Nervous System as a Closed Neuronal Network: Behavioral and Cognitive Consequences

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Abstract.

We present here a theoretical framework about the nervous system operation that explains the origin of coordinated behavior without violating the structural determinism inherent to the constitutive autonomy of living systems. At the same time we will show that cognition is not the outcome of a computational task, as it is envisaged by the tradicional paradigm that considers the brain an information processing device, but rather is the results of the spontaneous structural coupling that take place ontogenically and phylogenically between a living system and its circumstances of living .

Introduction

Modern neurobiological thinking assumes that the nervous system, moment by moment, senses the external world, recognizes the configuration of stimuli and finally chooses an appropriate response. Under such view, the response of the nervous system is based on the correct determination of the entities present in the outside world, and in the ontogeny and phylogeny of that particular nervous system. This point of view (which we will call the "representationist framework" and wich could be summarized by the dictum "the brain is an information processing machine") underlies most of the research with respect to brain operation that has taken place during the second half of this century. But, in spite of the explosive development of the experimental research in the last two decades, it has become clear that many of the main questions about brain operation arising from such framework (such as object recognition or motor coordination) are still pretty much unsolved. The study of the vertebrate visual system gives a perfect example of such situation. In effect, if we arbitrary define Kuffler's experiments (1953) on the properties of retinal ganglion cells as the starting point of the research effort on this field, we find ourselves in the necessity to explain that 40 years latter, although immersed in a sea of anatomical and physiological details, we cannot imagine the "shape" that the representationist answer to the question "what is it to see?" will finally have.

The representationist framework has also been challenged from a theoretical perspective that considers autonomy and structural determinism as central features of living systems (Maturana, 1969, 1970, Maturana and Varela, 1973, 1980. A review of this growing field could be found in Mingers, 1995). Such theoretical thinking, embodied in the notion of "Autopoietic Systems", considers that the internal dynamics produced by the circular network of processes constituting the living organization cannot be specified by external stimuli. The internal dynamics and the observable states of autopoietic systems are the result of the operations of the living system itself, while external stimuli can only trigger, but never define, the magnitude, kind and direction of the structural changes that the system undergoes. Its seems that this new point of view creates for itself an apparently insurmountable problem, namely, to explain the origin of coherent and adequate behavior. This problem does not exist in the context of the representationist framework, as the observed congruence between behavior and medium is implicitly explained by assuming that such coherence is the outcome of an adequate operation of the nervous system on the representation that it has of the medium.

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In this paper we propose a new conceptual framework to understand the operation of the nervous system that: a) uses the autonomy of living systems as a central and starting point and b) avoids the seductive but sterile metaphor of "processing information". Developing this point of view, we shall also show: a) the unexpected relation between the problem of the nature of the living organization and cognition, b) the behavioral, as opposed to the computational, nature of cognition, and, perhaps more fundamentally, c) how the "external world" is not a given problem that the organism has to "solve" but that it is constituted through the interactions between an organism and its circumstances of living. We shall first present our biological fundaments, after that we shall develop our views about nervous system and its operation as component of the living systems, and finally we shall reflect about the behavioral nature of cognition.

I. Living Systems.

1) Living systems, as all systems that we deal with in our daily life and scientific endeavours, are structure determined systems (SDS). That is, they are systems such that all that happens in them and to them arises determined in their structure. Nothing external to an SDS can specify what happens in it. An external agent that incides on an SDS can only trigger in it a structural change determined by it. Moreover, the structure of an SDS determines also what it admits in an encounter as an agent that triggers in it a structural change (Maturana and Mpodozis, 1987). Structural determinism is not an a priori truth, not a principle, and not an ontological assumption, it is an abstraction that observers make of the regularities of theirs experiences as they use them to explain these experiences (Maturana, 1990).

2). Living systems are dynamic molecular structure determined systems, organized as closed networks of molecular interactions that produce the same kinds of molecules that produced them, and specify dynamically at every instant the extension and boundaries of the network. Such a network is closed in terms of its dynamics of states of molecular productions, but is open to the flow of matter and energy through it. Maturana (1970) and Maturana and Varela (1973) have shown that those statements constitute a complete characterization of living systems as molecular systems, specifying their conditions of existence and autonomy. Maturana and Varela (1973) called this organization the autopoietic organization, and claim that living systems are molecular autopoietic systems. According to this notion, cells are first order autopoietic systems and multicellular systems are second order autopoietic systems. A multicellular living system is realized through the autopoiesis of its cellular components, and through its own realization as a multicellular totality, make possible the autopoiesis of these. As autopoietic systems, living systems are in a continuous structural change, both as a result of their intrinsic internal dynamics, and as a result of the changes triggered in them in the course of their recurrent interactions in a medium. A living system lives as long as its structural changes take place in the conservation of its first or second order autopoietic organization.

3). A living system, as a composite cellular and molecular system, exists in two domains: a) in the domain in which its components realize it as a first or second order autopoietic entity, namely in the metabolic or physiological domain, and b) in the domain in which it interacts and relates with the medium that contains it as a totality, namely in the relational or behavioral domain. The phenomena of the metabolic or physiological domain take place in the structural dynamics of the components of the living system, and are totally contained in it. Contrariwise, the phenomena of the behavioral domain arise in the relation living system/medium, and are not determined by the living system or the medium alone. That is, the behavior of a living system is not something that the living system does, not something that the medium specifies of its own, the behavior arises and takes place in the relation living system/medium (Maturana and Mpodozis, 1987, 1992). There are, of course, as many different kinds of physiological and behavioral domains as there are different kinds of living systems with different structures and different manners of living.

4). The two phenomenal domains in which a living system exists cannot be reduced to each other because they take place in non intersecting phenomenal domains, and then, any attempt to explain the phenomena of one domain in terms of the other, is inadequate. There is, however, a recursive dynamic generative relation between them through the structural changes that living system and medium trigger in each other in the course of their interactions: A) as living system and medium interact, they trigger in each other structural changes; B) the structural changes triggered in the living system result in a change in the manner in which the living system encounters the medium in the next interaction, and the same happens with the medium with respect to the living system; C) as a result of what happens in moments A) and B), the relation between living system and medium changes, and the structural changes that living system and medium trigger in each other in their next encounter change too; and D) the process indicated in points A), B) & C), repeats recursively in a manner that appears to an observer both as if the behavior modulated the physiology, and as if the physiology modulated the behavior, even though they take place in phenomenal domains that do not intersect.

5). The ontogeny of a living system from its inception to its death takes place as an epigenetic process that results from a systemic dynamics involving a recursive interplay of physiological and relational phenomena, in the manner indicated above. So, a living system is a systemic entity that: exists as a living being in the physiological domain of its bodyhood and, realizes its manner of living in its domain of relations in recurrent interactions with the medium, through a dynamic interplay of its body dynamics and its behavior. Accordingly, what reproduces when a particular living system reproduces, is a particular systemic entity whose realization takes place in the continuous dynamic interplay of a particular bodyhood and a particular configuration of dynamic circumstances that have arisen in the medium along the phylogenic history of the reproducing living system. At the same time, what is organically passed to the next generation through reproduction is an initial structural configuration that makes possible the epigenetic realization of a particular manner of living that entails the systemic conservation of a particular bodyhood and bodyhood dynamics if it is placed in the proper circumstances of the medium. Inheritance, then, as it consist in the reproductive conservation of an epigenetic manner of living, is a systemic process, and as such is not determined by any particular set of molecular or cellular components, however essential these may be for its occurrence (Maturana and Mpodozis, 1992).

6). When the realization of a manner of living begins to be systemically conserved generation after generation through reproduction, a lineage is constituted and established. Such lineage will last as long as that manner of living remains conserved. Moreover, as a lineage is constituted and conserved in the systemic conservation of the manner of living that defines it, all the features of the physiological domain, as well as all the features of the relational domain of the living systems that realize the lineage, become free to change around that which is conserved, in a way in which both living systems and medium remain in dynamic reciprocal operational congruence (Maturana and Mpodozis 1992). In these circumstances a new lineage arises when some variation in the realization of a particular manner of living becomes part of the manner of living henceforth systemically conserved generation after generation (Maturana and Mpodozis, 1992).

7). As a conclussion, it is possible to say that the recursive ontogenic and phylogenic mutual modulation of behavior and structure that take place trough the interactions between living systems and medium have two fundamental results. The first is that the structure of the living system and the structure of the medium change together, and in congruence, both in ontogeny and philogeny. The second is that all living systems at every moment of their ontogenic an phylogenic histories necessarily have dynamic structures that are adequate for the generation of a behavior adequate for the dynamic medium in which they are alive, or they die.

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II. Nervous System and Behavior.

1). Multicellular organisms usually present a nervous system, that is, a closed network of synaptically interacting active cellular components (nerve, muscle and secretor cells), that we shall call neural elements . The nervous system operates as a closed network of changing relations of activity between its neuronal components: any change in the relations of activity holding between some components of the network leads to further changes in the relations of activity holding between other components of it, an so on recursively, in a potentially never ending dynamic (Maturana 1969; Maturana and Varela, 1980; Maturana and Mpodozis 1987). The course that follows these changes of relations of activity is at every moment determined by the state of the activity of the neuronal elements of the network at that moment. At the same time, the state of activity of the cells that compose the neuronal network is at any moment the result of the state of their dynamic structure at that moment, and change as this change through their synaptic operations within the network and through their structural intersection (by means of synaptic, trophic, hormonal and transducer-like effects; see below) with other components of the network and the organism.

2). The nervous system structurally intersects the organism at several body areas that constitute the latter' s internal and external sensory and effector surfaces. The external surfaces constitute the interfaces by which the organism encounters the medium. The internal surfaces constitute the interfaces by which the nervous system, as a component of the organism, encounters the physiological dynamics of the organism. Accordingly, the neural components of the sensory and effector areas have a double identity and a double operation. First, as elements of the nervous system they operate in the closed dynamics of changing relations of activities of the nervous system. Second, as parts of the organism they operate as components of its surfaces of internal and external interactions.

3). As a consequence of this structural intersection, the nervous system through its operations as a closed network of changing relations of activity between its neuronal components, continuously generates in the organism sensory/effector correlations that modulate both the flow of its interactions in the medium, and the flow of its physiological dynamics. The behavior of the organism arises in the dynamic encounter organism-medium through the sensory/effector correlations of the organism and the structural dynamics of the medium. Therefore, the nervous system participates in the generation of the behavior of the organism through the sensory/effector correlations to which it gives rise at any moment, according to its structure at that moment.

4). The nervous system does not interact with the medium, it is the organism that does so through the operation of its effector and sensory surfaces. It is the structure of the organism as a whole that determines wich sensory/effector correlations are possible for it, not the dynamics of the nervous system alone. All that the nervous system can do as it intersects with the external and internal sensory and effector surfaces of the organism, is trigger in these structural changes that result in one or another of the sensory/effector correlations that are possible for the organism according to its present structural dynamics (Maturana and Mpodozis, 1987). Furthermore, the structural changes triggered in the external sensors both, as components of the sensory surfaces of the organism and as neuronal elements, are determined in their structure and not by the circumstances of the interaction that trigger them. In these circumstances, as the organism interacts with its medium, its nervous system undergoes changes in the flow of its synaptic operations that are contingent to the interactions organism-medium, but that are determined by the structure of the nervous system, and not by the characteristics of the medium. As a result, the nervous system does not and cannot operate with representations of the medium, and what it does, it does according to its structure at any moment.

5). The structure of the neural cells is in continuous change, both as a consequence of its own autopoietic dynamics and as a consequence of its participation as components of the nervous system and the organism. Some of these structural changes are specially relevant,

because they entail long term changes in the synaptic dynamics of the neural cells. As far as we know, these structural changes happen in four ways: A) Through the so called "transducer effects", that are structural changes triggered at the neural component of the sensors through the encounters of the organism with the medium. These structural changes have been traditionally called "transducer effects", through thinking that what is significant in them is an energy transfer. According to us, what is significant is that these structural changes are those that coupled the activity of the nervous system to the flow of interactions of the organism or to is internal physiological dynamics. B) Through synaptic effects, which are structural changes of different time constants triggered in the neural cells by the actual flow of synaptic interactions. C) Through trophic effects, which are structural changes that arises in the neural cells triggered by substances of neural origin that are produced by processes orthogonal to the synaptic flow (because they involve molecules and cellular interactions which are not proper to the synaptic operation of the nervous system) but contingent to it. D) Through hormonal effects, which are structural changes triggered in the neural cells by substances produced in the organism through physiological process that do not involve directly the operation of the nervous system.

6). If we consider together points II-3, II-4 and II-5, it becomes clear that although the medium does not specifiy what happens in the nervous system, during the ontogeny of an organism the structure of its nervous system (the neural conectivity, the cellular dynamics of production of neurohumors, membrane receptors, molecular channels, etc.) changes in a manner contingent to the flow of interactions of the organism in the medium, to the internal physiological and developmental history of the organism, and to the flow of the operation of the nervous system as a component of the organism.

7). The structure of an organism and the structure of its nervous system are structures that have arisen in a evolutionary history of transgenerational conservation of a manner of living (see I-5). Such history is in fact an epigenetic relational dynamics organism-medium, that consists of the realization of the living of the organism. For these reasons, the structure of the nervous system, as it arises through its development in any particular organism, and the closed dynamics of changing relation of activity that it generates during its development, cannot but be adequate for the generation of the particular interactional behavioral dynamic that the manner of living of the organism entails.

8). The course of the structural changes that the nervous system undergoes through the life history of the organism that it integrates, is de facto constrained by two conditions: A) by the structure that the nervous system has as a component of an organism that belongs to a particular lineage, as its follows from I-7, and B) by the actual contingencies that occur in the living of the organism, through the processes described in I-5, II-5 and II-6. As a consequence of this, every organism has at every moment a nervous system adequate to the generation of the sensory/effector correlations proper to its particular history of realization of its manner of living, precisely because the structure of its nervous system is the present of a history of structural changes contingent to the course of the phylogenetic an ontogenetic history of this organism. In other words, every animal always has a nervous system proper to its biological identity, as this consists and is realized in the relational space of its manner of living.

9). It follows from the previous points that a nervous system operates with different dimensions than those with which the observer sees the organism to operate in the relational and interactional space in which it exists as a totality. The observer sees the organism in its relational and interactional space interacting and relating with entities of different kinds or (in the case of social animals) with relations and symbols as if these were also entities. The nervous system in its internal dynamics, however, operates as a closed network of changing relations of activities between its component elements, and not with the kinds of entities that arise in the domain of relations and interactions of the organism.

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10). In summary, the nervous system as a component of a living system, is constituted as a closed network of neuronal elements that operates as a closed recursive network of changing relations of activities (between the neuronal components) in which every change of relation of activity recursively leads to other changes of relations of activities in it. The nervous system as such a neuronal system intersects with the organism at its sensory and effector surfaces, and its closed operation gives rise to sensory/effector correlations in the organism that in the interactions of the organism in its medium, constitute its behavior. The nervous system does not operate making representations of the medium in which the living system that it integrates exists. Nevertheless, it has a plastic structure that changes following the contingencies of the living system while this system maintains its autopoietic organization in a medium. As a result of these structural changes, the closed operation of the nervous system continuously gives rise to configurations of sensory/effector correlations in the organism that realize its living in its changing medium, until this congruence is lost and the organism dies.

III. Final reflections. Cognition or Behavior ?

In general terms, an observer claims that cognition takes place in a system when he or she sees that the system behaves adequately as it operates in a given domain of interactions, in the understanding that a behavior is adequate because the system conserves through it certain features, or gives rise to some results that the observer defines as of importance. When the systems is a living system, and the observer is a biologist, adequate behavior usually means behavior adequate to the survival and to the realization of the manner of living of the living system .

In the representationist framework, cognition cannot but be the result of a process trough wich a system generates an internal representation of its medium, and computes a behavior according to its goals or purposes. In this framework, cognition is a feature adscribed to a system, both to describe the operational congruence of a living system and its medium, and to explain such operational congruence as a result of the operation of some special "cognitive"processes. The existence of these special cognitive processes indeed violates the constituve autonomy of living systems as structure determined systems, since it would requiere that the perturbations that impinge upon a system could specify the characteristic of the internal structural transitions that the system will undergoe. To accept that would be equivalent to state that the finger that dials a telephone number has the property of specifying the subsequent behavior of the thelephone network. Even more, this example makes easy to note that from the point of wiev of the internal telephone mechanism it is absolutely impossible to ascertain wich finger operated it, or even whether the mechanism was triggered by a finger, a pencil, or any other object or circumstance.

What we have said in this article can be used to explain cognition without having to suppose the existence of any special computational or informational process. It is esay to follows from the previous points that cognition is not something that a system has, nor something that a system acquieres trough its interactions. Cognition is the adequate behaviour of a system in a medium, that results from the dynamic structural congruence between such a system and that medium. As such, cognition only entails the dynamic structural congruence which arises spontaneously between systems that do enter in recursive interactions, as a dynamic system and its medium nessesarily does. Cognition, then, will takes place in the relational space or domain of interactions of any dynamic system while it operates in structural coupling with its circumstances, and then cannot be consider as a feature or property of the system itself. Therefore, cognition does not requiere nor does its involve any operation that an observer could treat as generating a representation of the medium to be used to obtain behavioural effectiveness.

Although living systems are autopoietic systems, it is not their autopoiesis which makes them cognitive systems. Rather, it is their manner of operation as dynamic autonomous entities with a plastic structure. In living systems, cognition arises as a result of its phylogenic and ontogenic history of structural coupling with its circumstances of

living. All living systems at all moments of the history of the biosphere are born with an initial structure which, if deposited in the proper place, allows them to live an epigenesis in which they become transformed in congruence with the medium while realizing the particular manner of living of their kind. In a strict sense, as a living system lives, it does not encounter a preexisting medium, but this medium arises with its operation, even if for the observer it seems to be already there. Also, the characteristics that the medium acquires as the space of living (niche) of each living system, arise in the realization of the manner of living of the living system (Maturana and Mpodozis, 1992). It is here where the nervous system has a central participation in the generation of a domain of structural plasticity that goes beyond of what the organism does alone, and allows for an enormous expansion of the domain of possible states of the organisms in autopoiesis.

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