings of the sensing instruments according to a specified sequence of variations, which either is fixed (specified through evolution) or can be varied during the flight as a result of the state of the flight (learning). The same is apparent in the experiments with innate perception of depth [Cf. Gibson, 1950] that show that there is an innate system of correlations between certain states of the receptor and effector surfaces. The reference to a pre-established perception of depth is a description that lies in the cognitive domain of the observer, and as such only alludes to relations, through the observer, between elements that lie in his cognitive domain; but, as a process, this innate behavior obviously corresponds to one of optimization of sensory states.

Description

(1) A living system, due to its circular organization, is an inductive system and functions always in a predictive manner: what happened once will occur again. Its organization, (genetic and otherwise) is conservative and repeats only that which works. For this same reason living systems are historical systems; the relevance of a given conduct or mode of behavior is always determined in the past. The goal state (in the language of the observer) that controls the development of an organism is, except for mutations, determined by the genome of the parent organism. The same is true for behavior in general; the present state is always specified from the previous state that restricts the field of possible modulations by independent concomitances. If a given state of relative activity in the nerve cells originates a given behavior, a recurrence of the "same state" of relative activity should give rise to the "same behavior" no matter how the recurrence originates. The relevance of such a behavior is determined by the significance that it has for the maintenance of the living organization, and it is in relation to this relevance that any subsequent behaviors are the same. With the expansion of the cognitive domain during evolution, the types of behavior have changed as well as how their relevance is implemented; different kinds of behavior are relevant to the maintenance of the basic circularity of the living organization through different domains of interactions, and hence, different fields of causal relations.

(2) Since the niche of an organism is the set of all classes of interactions into which it can enter, and the observer beholds the organism in an environment that he defines, for him any one of the organism's behaviors appears as an actualization of the niche, that is, as a first order description of the environment (henceforth denoted by a capital D: Description) This Description, however, is a description in terms of behavior (interactions) of the observed organism, not of representations of environmental states, and the relation between behavior and niche lies exclusively in the cognitive domain of the observer.

(3) An organism can modify the behavior of another organism in two basic ways:

(*a*) By interaction with it in a manner that directs both organisms toward each other in such a way that the ensuing behavior of each of them depends strictly on the following behavior of the other, e.g.: courtship and fight. A chain of interlocked behavior can thus be generated by the two organisms.

(*b*) By orienting the behavior of the other organism to some part of its domain of interactions different from the present interaction, but comparable to the orientation of that of the orienting organism. This can take place only if the domains of interactions of the two organisms are widely coincident; in this case no interlocked chain of behavior is elicited because the subsequent conduct of the two organisms depends on the outcome of independent, although parallel, interactions.

In the first case it can be said that the two organisms interact; in the second case that they communicate. The second case is the basis for any linguistic behavior; the first organism generates (as is apparent for the observer) a Description of its niche that, in addition to its own significance as a behavior (within the cognitive domain of the first organism, and independently of it), orients the second organism within its cognitive domain to an interaction from which ensues a conduct parallel to that of the first one, but unrelated to it. The conduct thus elicited by the orienting behavior is denotative: it points to a feature of the environment that the second organism encounters in its niche and Describes by the appropriate conduct, and that he can treat as an independent entity. The orienting behavior is, for the observer, a second order description (henceforth denoted by italics: *description*) that represents that which he considers it to denote. By contrast, the orienting behavior of the first organism is connotative for the second one, and implies for it an interaction within its cognitive domain which, if actualized, originates a behavior that Describes a particular aspect of its niche; that which an orienting behavior connotes is a function of the cognitive domain of the orientee, not the orienter.

(4) In an orienting interaction the behavior of the first organism, as a communicative *description* causes in the nervous system of the second one a specific state of activity; this state of activity embodies the relations generated in the interaction and represents the behavior of the second organism (Description of its niche) connoted by the orienting behavior of the first one. This representation, as a state of neuronal activity, can in principle be treated by the nervous system as a unit of interactions, and the second organism, if capable of doing so, can thus interact with representations of its own Descriptions of its niche as if these were independent entities. This generates yet another domain of interactions (and hence, another dimension in the cognitive domain), the domain of interactions with representations of behavior (interactions), orienting interactions included, as if these representations were independent entities within the niche: the *linguistic* domain.

(5) If an organism can generate a communicative *description* and then interact with its own state of activity that represents this *description*, generating another such *description* that orients towards this representation . . . , the process can in principle be carried on in a potentially infinite recursive manner, and the organism becomes an *observer*: it generates discourse as a domain of interactions with representations of communicative *descriptions* (orienting behaviors).

Furthermore: if such an observer through orienting behavior can orient himself towards himself, and then generate communicative *descriptions* that orient him towards his *description* of this self-orientation, he can, by doing so recursively, *describe* himself *describing* himself … endlessly. Thus discourse through communicative *description* originates the apparent paradox of self-description: *self-consciousness*, a new domain of interactions.

(6) A nervous system capable of recursively interacting with its own states as if these were independent entities can do so regardless of how these states are generated, and in principle can repeat these recursive interactions endlessly. Its only limitation lies in the need that the progressive transformation of its actual and potential behavior, which in such a system is a necessary concomitant to behavior itself, be directly or indirectly subservient to the basic circularity of the living organization. The linguistic domain, the observer and self-consciousness are each possible because they result as different domains of interactions of the nervous system with its own states in circumstances in which these states represent different modalities of interactions of the organism.

Thinking

(1) I consider that in a state-determined nervous system, the neurophysiological process that consist in its interacting with some of its own internal states as if these were independent entities corresponds to what we call thinking. Such internal states of nervous activity, otherwise similar to other states of nervous activity that participate in the specification of behavior, as in reflex mechanisms, cause conduct by determining specific changes of state in the nervous system. Thinking thus conceived, and reflex mechanisms, are both neurophysiological processes through which behavior emerges in a deterministic manner; they differ, however, in that in a reflex action we can, in our *description* trace a chain of nervous interactions that begins with a specific state of activity at the sensory surfaces; while in thinking, the chain of nervous interactions that leads to a given conduct (change in the effector surfaces) begins with a distinguishable state of activity of the nervous system itself, whichever way it may have originated. Accordingly, thinking is a mode of operation of the nervous system that reflects functionally its internal anatomical projection (possibly multiply) onto itself.

(2) The process of thinking as characterized above is necessarily independent of language. That this is so even for what we call "abstract thinking" in man is apparent from the observations of humans with split brains [Cf. Gazzaniga, Bogen and Sperry, 1965]. These observations show that the inability of the non-speaking hemisphere to speak does not preclude in it operations that the observer would call abstract thinking, and that the lack of language only implies that it cannot generate discourse. When we talk about concepts or ideas we *describe* our interactions with representations of our *descriptions*, and we think through our operation in the linguistic domain. The difficulty arises from our considering thinking through our *description* of it in terms or concepts as if it were something peculiar to man, and in some way isomorphic with the notions embodied in the *descriptions*, instead of attending to the functional process that makes these *descriptions* possible.

Natural Language

(1) Linguistic behavior is orienting behavior; it orients the orientee within his cognitive domain to interactions that are independent of the nature of the orienting interactions themselves. To the extent that the part of its cognitive domain toward which the orientee is thus oriented is not genetically determined and becomes specified through interactions, one organism can in principle orient another to any part of its cognitive domain by means of arbitrary modes of conduct also specified through interactions. However, only if the domains of interactions of the two organisms are to some extent comparable, are such consensual orienting interactions possible and are the two organisms able to develop some conventional, but specific, system of communicative *descriptions* to orient each other to cooperative classes of interactions that are relevant for both.

(2) The understanding of the evolutionary origin of natural languages requires the recognition in them of a basic biological function which, properly selected, could originate them. So far this understanding has been impossible because language has been considered as a denotative symbolic system for the transmission of information. In fact, if such were the biological function of language, its evolutionary origin would demand the pre-existence of the function of denotation as necessary to develop the symbolic system for the transmission of information, but this function is the very one whose evolutionary origin should be explained. Conversely, if it is recognized that language is connotative and not denotative and that its function is to orient the orientee within his cognitive domain, and not to point to independent entities, it becomes apparent that learned orienting interactions embody a function of non-linguistic origin that, under a selective pressure for recursive application, can originate through evolution the system of cooperative consensual interactions between organisms that is natural language. Particular orienting interactions, like any other learned conduct, arise from the substitution of one type of interaction for another as a cause for a given behavior, and their origin as a function of the general learning capacity of the nervous system is completely independent of the complexities of the system of cooperative interactions to which their recursive application gives rise. Widespread among animals other than man-orienting interactions are particularly evident in primates, in which it is easy to see how the audible and visible behavior of one individual orients others within their respective cognitive domains [Cf. Jay, 1968], and in dolphins which seem to have evolved a rich and efficient system of auditive cooperative interactions [Cf. Lilly, 1967]. In accordance with all this I maintain that learned orienting interactions, coupled with some mode of behavior that allowed for an independent recursive expansion of the domain of interactions of the organism, such as social life [Cf. Gardner and Gardner, 1969] and/or tool making and use, must have offered a selective basis for the evolution of the orienting behavior that in hominids led to our present-day languages.

(3) Behavior (function) depends on the anatomical organization (structure) of the living system, hence anatomy and conduct cannot legitimately be separated and the evolution of behavior is the evolution of anatomy and vice versa; anatomy provides the basis for behavior and hence for its variability; behavior provides the ground for the action of natural selection and hence for the historical anatomical transformations of the organism. Structure and function are, however, both relative to the perspective of interactions of the system and cannot be considered independently of the conditions that define it as a unit of interactions, for what is from one perspective a unit of interactions, from another may only be a component of a larger one, or may be several independent units. It is the dynamics of this process of individuation, as an historical process in which every state of a changing system can become a unit of interactions if the proper circumstances are given, what makes the evolution of living systems a deterministic process of necessarily increasing complication. Thus, in the evolution of language, natural selection, by acting upon orienting behavior as a function that if enhanced strongly increases the cooperation between social animals, has led to anatomical transformations which provide the basis for the increased complexity of the orienting conduct and the diversity of the interactions toward which man can be oriented in his cognitive domain. The complexity of the orienting conduct has increased through an increase in the complexity and variety of motor behavior, particularly through vocalization and tool making. The diversity of the interactions toward which man can be oriented has increased through a concomitant expansion of the internal projection of the brain onto itself, by means of new interconnections between different cortical areas (as compared with other primates), between cortical areas and subcortical nuclei [Cf. Geschwind, 1964], and possibly also between different cortical layers and cellular systems within the cortex itself.

(4) So long as language is considered to be denotative it will be necessary to look at it as a means for the transmission of information, as if something were transmitted from organism to organism, in a manner such that the domain of uncertainties of the "receiver" should be reduced according to the specifications of the "sender". However, when it is recognized that language is connotative and not denotative, and that its function is to orient the orientee within his cognitive domain without regard for the cognitive domain of the orienter, it becomes apparent that there is no transmission of information through language. It behooves the orientee, as a result of an independent internal operation upon his own state, to choose where to orient his cognitive domain; the choice is caused by the "message", but the orientation thus produced is independent of what the "message" represents for the orienter. In a strict sense then, there is no transfer of thought from the speaker to his interlocutor; the listener creates information by reducing his uncertainty through his interactions in his cognitive domain. Consensus arises only through cooperative interactions in which the resulting behavior of each organism becomes subservient to the maintenance of both. An observer beholding a communicative interaction between two organisms who have already developed a consensual linguistic domain, can describe the interaction as denotative; for him, a message (sign) appears as denoting the object which the conduct of the orientee *Describes* (specifies), and the conduct of the orientee appears determined by the message. However, because the outcome of the interaction is determined in the cognitive domain of the orientee regardless of the significance of the message in the cognitive domain of the orienter, the denotative function of the message lies only in the cognitive domain of the observer and not in the operative effectiveness of the communicative interaction. The cooperative conduct that may develop between the interacting organisms from these communicative interactions is a secondary process independent of their operative effectiveness. If it appears acceptable to talk about transmission of information in ordinary parlance, this is so because the speaker tacitly assumes the listener to be identical with him and hence as having the same cognitive domain which he has (which never is the case), marveling when a "misunderstanding" arises. Such an approach is valid, for man created systems of communication where the identity of sender and receiver is implicitly or explicitly specified by the designer, and a message, unless disturbed during transmission, necessarily selects at the reception the same set of states that it represents at the emission, but not for natural languages.

(5) It behooves the interlocutor to choose where to orient in his cognitive domain as a result of a linguistic interaction. Since the mechanism of choice, as in every neuronal process, is state-dependent, the state of activity from which the choice (new state of neuronal activity) must arise restricts the possible choices and constitutes a reference background in the orientee. The same is valid for the speaker; the state of activity from which his communicative *description* (linguistic utterance) arises constitutes the reference background that specifies his choice. All the interactions that independently specify the reference background of each interlocutor constitute the context in which a given linguistic interaction takes place. Every linguistic interaction is thus necessarily context-dependent, and this dependency is strictly deterministic for both orienter and orientee, notwithstanding the different backgrounds of the two processes. It is only for the observer that there is any ambiguity in a linguistic interaction that he observes; this is because he has no access to the context in which it occurs. The sentence, "They are flying planes," is unambiguous for both interlocutors, regardless of the subsequent behavior which it originates in each of them; for the observer, however, who wants to predict the course of the ensuing interactions, it is ambiguous.

(6) If one considers linguistic interactions as orienting interactions it is apparent that it is not possible to separate, functionally, semantics and syntax, however separable they may seem in their *description* by the observer. This is true for two reasons:

(*a*) A sequence of communicative *descriptions* (words in our case) must be expected to cause in the orientee a sequence of successive orientations in his cognitive domain, each arising from the state left by the previous one. "They are flying planes" clearly illustrates this; each successive word orients the listener to a particular interaction in his cognitive domain that is relevant in a particular manner (apparent in the conduct it generates) that depends on the previous orientation. The fact that it seems that the observer can more easily describe the word *are* (or any word) by referring to its grammatical and lexical functions, rather than by specifying the nature of the orientation that it causes (in terms of conduct or interactions), should not obscure the problem. The observer speaks, and any explanation of the word *are* that he may give lies in the descriptive domain, while the orientation caused by the word itself, as a change of state of the listener, is an internal interaction in *his* cognitive domain.

(*b*) An entire series of communicative *descriptions* can itself be a communicative *description*: the whole sequence once completed may orient the listener from the perspective of the state to which the sequence itself has led him. The limit to such complications lies exclusively in the capacity of the nervous system to discriminate between its own discriminable internal states, and to interact with them as if with independent entities.

(7) Linguistic behavior is an historical process of continuous orientation. As such, the new state in which the system finds itself after a linguistic interaction emerges from the linguistic behavior. The rules of syntax and generative grammar [Cf. Chomsky, 1968] refer to regularities that the observer sees in the linguistic behavior (as he *would* see in any behavior) which, arising from the functional organization of the system, specify the interactions that are possible at any given moment. Such rules, as rules, lie exclusively in the cognitive domain of the observer, in the realm of *descriptions*, because the transitions from state to state as internal processes in any system are unrelated to the nature of the interactions to which they give rise. Any correlation between different domains of interactions lies exclusively in the cognitive domain of the observer, as relations emerging from his simultaneous interactions with both.

(8) The coordinated states of neuronal activity which specify a conduct as a series of effector and receptor states whose significance arises in a consensual domain, does not differ in its neurophysiological generation from other coordinated states of neuronal activity which specify other conducts of innate or acquired significance (walking, flying, playing a musical instrument). Thus, however complex the motor and sensory coordinations of speech may be, the peculiarity of linguistic behavior does not lie in the complexity or nature of the series of effector and receptor states that constitute it, but in the relevance that such behavior acquires for the maintenance of the basic circularity of the interacting organisms through the development of the consensual domain of orienting interactions. Speaking, walking, or music-making do not differ in the nature of the coordinated neuronal processes which specify them but in the sub-domains of interactions in which they acquire their relevance.

(9) Orienting behavior in an organism with a nervous system capable of interacting recursively with its own states expands its cognitive domain by enabling it to interact recursively with *descriptions* of its interactions. As a result:

(*a*) Natural language has emerged as a new domain of interaction in which the organism is modified by its *descriptions* of its interactions, as they become embodied in states of activity of its nervous system, subjecting its evolution to its interactions in the domains of observation and self-consciousness.

(*b*) Natural language is necessarily generative because it results from the recursive application of the same operation (as a neurophysiological process) on the results of this application.

(*c*) New sequences of orienting interactions (new sentences) within the consensual domain are necessarily understandable by the interlocutor (orient him), because each one of their components has definite orienting functions as a member of the consensual domain that it contributes to define.

Memory and Learning

(1) Learning as a process consists in the transformation through experience of the behavior of an organism in a manner that is directly or indirectly subservient to the maintenance of its basic circularity. Due to the state determined organization of the living system in general, and of the nervous system in particular, this transformation is an historical process such that each mode of behavior constitutes the basis over which a new behavior develops, either through changes in the possible states that may arise in it as a result of an interaction, or through changes in the transition rules from state to state. The organism is thus in a continuous process of becoming that is specified through an endless sequence of interactions with independent entities that select its changes of state but do not specify them.

(2) Learning occurs in a manner such that, for the observer, the learned behavior of the organism appears justified from the past, through the incorporation of a representation of the environment that acts, modifying its present behavior by recall; notwithstanding this, the system itself functions in the present, and for it learning occurs as an atemporal process of transformation. An organism cannot determine in advance when to change and when not to change during its flow of experience, nor can it determine in advance which is the optimal functional state that it must reach; both the advantage of any particular behavior and the mode of behavior itself can only be determined *a posteriori*, as a result of the actual behaving of the organism subservient to the maintenance of its basic circularity.

(3) The learning nervous system is a deterministic system with a relativistic self-regulating organization that defines its domain of interactions in terms of the states of neuronal activity that it maintains constant, both internally and at its sensory surfaces, and that specifies these states at any moment through its functioning, and through the learning (historical transformation) itself. Consequently, it must be able to undergo a continuous transformation, both in the states it maintains constant, and in the way it attains them, so that every interaction in which new classes of concomitances occur effectively modifies it (learning curves) in one direction or the other. Since this transformation must occur as a continuous process of becoming without the previous specification of an end state, the final specification and optimization of a new behavior can only arise through the cumulative effect of many equally directed interactions, each of which selects, from the domain of structural changes possible to the nervous system in its structural dynamism, that which at that moment is congruent with its continued operation subservient to the basic circularity of the organism. Otherwise the organism disintegrates.

(4) The analysis of the nervous system made earlier indicated that the states of neuronal activity that arise in it through each interaction embody the relations given in the interaction, and not representations of the niche or the environment as the observer would describe them. This analysis also indicated that functionally such embodiments constitute changes in the reactivity of the nervous system, as a system closed on itself, to the modulating influences of further interactions. Consequently what the observer calls "recall" and "memory" cannot be a process through which the organism confronts each new experience with a stored representation of the niche before making a decision, but the expression of a modified system capable of synthesizing a new behavior relevant to its present state of activity.

(5) It is known that many neurons change their transfer functions as a result of the different concomitances of activity that occur in the neuropils of their collector and effector areas. Although it is not known what these changes are (development of new synapses or changes in their size, membrane changes, or changes in the pattern of spike invasion at the branching points of the axons), it can be expected from the relativistic organization of the nervous system that they should result in local morphological and functional changes that do not represent any particular interaction, but which permanently alter the reactivity of the system. This anatomical and functional transformation of the nervous system must necessarily be occurring continuously as changes that the cells are able to stabilize with a permanency that lasts until the next modification, which can occur in any direction with respect to the previous one, or that subside by themselves after a certain number of interactions, but which are being locally triggered and selected through the actual concomitances of activity taking place in the neuropil itself.

(6) All changes in the nervous system during learning must occur without interference with its continued functioning as a self-regulating system; the unity that the observer sees in a living system throughout its continuous transformation is a strictly functional one. Accordingly, what appears constant for the observer when he ascertains that the same behavior is reenacted on a different occasion, is a set of relations that he defines as characterizing it, regardless of any change in the neurophysiological process through which it is attained, or any other unconsidered aspect of the conduct itself. Learning, as a relation between successive different modes of conduct of an organism such that the present conduct appears as a transformation of a past conduct arising from the recall of a specifiable past event, lies in the cognitive domain of the observer as a description of *his* ordered experiences. Likewise, memory as an allusion to a representation in the learning organism of its past experiences, is also a description by the observer of his ordered interactions with the observed organism; memory as a storage of representations of the environment to be used on different occasions in recall does not exist as a neurophysiological function.

(7) It is sufficient for a system to change its state after an interaction in a manner such that whenever a similar interaction recurs some internally determined concomitant state does not recur, although the same overt behavior is reenacted for it to treat two otherwise equivalent interactions as different elements of the same class. Such a peculiar state could be described as representing the emotional connotation of uncertainty which, present whenever a class of interactions is experienced for the first time, is suppressed after such an experience; the absence of such a concomitant state would suffice henceforth to treat differently (as known) all recurrent interactions of the same class. I maintain that modifications of this sort in the reactivity of the nervous system constitute the basis for the unidirectional ordering of experiences in a living system through "recognition" without any storage of representations of the niche. First interactions that by error of the system are not accompanied by the above mentioned concomitant internal state (emotional connotation of uncertainty) would be treated as if known, as occurs in the *déjà vu*. Conversely, interference with the suppression of the concomitant state of activity corresponding to this emotional connotation would result in the treatment of any recurrent interaction as if new (loss of recent memory).

If such a system is capable of discourse, it will generate the temporal domain through the ascription of a unidirectional order to its experiences as they differ in their emotional connotations, and although it will continue to function in the present as an atemporal system, it will interact through its *descriptions* in the temporal domain. Past, present, and future, and time in general belong exclusively to the cognitive domain of the observer.

The Observer

Epistemological and Ontological Implications

(1) The cognitive domain is the entire domain of interactions of the organism. The cognitive domain can be enlarged if new modes of interactions are generated. Instruments enlarge our cognitive domain.

(2) The possibility of enlargement of the cognitive domain is unlimited; it is a historical process. Our brain, the brain of the observer, has specialized during evolution as an instrument for the discrimination of relations, both internally and externally generated relations, but relations given through and by interactions and embodied in the states of relative activity of its neurons. Furthermore, this occurs under circumstances in which the discriminations between states of relative activity—that for an observer represent the interactions of the organism, for the nervous system, that operate as a closed network—constitute only changes of relations of activity that arise between its components while it generates the internal and the sensory motor correlations that the states of the organism select. This has two aspects: one refers to the functional organization of the nerve cells which, with their responses, discriminate between different states of relative activity impinging upon them; the other refers to the ability of the nervous system, as a neuronal organization, to discriminate between its own states as these are distinguished and specified by the further states of activity that they generate. From this capacity of the nervous system to interact discriminately with its own states in a continuous process of self transformation, regardless of how these states are generated, behavior emerges as a continuum of self-referred functional transformation. We cannot say in absolute terms what constitutes an input to our nervous system (the nervous system of the observer), because every one of its states can be its input and can modify it as an interacting unit. We can say that every internal interaction changes us because it modifies our internal state, changing our posture or perspective (as a functional state) from which we enter into a new interaction. As a result new relations are necessarily created in each interaction and, embodied in new states of activity, we interact with them in a process that repeats itself as a historical and unlimited transformation.

(3) The observer generates a spoken *description* of his cognitive domain (which includes his interactions with and through instruments). Whatever *description* he makes, however, that *description* corresponds to a set of permitted states of relative activity in his nervous system embodying the relations given in his interactions. These permitted states of relative activity and those recursively generated by them are made possible by the anatomical and functional organization of the nervous system through its capacity to interact with its own states. The nervous system in turn has evolved as a system structurally and functionally subservient to the basic circularity of the living organization, and hence, embodies an inescapable logic: that logic which allows for a match between the organization of the living system and the interactions into which it can enter without losing its identity.

(4) The observer can *describe* a system that gives rise to a system that can *describe*, hence, to an observer. A spoken explanation is a paraphrase, a *description* of the synthesis of that which is to be explained; the observer explains the observer. A spoken explanation, however, lies in the domain of discourse. Only a full reproduction is a full explanation.

(5) The domain of discourse is a closed domain, and it is not possible to step outside of it through discourse. Because the domain of discourse is a closed domain it is possible to make the following ontological statement: *the logic of the*description *is the logic of the* describing *(living) system (and his cognitive domain).*

(6) This logic demands a substratum for the occurrence of the discourse. We cannot talk about this substratum in absolute terms, however, because we would have to *describe* it, and a *description* is a set of interactions into which the *describer* and the listener can enter, and their discourse about these interactions will be another set of *descriptive* interactions that will remain in the same domain. Thus, although this substratum is required for epistemological reasons, nothing can be said about it other than what is meant in the ontological statement above.

(7) We as observers live in a domain of discourse interacting with *descriptions* of our *descriptions* in a recursive manner, and thus continuously generate new elements of interaction. As living systems, however, we are closed systems modulated by interactions through which we define independent entities whose only reality lies in the interactions that specify them (their Description).

(8) For epistemological reasons we can say: there are properties which are manifold and remain constant through interactions. The invariance of properties through interactions provides a functional origin to entities or units of interactions; since entities are generated through the interactions that define them (properties), entities with different classes of properties generate independent domains of interactions: *no reductionism is possible*.

V. Problems in the Neurophysiology of Cognition

(1) The observer can always remain in a domain of interactions encompassing his own interactions; he has a nervous system capable of interacting with its own states, which, by doing so in a functional context that defines these states as representations of the interactions from which they arise, allows him to interact recursively with representations of his interactions. This is possible because due to the general mode of organization of the nervous system there is no intrinsic difference between its internally and externally generated states of activity, and because each one of its specific states of activity is specifiable only in reference to other states of activity of the system itself.

(2) An organism with a nervous system capable of interacting with its own states is capable of *descriptions* and of being an observer if its states arise from learned orienting interactions in a consensual domain: it can *describe* its describing [Cf. Gardner and Gardner, 1969]. Through *describing* itself in a recursive manner, such an organism becomes a self-observing system that generates the domain of self-consciousness as a domain of self-observation. Self-consciousness then is not a neurophysiological phenomenon, it is a consensual phenomenon emerging in an independent domain of interactions from self-orienting behavior and lies entirely in the linguistic domain. The implications are twofold:

(*a*) The linguistic domain as a domain of orienting behavior requires at least two interacting organisms with comparable domains of interactions, so that a cooperative system of consensual interactions may be developed in which the emerging conduct of the two organisms is relevant for both. The specifiability through learning of the orienting interactions allows for a purely consensual (cultural) evolution in this domain, without it necessarily involving any further evolution of the nervous system; for this reason the linguistic domain in general, and the domain of self-consciousness in particular, are, in principle, independent of the biological substratum that generates them. However, in the actual becoming of the living system this independence is incomplete, on the one hand because the anatomical and neurophysiological organization of the brain, by determining the actual possibilities of confluence of different states of activity in it, specifies both the domain of possible interactions of the organism with relations and the complexity of the patterns of orienting interactions that it can distinguish, and on the other hand because the necessary subservience of the linguistic domain to the maintenance of the basic circularity of the organism through the generation of modes of behavior that directly or indirectly satisfy it limits the type of conduct that the organism can have without an immediate or eventual disintegration, or, of course, reduced rate of reproduction. Consequently, then, although the purely consensual aspects of the cultural evolution are independent of a simultaneous evolution of the nervous system, those aspects of the cultural evolution which depend on the possibility of establishing new classes of concomitances of activity in the nervous system, and generate new relations between otherwise independent domains, are not thus independent. Accordingly, once a cultural domain is established, the subsequent evolution of the nervous system is necessarily subordinated to it in the measure that it determines the functional validity of the new kinds of concomitances of activity that may arise in the nervous system through genetic variability.

(*b*) Since self-consciousness and the linguistic domain in general are not neurophysiological phenomena, it is impossible to account for them in terms of excitation, inhibition, networks, coding, or whatever else is the stuff of neurophysiology. In fact, the linguistic domain is fully explained only by showing how it emerges from the recursive application of orienting interactions on the results of their applications without being restricted as a domain by the neurophysiological substratum; what indeed is the problem is the need to account in purely physiological terms, without reference to meaning, for the synthesis of behavior in general, and for the synthesis of orienting behavior in particular. Accordingly, the fundamental quest in this respect should be to understand and explain

(*i*) *how does the nervous system interact with its own states and is modified by them as if they were independent entities?*

(*ii*) *how are these states specified neurophysiologically if they are defined by their own effectiveness in bringing forth certain internal or sensory states in the system?*

(*iii*)) *how is a given effector performance synthesized that is defined by the relative states of activity that it generates in the sensory surfaces and in the system itself?*; and

(*iv*) *how do the double or triple internal anatomical projections of the nervous system onto itself determine its capacity to single out some of its own states and interact with them independently?*.

(3) At any moment each nerve cell responds in a deterministic manner, and according to well defined transfer functions to classes of spatio-temporal activity caused at its collector area by the afferent influences impinging upon it; this occurs independently of how these afferent influences arise. This mode of cellular operation constitutes the basis for an associative process in which, whenever a given state of activity is produced in the nervous system, all neurons for which this state generates the proper classes of afferent influences enter into activity. Association thus conceived neurophysiologically is an inevitable process that calls into activity all cells that can be activated at any moment by a given state of the nervous system. No consideration of meaning enters into such a notion, since meaning, as a *description* by the observer, refers to the relevance that a mode of behavior has in the maintenance of the basic circularity of the organism as a consequence of self-regulation, and not in the mechanisms of the genesis of conduct. Association in terms of representations related by meaning lies in the cognitive domain of the observer exclusively. The nervous system is a system that functions maintaining constant certain states of relative activity, both internally and at the sensory surfaces, with reference only to some of its other states of relative activity. In this context the following considerations about its functional organization are significant:

(*a*) The nervous system can be described as a system that has evolved to specialize in the discrimination between states of neuronal relative activity (particularly in man) each of which is defined by the behavior it generates. This is valid for innate and learned behavior in circumstances in which every behavior is defined either by a set of states of activity maintained constant, or by their path of variation, both internally and at the sensory surfaces.

(*b*) The basic connectivity of the nervous system, and the original reactive capacity of the nerve cells, with which any animal is endowed by development, secures a basic pattern of flow for the nervous activity originating at any point in it. Thus, development specifies and determines both an initial repertoire of behavior over which all new conduct is built in a historical process of transformation, and an initial structurally specified set of possible associations that changes in an integrated manner with the historical transformation of behavior [Cf. Lorenz, 1966].

(*c*) Any modification of the transfer function of a nerve cell, resulting from new concomitances of activity, occurs modifying a preexisting behavior in a system that operates through maintaining invariant its definitory internal relations. In fact, any local change that would lead to the synthesis of a modified conduct by the organism, must be immediately accompanied by other changes arising through the adjustments that this must undergo in the process of maintaining constant its internal relations under its changed behavior. This is why it is the immediate relevance of a conduct for the maintenance of the organism in the present which at any moment selects the changes that take place during learning, and not the possible value of the conduct for future action.

(*d*) It is apparent that the nervous system cannot determine in advance the concomitances of activity under which it should change in a permanent manner; for it to satisfy future needs of the organism, it must operate under non-predictive changes continuously selected by the concomitances of activity arising in it. For this the nervous system must be capable of successful operation under the continuous transformation of its capacity to synthesize behavior, which necessarily results from a continuous change of the neurophysiological concomitances that determine the effective spatio-temporal configuration of activity impinging on the collector areas of its component neurons. Accordingly, it would seem of fundamental importance for the functional transformation of the system that many of its neurons should be able to change their relative participation in the synthesis of behavior as elements of different states of relative neuronal activity, independently of whether or not this is accompanied by any change in their transfer functions. In these circumstances the actual problem for the successful operation of the nervous system is the generation at any moment of the optimal configuration of activity necessary to synthesize a given behavior. However, since this continuous transformation of the functional capacity of the nervous system necessarily occurs under continuously successful behavior, such optimization requires no other specification than its attainment through the converging transformation of behavior itself.

(*e*) Since the nervous system is an inferential system, that is, since it functions as if any state that occurred once will occur again, a significant feature of its organization must be its necessary and continuous transformation as a function of the new concomitances of activity occurring in it. This functional requirement could be satisfied, for example, if any new local concomitance of activity in the neuropils changes the nerve cells in a deterministic and specific manner which does not represent any entity or event, but which modifies the neurophysiological circumstances under which the corresponding post-synaptic neurons are activated. Such can occur if the probability of spike invasion at the branching points of the afferent axons in the neuropils is permanently modified in one direction or another by the coincident novel activity in the neighboring structures, which, in the absence of synaptic interactions, cause, through local currents, local processes of growth or ungrowth in the branching zones of these axons. If this were the case four things would occur:

(*i*) The state of the nervous system would change, and hence, also its conduct, according to the new concomitances of activity produced in the neuropils through its different interactions.

(*ii*) Each state of activity of the system (as a state of relative neuronal activity) would be defined by the concomitances of activity in the neuropil that generate it, such that if they recur, it recurs.

(*iii*) Each new functional state of the neuropils would necessarily constitute the basis for their further modification, in such a manner that their morphological and functional organization would be under continuous historical transformation.

(*iv*) These changes in the neuropils would change the participation of the different neurons in the synthesis of behavior, independently of whether or not there are also changes in their transfer functions, by changing the circumstances of their activation. Accordingly, if an interaction (as described by the observer) recurs, no past conduct could be strictly reenacted by the organism, but this would have to synthesize a new adequate behavior that generates, in the context of its present interaction and in a manner that became specified through its structural transformation along its history of interactions, the internal and sensory motor correlations that maintain its identity.

(4) Learning is not a process of accumulation of representations of the environment; it is a continuous process of transformation of behavior through continuous change in the capacity of the nervous system to synthesize it. Recall does not depend on the indefinite retention of a structural invariant that represents an entity (an idea, image, or symbol), but on the functional ability of the system to create, when certain recurrent conditions are given, a behavior that satisfies the recurrent demands or that the observer would class as a reenacting of a previous one. As a consequence, the quest in the study of the learning process must answer two basic questions:

"What changes can a neuron undergo (in any of its component parts) which it can maintain constant for a certain time, and which modify in a definite manner its possible participation in different configurations of relative neuronal activity?"; and

"What organization of the nervous system would permit continuous changes in the relative activity of its anatomical components, as a result of different concomitances in their activity, and still permit the synthesis of a conduct that is defined only by the states of relative neuronal activity that it generates, and not by the components used?".

(5) The nervous system is a strictly deterministic system whose structure specifies the possible modes of conduct that may emerge (be synthesized) from its functioning in a manner that varies according to the species, and the reactive perspective from which these modes of conduct may emerge. The reactive perspective, which the observer would call the emotional tone, does not specify a particular conduct, but determines the nature (aggressive, fearful, timid, etc.) of the course of the interaction [Cf. Kilmer, McCulloch and Blum, 1968]. Changes during development, maturation, hormonal action, drugs, or learning, do not modify the deterministic character of this organization but change the capacity that the system has at any moment to synthesize behavior. Furthermore, although any conduct or functional state always arises through a process of historical transformation from pre-existing modes of conduct or functional states, the nervous system functions in the present, and past history does not participate as an operant neurophysiological factor in the synthesis of conduct; nor does meaning, the relevance that a particular mode of conduct has, participate in it either. Time and meaning are effective factors in the linguistic domain, but as relational entities do not have neurophysiological correlates in the operation of the nervous system. Nor is the functional unity of the nervous system attained through a specific feature of its organization, but emerges from the functioning of its components (whatever these may be), each one to its own accord, under circumstances that define the ensemble as a unit of interactions in a particular domain [Cf. Lindauer, 1967, as an example in a social organism], and has no reality independent of these circumstances. Thus there is no peculiar neurophysiological process that could be shown to be responsible for this unity and to explain it. Furthermore, in a strict sense, although the nervous system has anatomical components it does not have functional parts since any mutilation leaves a functioning unit, with different properties as expressed by its possible interactions, but a unit in the corresponding domain. It appears incomplete only for the observer who beholds it as an entity from the perspective of what he thinks it should be. Each component of the nervous system that the observer *describes* is defined in the domain of interactions of his observations, and as such is alien to the system which it is supposed to integrate. Every function has a structure which embodies it and makes it possible, but this structure is defined by the function in the domain of its operation as a set of relations between elements also defined in this domain. Neurons are the anatomical units of the nervous system, but are not the structural elements of its functioning. The structural elements of the functioning nervous system have not yet been defined, and it will probably be apparent when they are defined that they must be expressed in terms of invariants of relative activities between neurons, in some manner embodied in invariants of relations of interconnections, and not in terms of separate anatomical entities. In manmade systems this conceptual difficulty has not been so apparent because the system of relations (the theory) that integrates the parts that the describer (the observer) defines is provided by him, and is specified in his domain of interactions; as a consequence, these relations appear so obvious to the observer that he treats them as arising from the observation of the parts, and deludes himself, denying that he provides the unformulated theory that embodies the structure of the system which he projects onto them. In a self-referring system like a living system the situation is different: the observer can only make a *description* of his interactions with parts that he defines through interactions, but these parts lie in his cognitive domain only. Unless he explicitly or implicitly provides a theory that embodies the relational structure of the system, and conceptually supersedes his *description* of the components, he can never understand it. Accordingly, the full explanation of the organization of the nervous system (and of the organism) will not arise from any particular observation or detailed description and enumeration of its parts, but rather like any explanation, from the synthesis, conceptual or concrete, of a system that does what the nervous system (or the organism) does.

VI. Conclusions

The aim set forth in the introduction has been accomplished. Through the *description* of the self-referring circular organization of the living system, and through the analysis of the domains of interactions that such an organization specifies, I have shown the emergence of a self-referring system capable of making *descriptions* and of generating, through orienting interactions with other, similar, systems and with itself, both a consensual linguistic domain and a domain of self-consciousness, that is: I have shown the emergence of the observer. This result alone satisfies the fundamental demand put forth at the outset: *"The observer is a living system and any understanding of cognition as a biological phenomenon must account for the observer and his role in it"*, and proves the validity of this analysis.

Although the answers to the various questions posed in the introduction and the fundamental implications of the analysis are to be found in the text itself to the extent that the theory adequately founds its whole development, there are several conclusions that I would like to state explicitly:

i) The living organization is a circular organization which secures the production or maintenance of the *components* that specify it in such a manner that the product of their functioning is the very same organization that produces them. Accordingly, a living system is an homeostatic system whose homeostatic organization has its own organization as the variable that it maintains constant through the production and functioning of the *components* that specify it, and is defined as a unit of interactions by this very organization. It follows that living systems are a subclass of the class of circular and homeostatic systems. Also, it is apparent that the components referred to above cannot be specified as parts of the living system by the observer who can only subdivide a system in parts that he defines through his interactions, and which, necessarily, lie exclusively in his cognitive domain and are operationally determined by his mode of analysis. Furthermore, the relations through which the observer claims that these parts constitute a unitary system are relations that arise only through him by his simultaneous interactions with the parts and the intact system, and, hence, belong exclusively to his cognitive domain. Thus, although the observer can decompose a living system into parts that he defines, the *description* of these parts does not and cannot represent a living system. In principle a part should be definable through its relations within the unit that it contributes to form by its operation and interactions with other parts; this, however, cannot be attained because the analysis of a unit into parts by the observer destroys the very relations that would be significant for their characterization as effective components of the unit. Furthermore, these relations cannot be recovered through a *description* which lies in the cognitive domain of the observer and reflects only his interactions with the new units that he creates through his analysis. Accordingly, in a strict sense a unit does not have parts, and a unit is a unit only to the extent that it has a domain of interactions that defines it as different from that with respect to which it is a unit, and can be referred to only, as done above with the living system, by characterizing its organization through the domain of interactions which specify this distinction. In this context, the notion of *component* is necessary only for epistemological reasons in order to refer to the genesis of the organization of the unit through our *description*, but this use does not reflect the nature of its composition.

ii) For every living system its particular case of self referring circular organization specifies a closed domain of interactions that is its cognitive domain, and no interaction is possible for it which is not prescribed by this organization. Accordingly, for every living system the process of cognition consists in the creation of a field of behavior through its actual conduct in its dosed domain of interactions, and not in the apprehension or the description of an independent universe. Our cognitive process (the cognitive process of the observer) differs from the cognitive processes of other organisms only in the kinds of interactions into which we can enter, such as linguistic interactions, and not in the nature of the cognitive process itself. In this strictly subject-dependent creative process, inductive inference is a necessary function (mode of conduct) that emerges as a result of the self-referring circular organization which treats every interaction and the internal state that it generates as if it were to be repeated, and as if an element of a class. Hence, functionally, for a living system every experience is the experience of a general case, and it is the particular case, not the general one, which requires many independent experiences in order that it be specified through the intersection of various classes of interactions. Consequently, although due to the historical transformation they have caused in organisms, or in their nervous systems, past interactions determine the inductive inferences that these make in the present, they do not participate in the inductive process itself. Inductive inference as a structural property of the living organization and of the thinking process, is independent of history, or of the relations between past and present that belong only to the domain of the observer.

iii) Linguistic interactions orient the listener within his cognitive domain, but do not specify the course of his ensuing conduct. The basic function of language as a system of orienting behavior is not the transmission of information or the description of an independent universe about which we can talk, but the creation of a consensual domain of behavior between linguistically interacting systems through the development of a cooperative domain of interactions.

iv) Through language we interact in a domain of *descriptions* within which we necessarily remain even when we make assertions about the universe or about our knowledge of it. This domain is both bounded and infinite; bounded because everything we say is a *description*, and infinite because every *description* constitutes in us the basis for new orienting interactions, and hence, for new *descriptions*. From this process of recursive application of *descriptions* self-consciousness emerges as a new phenomenon in a domain of self-description, with no other neurophysiological substratum than the neurophysiological substratum of orienting behavior itself. The domain of self-consciousness as a domain of recursive self-descriptions is thus also bounded and infinite.

v) A living system is not a goal-directed system; it is, like the nervous system, a stable state-determined and strictly deterministic system closed on itself and modulated by interactions not specified through its conduct. These modulations, however, are apparent as modulations only for the observer who beholds the organism or the nervous system externally, from his own conceptual (*descriptive*) perspective, as lying in an environment and as elements in his domain of interactions. Contrariwise, for the functioning of the self-referring system itself all that there is is the sequence of its own self-subservient states. If this distinction is not made, one is liable to fail by including in the explanation of the organism and the nervous system features of interactions (*descriptions*) that belong exclusively to the cognitive domain of the observer.

vi) It is tempting to talk about the nervous system as one would talk about a stable system with input. This I reject because it misses entirely the point by introducing the distortion of our participation as observers into the explanation of systems whose organization must be understood as entirely self-referring. What occurs in a living system is analogous to what occurs in an instrumental night where the pilot does not have access to the outside world and must function only as a controller of the values shown in his flight instruments. His task is to secure a path of variations in the readings of his instruments, either according to a prescribed plan, or to one that becomes specified by these readings. When the pilot steps out of the plane he is bewildered by the congratulations of his friends on account of the perfect flight and landing that he performed in absolute darkness. He is perplexed because to his knowledge all that he did at any moment was to maintain the readings of his instruments within certain specified limits, a task which is in no way represented by the *description* that his friends (observers) make of his conduct.

In terms of their functional organization living systems do not have inputs and outputs, although under perturbations they maintain constant their set states, and it is only in our *descriptions*, when we include them as parts of larger systems which we define, that we can say that they do. When we adopt this *descriptive* approach in our analysis of the living organization we cannot but subordinate our understanding of it to notions valid only for man-made (allo-referring) systems, where indeed input and output functions are all important through the purposeful design of their role in the larger systems in which they are included, and this is misleading. In the organization of the living systems the role of the effector surfaces is only to maintain constant the set states of the receptor surfaces, not to act upon an environment, no matter how adequate such a description may seem to be for the analysis of adaptation, or other processes; a grasp of this is fundamental for the understanding of the organization of living systems.

vii) The cognitive domain of the observer is bounded but unlimited; he can in an endless recursive manner interact with representations of his interactions and generate through himself relations between otherwise independent domains. These relations are *novelties* which, arising through the observer, have no other (and no less) effectiveness than that given to them by his behavior. Thus, he both creates (invents) relations and generates (specifies) the world (domain of interactions) in which he lives by continuously expanding his cognitive domain through recursive *descriptions* and representations of his interactions. The *new*, then, is a necessary result of the historical organization of the observer that makes of every attained state the starting point for the specification of the next one, which thus cannot be a strict repetition of any previous state; creativity is the cultural expression of this unavoidable feature.

viii) The logic of the *description* and, hence, of *behavior* in general is, necessarily, the logic of the describing system; given *behavior as a referential and deterministic sequence of states of nervous activity in which each state determines the next one within the same frame of reference*, no contradiction can possibly arise in it as long as the latter remains unchanged by intercurrent interactions. If a change in the frame of reference takes place while a given *behavior* develops, a new one appears, such that the states following the change are determined with respect to it. If the new sequence of states (behavior) appears to an observer as contradicting the previous ones, this is so because he provides an independent and constant frame of reference in relation to which the successive sequences of states (behaviors) are contradictory. Such contradiction, however, lies exclusively in the cognitive domain of the observer, or of whatever provides the independent constant frame of reference. Contradictions (inconsistencies) then, do not arise in the generation of *behavior* but pertain to a domain in which the different *behaviors* acquire their significance by confronting an encompassing frame of reference through the interactions of the organism. Accordingly, thinking and discourse as modes of *behavior* are necessarily logically consistent in their generation, and that which the observer calls *rational* in them because they appear as concatenations of non-contradictory sequence dependent *descriptions*, is an expression of this necessary logical consistency. It follows that inconsistencies (*irrationalities*) in thinking and discourse as they appear to the observer arise from contextual changes in the circumstances that generate them while the independent frame of reference provided by the observer remains unchanged.

ix) Due to the nature of the cognitive process and the function of the linguistic interactions, we cannot say anything about that which is independent of us and with which we cannot interact; to do that would imply a *description* and a *description* as a mode of conduct represents only relations given in interactions. Because the logic of the *description* is the same as the logic of the *describing* system we can assert the epistemological need for a substratum for the interactions to occur, but we cannot characterize this substratum in terms of properties independent of the observer. From this it follows that reality as a universe of independent entities about which we can talk is, necessarily, a fiction of the purely *descriptive* domain, and that we should in fact apply the notion of reality to this very domain of *descriptions* in which we, the *describing* system, interact with our descriptions as if with independent entities. This change in the notion of reality must be properly understood. We are used to talking about reality orienting each other through linguistic interactions to what we deem are sensory experiences of concrete entities, but which have turned out to be, as are thoughts and *descriptions*, states of relative activity between neurons that generate new *descriptions*. The question, *"What is the object of knowledge?"* becomes meaningless. There is no object of knowledge. To know is to be able to operate adequately in an individual or cooperative situation. We cannot speak about the substratum in which our cognitive behavior is given, and about that of which we cannot speak, we must remain silent, as indicated by Wittgenstein. This silence, however, does not mean that we fall into solipsism or any sort of metaphysical idealism. It means that we recognize that we, as thinking systems, live in a domain of *descriptions*, as has already been indicated by Berkeley, and that through *descriptions* we can indefinitely increase the complexity of our cognitive domain. Our view of the universe and of the questions we ask must change accordingly. Furthermore, this re-emergence of reality as a domain of *descriptions* does not contradict determinism and predictability in the different domains of interactions; on the contrary, it gives them foundation by showing that they are a necessary consequence of the isomorphism between the logic of the *description* and the logic of the *describing* system. It also shows that determinism and predictability are valid only within the field of this isomorphism; that is, they are valid only for the interactions that define a domain.

x) The genetic and nervous systems are said to code information about the environment and to represent it in their functional organization. This is untenable; the genetic and nervous systems code processes that specify series of transformations from initial states, which can be decoded only through their actual implementation, not *descriptions* that the observer makes of an environment which lies exclusively in *his* cognitive domain [Cf. Bernal, 1965]. The following is an illustration of the problem:

Let us suppose that we want to build two houses. For such a purpose we hire two groups of thirteen workers each. We name one of the workers of the first group as the group leader and give him a book which contains all the plans of the house showing in a standard way the layout of walls, water pipes, electric connections, windows, etc., plus several views in perspective of the finished house. The workers study the plans and under the guidance of the leader construct the house, approximating continuously the final state prescribed by the *description*. In the second group we do not name a leader, we only arrange the workers in a starting line in the field and give each of them a book, the same book for all, containing only neighborhood instructions. These instructions do not contain words such as house, pipes, or windows, nor do they contain drawings or plans of the house to be constructed; they contain only instructions of what a worker should do in the different positions and in the different relations in which he finds himself as his position and relations change.

Although these books are all identical the workers read and apply different instructions because they start from different positions and follow different paths of change. The end result in both cases is the same, namely, a house. The workers of the first group, however, construct something whose final appearance they know all the time, while the workers of the second group have no views of what they are building, nor do they need to have obtained them even when they are finished. For the observer both groups are building a house, and he knows it from the start, but the house that the second group builds lies only in his cognitive domain; the house built by the first group, however, is also in the cognitive domains of the workers. The coding is obviously different in the two cases. In fact, the instructions contained in the book given to the first group clearly code the house as the observer would *describe* it, and the decoding task of the workers consists in purposefully doing things that will approximate to the construction of the *described* final state; this is why the house must be in their cognitive domain. In the second case, the instructions contained in each one of the thirteen identical books do not code a house. They code a process that constitutes a path of changing relationships which, if carried through under certain conditions, results in a system with a domain of interactions which has no intrinsic relationship with the beholding observer. That the observer should call this system a house is a feature of his cognitive domain, not of the system itself. In the first case the coding is isomorphic with a *description* of the house by the observer, and in fact constitutes a representation of it; in the second case it is not. The first case is typical of the way in which the observer codes the systems that he builds; the second corresponds to the way that the genome and nervous system constitute codes for the organism and for behavior, respectively, and one would never find in these codes any isomorphism with the *description* that the observer would make of the resultant systems with which he interacts. In what sense could one then say that the genetic and nervous systems code information about the environment? The notion of information refers to the observer's degree of uncertainty in his behavior within a domain of alternatives defined by him, hence the notion of information only applies within his cognitive domain. Accordingly, what one could at most say is that the genetic and nervous systems generate information through their self-specification when witnessed by the observer as if in their progressive self-decoding into growth and behavior.

xi) There are different domains of interactions, and these different domains cannot explain each other because it is not possible to generate the phenomena of one domain with the elements of another; one remains in the same domain. One domain may generate the elements of another domain, but not its phenomenology, which in each domain is specified by the interactions of its elements, and the elements of a domain become defined only through the domain that they generate. Any nexus between different domains is provided by the observer who can interact as if with a single entity with the conjoined states of nervous activity generated in his brain by his concomitant interactions in several domains, or with independent *descriptions* of these interactions. Through these concomitant interactions in different domains (or with several *descriptions* within the *descriptive* domain) the observer generates relations between different domains (or between different *descriptions*) as states of neuronal activity that in him lead to definite modes of conduct (*descriptions*) that represent these conjoined interactions as singular independent entities. The number and kinds of relations the observer can generate in this manner is potentially infinite due to his recursive interactions with *descriptions*. Thus, relations, as states of neuronal activity arising from the concurrent interactions of the observer in different domains (physical and relational) constitute the elements of a new domain in which the observer interacts as a thinking system, but do not reduce one phenomenological domain into another. It is the simultaneous logical isomorphism of the new element (relations) with their source systems through their mode of origin (class intersection) that gives the new domain thus generated (*descriptions*) its explanatory capacity. An explanation is always a reproduction, either a concrete one through the synthesis of an equivalent physical system, or a conceptual one through a description from which emerges a system logically isomorphic to the original one, but never a reduction of one phenomenological domain into another. An adequate understanding of this irreducibility is essential for the comprehension of the biological phenomena, the consensual domains that living systems generate, and their conjoined evolution.

Many conclusions about self-consciousness and knowledge which arise from this mode of analysis have been proposed in one way or another by scientists and philosophers from their intuitive understanding, but never, to my knowledge, with an adequate biological and epistemological foundation. This I have done through the distinction between what pertains to the domain of the observer, and what pertains to the domain of the organism, and through carrying to their ultimate consequences the implications of the circular self-referring organization of the living systems: the implications of the functionally closed nature of the relativistic organization of the nervous system as a system under continuous transformation determined by relations of neuronal activity without the system ever stepping outside itself; and the implications of the non-informative orienting function of linguistic interactions. It is only after this has been done that the functional complexity of the living and linguistically interacting system can be properly grasped without its being concealed through such magic words as consciousness, symbolization, or information. Most of the detailed work is yet to be done, of course, but the fundamental first step of defining the perspective from which to look has here been taken. As a final remark, one could say what appears to be another paradox, but which points to the conceptual problem:

Living systems in general, and their nervous system in particular, are not made to handle a medium, although it has been through the evolution of their handling of their medium that they have become what they are, such that we can say what we can say about them.

Post Scriptum

No scientific work should be done without recognizing its ethical implications; in the present case the following deserve special attention:

i) Man is a deterministic and relativistic self-referring autonomous system whose life acquires its peculiar dimension through self-consciousness; ethic and morality arise as commentaries that he makes on his behavior through self-observation. He lives in a continuously changing domain of *descriptions* that he generates through recursive interactions within that domain, and which has no other constant element in its historical transformation than his maintained identity as an interacting system. That is, man changes and lives in a changing frame of reference in a world continuously created and transformed by him. Successful interactions directly or indirectly subservient to the maintenance of his living organization constitute his only final source of reference for valid behavior within the domain of descriptions, and, hence, for truth; but, since living systems are self-referential systems, any final frame of reference is, necessarily, relative. Accordingly, no absolute system of values is possible and all truth and falsehood in the cultural domain are necessarily relative.

ii) Language does not transmit information and its functional role is the creation of a cooperative domain of interactions between speakers through the development of a common frame of reference, although each speaker acts exclusively within his cognitive domain where all ultimate truth is contingent to personal experience. Since a frame of reference is defined by the classes of choices which it specifies, linguistic behavior cannot but be rational, that is, determined by relations of necessity within the frame of reference within which it develops. Consequently, no one can ever be rationally convinced of a truth which he did not have already implicitly in his ultimate body of beliefs.

iii) Man is a rational animal that constructs his rational systems as all rational systems are constructed, that is, based on arbitrarily accepted truths (premises); being himself a relativistic self-referring deterministic system this cannot be otherwise. But if only a relative, arbitrarily chosen system of reference is possible, the unavoidable task of man as a self-conscious animal that can be an observer of its own cognitive processes is to explicitly choose a frame of reference for his system of values. This task he has always avoided by resorting to god as an absolute source of truth, or to self-delusion through reason, which can be used to justify anything by confusing the frames of reference and arguing in one domain with relations valid in another. The ultimate truth on which a man bases his rational conduct is necessarily subordinated to his personal experience and appears as an act of choice expressing a preference that cannot be transferred rationally; accordingly, the alternative to reason, as a source for a universal system of values, is aesthetic seduction in favor of a frame of reference specifically designed to comply with his desires (and not his needs) and defining the functions to be satisfied by the world (cultural and material) in which he wants to live.