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Whether stated or not, the fundamental quest of neurophysiology is to understand the processes that determine the so-called higher functions in the brain. The present work is an explicit attempt in that direction. Whatever success I have in this endeavor I owe to the enriching discussions I had with my friend Heinz Von Foerster and my student Francisco Varela.

Statement of the problem

Propositions

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

If such an understanding is to be attained, two questions have to be considered:

1. What is cognition as a process?
2. How is it carried out?

I shall proceed accordingly. ❮Page 4❯

The connotations of the terms used will become apparent through their usage in the text, and the complete presentation is expected to provide the foundation for its parts.

Cognitive process in general

The observer

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

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 (the organism).

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 interactions (entities).

For the observer an entity is an entity (a unit of interactions) 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, even if this is the observer himself, and which serves as a reference for the description.

The set of all interactions into which an entity can enter is its domain of interactions. The set of all the relations (interactions through the observer) in which an entity can be observed is its domain of relations. (This latter domain lies in the cognitive domain of the observer.) An entity is an entity if it has a domain of interactions; and if it has a domain of interactions, it has 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.

The observer can define himself as an entity by specifying his own domain of interactions.

Any understanding of the cognitive process must account for the observer and his role in it. ❮Page 5❯

The living system

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Living systems are units of interactions; they exist in an environment. From a purely biological point of view they cannot be understood independently of the part of the environment with which they interact, the niche; nor can the niche be defined independently of the living system that occupies it. [Note 1]

Living systems as they exist on the earth today are characterized by exergonic metabolism, growth, and replication (and reproduction), all organized in a closed causal circular process that allows for evolutionary changes in the way the circularity is maintained, but not for loss of the circularity: exergonic metabolism is required to provide energy for the endergonic synthesis of specific polymers (proteins, nucleic acids, lipides, polysaccharides) from the corresponding monomers, that is for growth and reproduction; special replication procedures are needed to secure that the polymers synthesized be specific, that is, that they should have the monomeric sequence proper to their class; specific polymers (enzymes) are required for the exergonic metabolism and the synthesis of specific polymers (proteins, nucleic acids, lipides, polysaccharides). This circular organization determines that the components that specify it be those whose synthesis it secures. Hence, its circular nature is essential for its maintenance and its operation as a unit. That which is not in it is external to it or does not exist. This circular organization is the living organization.

It is the circularity of its organization that makes a living system a unit of interactions, and it is this circularity that it has to maintain in order to remain a living system and to retain its identity through different interactions. All the peculiar characteristics of the different kinds of organisms are superimposed on this basic circularity and are subservient to it, securing its continuance through successive interactions in an always changing environment. A living system defines through its organization the domain of all the interactions into which it can possibly enter without losing its identity; its identity is maintained as long as the basic circularity that defines the system 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 of being a unit of interactions remains unchanged.)

Due to the circular nature of its organization, a living system has a self-referring domain of interactions (self-referring system): the condition for being a unit of interactions of a living system is maintained, for its ❮Page 6❯ organization has functional significance only in relation to the maintenance of its circularity and defines its domain of interactions accordingly.

Living systems as interacting units cannot enter into interactions that are not prescribed 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 to proceed to the next one. The circular organization implies the prediction that a necessary interaction that took place once will take place again. If this does not happen, the system disintegrates; if the predicted interaction takes place, the system maintains its identity (integrity) and enters into a new prediction. In a continuously changing environment these predictions can be successful only 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 in its members which will allow the living system to retain its circular organization after the interaction and, thus, interact again. This makes living systems Inferential systems, and their domain of interactions a cognitive domain.

The niche is defined by the classes of interactions into which an organism can enter. The niche is, then, to the observer, part of the environment; to the living system, all that with which it can interact without losing its identity. For the observer the environment in which the organism lies is larger than the niche, but this environment lies in the domain of interactions (cognition) of the observer, not of the organism. If the living system enters into an interaction not prescribed by its organization, it enters it not as the unit of interactions defined by this organization (but as some other unit of interactions or part thereof), and this interaction remains outside its cognitive domain. For every living system, its niche is represented in its organization as the domain of its possible interactions, and this domain constitutes its entire cognitive reality.

Evolution

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Evolutionary change in living systems is the result of that aspect of their organization which secures the maintenance of their basic circularity, and which allows in each reproductive step for changes in the way it is attained. Reproduction and evolution are not essential for the living organization, but they have been essential for the evolution of the cognitive domains of the living systems on earth. ❮Page 7❯

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

In 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 than the parental one only if its organization is different, and, hence, implies different predictions about the niche.

Since predictions about the niche are inferences about classes of events to be encountered (interactions), particular encounters that for the observer (and hence for other units of relations, such as internal parts of the same living system) are different, may be indistinguishable for the organism. The observer can describe them as different members of a class defined by the mode of interaction of the organism. As a consequence, interactions that are identical for the organism, but are different for parts of it, may result in different modifications of its internal states and, hence, different changes. in its domain of interactions without loss of identity. These changes may bring about the production of an offspring with a domain of interactions different from the parental one. If this is the case and the new system predicts a niche that cannot be actualized, it disintegrates; otherwise it maintains its identity, and a new cycle begins.

What changes from generation to generation is the internal structure of the unit of interactions: that which through a circular organization retains its identity through numerous interactions. The manner in which the unit of Interactions is compounded, whether by a single unit, or through the aggregation of numerous ones that together become a new larger unit of interactions (multicellular organisms, insect societies, etc.) is of no significance; what evolves is the unit of interactions. The evolution of the living systems is the evolution of the niches of the units of interactions, hence the evolution of the cognitive domains.

The cognitive process

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A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of the system itself, and the process of cognition is the actual (inductive) ‹Page 8› 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.

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 losing its identity. In an organism without a nervous system (or its functional equivalent) its interactions are of 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 the internal states of the living systems also modifiable in a relevant manner by *pure relations*, and 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 (a bird). The sensors change through a physical interaction, the absorption of light quanta; the animal is modified through its interaction with the relations that hold between the activated sensors that absorbed light quanta at the sensory surface. The nervous system expands the cognitive domain of the living system by making it possible for it to interact with *pure relations;* it does not create cognition.

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.

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 these were independent entities, generating the apparent paradox of including in their cognitive domain their cognitive domain. In us, this paradox is resolved by what we call abstract thinking (a new cognitive domain).

Furthermore, the expansion of the cognitive domain into domains of pure relations by virtue of a nervous system allows for nonphysical interactions (representations) between organisms that orient each other toward other interactions. Herein lies the origin of communication. But this very process generates another apparent paradox: there are organisms that generate representations of their interactions by specifying ❮Page 9❯ entities with which they interact as if these entities belonged to an independent domain, while as representations they only map their own interactions. In us this paradox is resolved simultaneously in two ways.

1. By our becoming observers, we recursively generate representations of our interactions; and by interacting with their relations we remain in a domain of interactions that is always larger than that of the representations.
2. By our becoming conscious, we make descriptions of ourselves (that is representations); and by interacting with our descriptions we can describe ourselves describing ourselves – in an indefinite recursive process.

Cognitive process in particular (The nervous system) ↑ ↓

Nerve cells ↑ ↓

The neuron is the anatomical and functional unit of the nervous system. It is the anatomical unit because it is a cell and as such it is an integrated and self-referring metabolic and genetic unit (a living system indeed). It is the functional unit because as a collector and as a distributor of influences it functions as a unit.

Anatomically and functionally the neuron is formed by a collector (dendrites and sometimes the cell body) 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 both on 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 of a neuron depends on the state of activity of its collector area and on the presynaptic and nonsynaptic interactions with 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 amacrines cells, in which collector and effector areas may be intermingled. The distributive element determines where the effector exerts its influence.

At any moment the state of activity of a nerve cell is a function of the spatiotemporal 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 spatiotemposial configuration ‹Page 10› results in the recurrence of the same state of activity, independently of the way in which such a spatiotemporal configuration is generated. [Note 2] ,[Note 3] This is 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 activity that they generate in their effector area, and not because they are a one-to-one mapping of each other. Also, the spatiotemporal configuration of the Input on 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. Thus, there are neurons for which a given class of response is elicited by a given class of afferent influences.

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 spatiotemporal configuration of the afferent excitatory and inhibitory influences acting on it and, if any, on its own internal generating mechanism) 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 of 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 have to be seen as integral parts in the definition of the spatiotemporal configuration of afferent influences, not as independent processes. The shape of the collector area (its geometry) has to be seen as selecting the spatiotemporal configuration of afferent influences to which the cell will respond.

Although I expect in a significant number of neurons a continuous change in their transfer functions as a result of their past history, I think that for the understanding of the functional organization of the nervous system it is necessary at any given moment to consider all nerve cells as responding with definite transfer functions to classes of afferent spatiotemporal configurations in their input, and not to particular situations. This because of two reasons:

1. I consider that any interaction through the nervous system is represented by a state of activity in a collection of cells, and that this state of activity should lead to a given behavior. This behavior ‹Page 11› should be repeatable to the extent that the interaction is reproducible.
2. I consider that the nervous system always functions In the present. (The present is the time interval necessary for an interaction to take place; *past, future*, and *time*, in general, exist only for an observer.) Although nerve cells may be continuously changing their mode of operation, their past history can explain to an observer how their present mode of operation was reached, but not its present participation in the determination of behavior.

If nerve cells respond to classes of events, not to particular situations, they necessarily treat as equivalent particular afferent configurations that are otherwise unrelated.

Architecture

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 members. As a result, the members of the same class hold similar relations with each other and with other neurons: the shapes of the nerve cells (collector area, distributive conductor, 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, I think, are significant for the understanding of the functional organization of the nervous system.

1. 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 development. The functional organization of the nervous system must be such as to tolerate this variability.
2. 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.

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 ❮Page 12❯ 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, they have different interacting capabilities.

The organism ends at the boundary that its self-referring organization defines in the maintenance of its identity. At this boundary there are sensors through which the nervous system interacts in the domain of relations. These sensors 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, generally not one, but many sensory elements are excited.

Function

The way the nervous system functions is bound to its anatomical organization. The functioning of the nervous system, however, 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).

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 animals to discriminate objects by vision, the receptors in the eyes must absorb light quanta to be activated; yet the objects that the animal sees are determinded by the relations of receptor-induced activity within the functional and anatomical organization of the retina. Moreover, since the domain of interactions of the organism is defined by its structure, and this structure implies the prediction of the niche, the relations with which the nervous system interacts are defined by this prediction and arise in the domain of interactions of the organism. The (anatomical and functional) organization of the living system defines a *point of view*, a bias or a posture from which the interactions take place, and that determines the possible relations accessible to the nervous system. The anatomy of the retina and the properties of the various cell types define which relations, holding between the active receptors when a given visual object is viewed, will be accessible to the nervous system.

Due to the properties of neurons, and due to the architecture of the nervous system, interactions within the nervous system necessarily give origin 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 circumstance is it possible to associate the activity of any particular cell to any particular interaction of the living system. (This can be clearly shown by discussing the visual system. [Note 4]) 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. At the same time, although operational localizations can be established in the nervous system, [Note 5] these localizations are to be viewed in terms of areas where certain modalities of interactions converge, and not as localizations of faculties or functions, even though certain functions cannot be performed in the absence of these areas. The nervous system is localized in terms of the organism's interaction surfaces, but not in terms of the representations of the interactions it can generate.

Representation

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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 a different manner. 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 does, they appear in their mode of operation 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 an 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 origin are further states of relative activity in other nerve cells by directly conforming 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, cause a change in the state of relative activity of the receptor elements at the receptor surfaces, by generating an interaction. This has a fundamental consequence: unless they imply their origin (through concomitant events or their locations), there is no possible distinction between internally and externally generated states of nervous activity

distinction between internally and externally generated states of nervous activity. ❮Page 13❯

The relations with which the nervous system interacts are relations given by the physical interactions of the organism, 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 modify 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 interaction. These relations are not those that the observer can describe as holding between the 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 entity 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.

Any given state of activity of the nervous system consists of states of relative activity holding between neurons. If an 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. What is then represented in the different states of activity of the nervous system are the relations given in the interactions of the organism at its sensory surfaces and not an environment independent of it (least of all a description – in terms of entities – that lies in the cognitive domain of the observer).

Every relation is represented in a state of relative activity of nerve cells, but also, every state of relative activity acts modifying the relative activity of other nerve cells. Relations, thus, through their embodiment in states of relative activity become units of interactions and generate additional relations, again embodied in states of relative activity which can in turn become units of internal interactions in the nervous system.

The classes of relations that can be represented have been defined by evolution:

1. by the evolution of the structural organization of the organism in general, and of the sensors in particular, that define the classes of relations that will be accessible to the nervous system,
2. by the evolution of the particular organization of the nervous system, corresponding to that of a given class of animals (species), ❮Page 14❯ that defines the mode how these relations generate a behavior relevant to the maintenance of the organism.

Of a given class of relations the particular relation encountered as a result of a present interaction is represented by a particular state of activity given in the present. This is independent of history. However, the relevance of the behavior generated by this state of activity for the maintenance of the living system is history dependent, and may depend on both the evolutionary history of the species and the past experience of the organism. In the former case, one would talk of instinctive behavior and in the second case, of learning. 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 generating a description can treat as if in the present interactions which now do not recur. This apparent paradox he resolves generating the notion of time: past, present, and future.

There is no difference in the nature of the representation of internally and externally generated interactions. In an organism capable of interacting with the embodiment of his own interactions the nature of the representation does not change. What changes are the relations represented.

Since the nervous system interacts only with states of relative activity holding between neurons, and since a perception and a representation are states of relative activity holding between neurons, there is no objection in principle for the nervous system to interact with representations of its interactions. The distinction between the two kinds of interactions can only arise through the concomitance of events that indicate the source of the state of relative activity that embody them, of through the outcome of the new interactions which they initiated. A nervous system that is capable of treating its internally generated states as it treats its externally generated states (that is, distinguishing their origin) is capable of abstract thinking.

Description

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If a given state of relative activity in the nerve cells originates a given behavior, the recurrence of the same state of relative activity should give origin to the same behavior, no matter how the recurrent state originates. The relevance of such a behavior is determined by the significance that it has for the maintenance of the living organization. The living system, due to its circular organization, is an inductive system and functions always in a predictive manner: what occurred once will occur again. Its organization (both genetic and otherwise) is conservative ❮Page 15❯ and repeats only that which works. For this same reason living systems are historical systems: the relevance of a given conduct or mode of behaving is determined always 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 parent organism. In these circumstances, then, a behavior is relevant if it allows the organism to behave again in a similar manner, and does so by maintaining its basic circularity. With the expansion of the cognitive domain during evolution the types of behavior have changed as well as how they implement their relevance: different kinds of behavior are relevant to the maintenance of the basic circularity of the living organization through different d omains of interactions.

Through a given interaction a new interaction is generated whose relevance arises from the way the system maintains its circular organization, neutralizing the disturbances introduced by the first one and giving origin to new interactions. To the observer the second interaction appears as a description of the niche of the observed organism. And, indeed, the niche of an organism is the set of all the interactions into which it can enter; hence, the cognitive domain of an organism is a description of its niche. This description, however, is a description in terms of interactions into which the organism can enter, and not in terms of representations of environmental states.

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

1. by interacting with it in a manner such that the behaviors of the two organisms are directed to the interaction but each oriented from his own perspective, i.e. courtship. A chain of interlocked behavior can thus be produced between the two organisms;
2. by orienting the behavior of the other organism to some part of his domain of interactions different from the present interaction itself, but comparable to the orientation 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, though 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 to the observer) a communicable implicit description of the common niche by a behavior that orients the other organism within his domain of interactions, ‹Page 16› and elicits in it a conduct that the first could also have had but which is relevant independently of him. The elicited conduct, to the extent that it is an interaction into which the second organism enters, is a description of the niche. To the observer, the eliciting behavior is denotative, he can treat it as if it were pointing to a feature of the niche that can be described by the appropriate behavior. To the communicating organism the eliciting behavior is connotative, it implies the behavior that describes that particular aspect of the niche.

Linguistic behavior is orienting behavior (it orients the listener within his cognitive domain in a manner comparable to the orientation of the speaker) and its evolutionary history must be interdependent with the evolutionary increase in the complexity of the cognitive domain (the niche), through tool malting, for example, in strongly social animals. (The use of tools recursively increases the domain of interactions of an organism.)

During evolution only those interactions that are relevant to the maintenance of the circular organization of the living system are incorporated in his cognitive domain. As a consequence, the laws of interaction that govern the behavior of the organism (identity, distinction, order, etc.) are the same that it can encounter in its interactions.

If an organism can generate a communicable description of its interactions and then interact with the communicable description, the process can, in principle, be carried on in a potentially infinite recursive manner, and the organism becomes an observer. It can describe its interactions and communicate its descriptions to others or to itself, and through this very same process it can describe itself describing itself. Thus, discourse, originated through communicable descriptions, generates the apparent paradox of consciousness as a domain of pure self-description (hence, self-observation).

The observer: Epistemological and ontological comments ↑ ↓

The cognitive domain is the entire domain of interactions. This cognitive domain can be enlarged if new modes of interactions can be generated. Instruments enlarge our cognitive domain.

The possibility of enlargement of the cognitive domain is unlimited. Our brain, the brain of the observer, has specialized during evolution as an instrument to discriminate relations; both internally and externally generated relations, but relations given through and by the interactions. We cannot say in absolute terms what is the *input* to our nervous system (the nervous system of the observer) because *every* state of the nervous system can simultaneously be the input as well as the receiver and, hence, every change of state modifies the nervous system as an interacting unit. ‹Page 17› We can say that every interaction changes us because it modifies our internal state, changing the posture or perspective from which we enter into a new interaction. This necessarily creates new relations that we may detect.

The observer generates a spoken description (orienting behavior) of his cognitive domain, which Includes his interactions with instruments and through instruments. Whatever description he makes, however, the description is a set of permitted states of relative activity in his nervous system embodying his interactions. These permitted states of relative activity are made possible by the anatomical and functional organization of his nervous system, which, in turn, has evolved as a system subservient to the basic circularity of the living organizations, and, hence, embody an inescapable logic: that logic that allows for a match between the organization of the living system and-the interactions into which it can enter without losing its identity.

The observer can describe a system that gives origin to a system that can describe, hence, to an observer. This domain of discourse is a closed domain; it is not possible to step outside of it. Because it 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).

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 caan enter, and their discourse about these interactions will be another set of possible 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 made above.

For epistemological reasons we can say: there are properties; they are manifold and remain constant through interactions. The invariance of properties through interactions gives functional origin to entities or units of interactions, and, since entities are generated through the interactions that define them, they originate independent relational domains: no reductionism is impossible.

Aims of neurophysiology of cognition ↑ ↓

The observer can always remain in a domain of interactions encompassing that of the observed entity. The observer has a nervous system. He is able ‹Page 18› to interact with his own interactions and, hence, he is able to interact with (observe) his description of his niche. He can do this because in the general mode of organization of the nervous system there is no intrinsic difference between internally and externally generated states of nervous activity.

If the genetically determined (evolved) neurophysiological processes which permit orienting behavior (communicative behavior) do not specify particular orientations, but secure them in general, the organism can learn to orient itself to itself, that is, it can describe itself (self-description). Through describing itself in a recursive manner, the organism generates consciousness. Consciousness, then, is not a neurophysiological phenomenon, it is an epiphenomenon of orienting behavior that lies entirely in die linguistic domain. The consequences of this are twofold.

(1) The linguistic domain as a domain of orienting behavior requires not only two interacting organisms, but it also requires a basic coincidence in the domain of interactions of the latter, so that they may indeed orient each other to comparable interactions in their respective cognitive domains. Also, the specifiability of content of orienting behavior allows for a purely consensual (cultural) evolution in the domain of orienting behavior, without necessarily involving in it a further evolution of the nervous system: the contents of the linguistic domain are specified by agreement between the organisms interacting in this domain. For these reasons the linguistic domain in general, and consciousness in particular, appear to be independent of the biological substratum that generates them. This independence, however, is not complete, and the linguistic and conscious domains in man are biologically limited: *(a)* by the neurological and neurophysiological organization of the brain which specifies both, the domain of possible interactions through determining the actual possibilities for the confluence of different sensory modalities, and the complexity of the patterns of orienting behavior it can distinguish; *(b)* by the necessary subservience of these domains to the maintenance of the identity of the organism (its basic circular organization).

(2) If consciousness (and the linguistic domain in general) is not a neurophysiological phenomenon, but arises as an epiphenomenon from orienting behavior, the questions that one should then ask neurophysiology refer to the synthesis of meaningful behavior in general and of orienting behavior in particular. In other words, the encompassing neurophysiological questions become: How does the nervous system interact with its own internal states (states of rela–❮Page 19❯tive nervous activity that represent internal or external interactions), and is modified by them as if they were independent entities? And, how does the nervous system generate interactions which specify states of relative nervous activity which it can treat as entities (descriptions of the niche) with which it can interact in a recursive manner? In a system with a self-referred cognitive domain like a living system, meaning arises in relation to the interactions to which a given interaction gives origin by a sequence of processes through which the organism passes without losing its identity. In these circumstances, the concrete task is to elucidate how a given effector performance is synthesized so that it brings forth an interaction which, in turn, specifies a given state of activity at the receptor surfaces (that in turn specifies a state of relative activity in the subjacent neurons, and so on). How does this state of activity interact with the internal states of the nervous system to synthesize a new effector performance? All this is occurring in a deterministic manner akin to reflex processes, but different from these in that both the states of relative activity involved and the immediate relevance of any interaction for the generation of new interactions (meaning) are submitted to change through interactions.

Although there is the fundamental core of structural organization in the nervous system that is genetically and environmentally determined (during development, maturation, and under hormonal actions), which specifies the possible modes of conduct, the overall behavior of the organism should be looked at as a synthetic process; a synthetic process in which the relative weight of the interactions of the organism in the niche and its changing internal states in the generation of new behavior is determined by the past history (behavioral and developmental) of the organism. Thus, there are two complementary aspects to the understanding of the neurophysiology of cognition:

1. one that considers the nervous system as a state-determined system performing operations that in principle are indistinguishable from reflex processes, and which actually realize the behavioral processes that take places[Note 6]
2. one that considers how behavior acquires meaning by changing the transition rules (the relative weight of the different states of nervous activity) of the state-determined nervous system through actual behavior and survival. Consciousness, as all behavior that can be generated through language, arises in this manner. ❮Page 20❯

Artificial intelligence

To my understanding, the aim of research in artificial intelligence is to make an artificial cognitive system. Since much of what has been said above applies to machines, the following comments are ventured.

Machines differ from living systems not in the principles used for their function, but in their reference. The organization of machines is such that they always have an alloreferential domain of interactions, that is, the relevance of their functioning is determined by how they satisfy the desires of their maker. Living systems, on the contrary, as a result of their basic circular organization, necessarily have a self-referred domain of interactions; that is, the relevance of their functioning is determined by how it permits the maintenance of their basic circularity. If we consider the ordinary machines as alloreferential machines, we can consider the living systems as self-referential machines.

The artificial cognitive systems can be of two kinds:

1. those that will describe their interactions in our terms, that is, recognize what we recognize
2. those that will make descriptions in their own terms, but which we have to map afterward into ours.

In either case, I think, there is no need for imitating what occurs in our brain. In the first case, however, it would be essential to give the machine a domain of interactions like ours, not our description of it.

Postscriptum

There are numerous experimental studies and observations that show the neurophysiological processes associated with complex reflexes. [Note 7] Furthermore, much is known about networks and feedback interconnections associated with motor performances, particularly in relation to the cerebellum [Note 8] and spinal cord. Also, much has been investigated in relation to the reticular formation and its possible role in the control of behavior. [Note 9] The detailed list of specifiable modes of behavior that could be provided seems endless – how long must it grow? There are questions for which it is impossible to provide an answer because they are made in one relational domain and the answer must be expressed in the terms proper to another. Something like this, I think, has occurred in the study of the nervous system. The sum total of its component operation does not seem to account for the functioning of the whole, either because we have not yet discovered how certain operations are performed, or ❮Page 21❯ because the functioning of the whole belongs to a different phenomenological domain. The latter is obviously my view. It is stressed here, however, because of two reasons.

1. The consequences of considering the higher functions of man (and mammals in general) as being outside of the neurophysiological domain are paramount. It is not necessary to account for them in terms of neurophysiological process networks, spike potentials or whatever is of this domain; we have to account for the much simpler deterministic behavioral process which will give rise to them as a consequence of their operation in the domain of interactions between organisms. The nervous system is a state-determined system whose transition rules change and become specified through interactions that satisfy the basic circularity of the living organization.

2. There are different domains of interactions; these different domains cannot explain each other, that is, it is not possible to describe the phenomena of one domain with the notions proper to another. Any nexus between different domains is provided by the observer who can interact with the states of nervous activity generated in his brain by his concomitant interactions in several different domains, as if these conjoined states of activity constituted an independent entity (a relation). No reductionist position is tenable, and the number of such different and independent domains is, in principle, unlimited. A grasp of this situation is essential for the understanding of biological phenomena, their epiphenomena, and their evolution.

It was sometimes said during the conference that in the group there were no other biologists, hence no one could oppose my views. With this publication this, at least, is not true anymore.

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Endnotes

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