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The Organization of the Living: A Theory of the Living Organization*

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The fundamental feature that characterizes living systems is autonomy, and any account of their organization as systems that can exist as individual unities must show what autonomy is as a phenomenon proper to them, and how it arises in their operation as such unities. Accordingly the following is proposed.

(1) That autonomy in living systems is a feature of self-production (autopoiesis), and that a living system is properly characterized only as a network of processes of production of components that is continuously, and recursively, generated and realized as a concrete entity (unity) in the physical space, by the interactions of the same components that it produces as such a network. This organization 1 call the autopoietic organization, and any system that exhibits it is an autopoietic system in the space in which its components exist; in this sense living systems are autopoietic systems in the physical space.

(2) That the basic consequence of the autopoietic organization is that everything that takes place in an autopoietic system is subordinated to the realization of its autopoiesis, otherwise it disintegrates.

(3) That the fundamental feature that characterizes the nervous system is that it is a c10sed network of interacting neurons in which every state of neuronal activity generates other states of neuronal activity. Since the nervous system is a component subsystem in an autopoietic unity, it operates by generating states of relative neuronal activity that participate in the realization of the autopoiesis of the organism which it integrates.

(4) That the autopoietic states that an organism adopts are determined by its structure (the structure of the nervous system included), and that the structure of the organism (including its nervous system) is at any instant the result of its evolutionary and ontogenic structural coupling with the medium in which it is autopoietic, obtained while the autopoiesis is realized.

(5) That language arises as phenomenon proper to living systems from the reciprocal structural coupling of at least two organisms with nervous systems, and that self·consciousness arises as an individual phenomenon from the recursive structural coupling of an organism with language with its own structure through recursive self-description.

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PURPOSE

My purpose in this article is to present a theory of the organization of living systems as autonomous entities, and a theory of the organization of the nervous system as a closed network of interacting neurons structurally coupled to the living system to whose realization it contributes.

ANTECEDENTS

(a) There is no adequate theory of the organization of living systems as individual autonomous unities. There are only descriptions of sorne of their internal states and of their states of interaction as these appear projected upon the domain of observation and purposeful design of the observer. Thus, reproduction, processing of information or internal hierarchical relations, are described as fundamental constitutive features of the living organization. Yet, at a closer scrutiny, none of these features appears to be exclusive, or definitory of living systems. In fact, reproduction is trivially non-constitutive, even though it is necessary for evolution, because living systerns are living systems, whether in reproduction or not, as long as they are "alive". The notion of processing of information represents a way of description of the interactions and changes of state of a sysytem, and as such it is applicable to any possible dynamic system. Finally, the posession of internal hierarchical relations is a featurc that an observer can ascribe to any mechanistic system to which he assigns an initial and a final state in its sequential-state transitions. The same applies to the nervous system. There is no adequate theory of the nervous system as a neuronal network embedded in an autonomous living unity; there are only descriptions of the state transitions of the nervous system viewed as an input-output system designed for the processing of environmental information. The result of this view is the treatment of the nervous system as an organ through which the organism becomes semantically coupled to its environment, as if the features of the description (semantic relations) were effective operative components in the changes of state of the organismo

(b) It is the aim of many scientists who work in automata theory to model the most unique phenomena generated by living systems such as autonomy, language and self-consciousness. Such an aim, however, cannot be achieved in the absence of a theory that shows the nature of these phenomena and how they arise in biological systems.

PRELIMINARY CONCEPTS

Observer. An observer is a human being, a person; someone who can make distinctions and specify that which he distinguishes as an entity (a something) different from himself, and can do this with his own actions and thoughts recursively, being always able to operate as if external to (distinct from) the circumstances in which he finds himself. All the distinctions that we handle, conceptually or concretely, are made by us as observers: everything said is said by an observer to another observer.

Unity. A unity is any entity (concrete or conceptual) separated from a background by a concrete of conceptual operation of distinction. A unity may be treated as an unanalyzable whole endowed with constitutive properties, or as a composite entity with properties as a unity that are specified by its organization and not by the properties of its components.

Interaction. Whenever two unities, specified by their properties and as a result of the interplay of these properties, appear to modify their relative states in reference to the larger systems in which they are embedded, there is an interaction.

Space. Space is the domain of all the possible relations and interactions of a collection of elements that the properties of these elements define.

Explanation. An explanation is always addressed by an observer to another observer. An explanation is an intended reproduction. A system is explained when the relations which define it as a unity are, either conceptually or concretely, intentionally reproduced. A phenomenon is explained when the processes which generate it are, either conceptually or concretely, intentionally reproduced in a manner that shows that by their operation they generate the phenomenon to be explained. It follows that there are two basic problems that must be solved in any explanation, namely: (a) the distinction and identification of the unity or phemonenon to be explained; and (b) the conceptual or concrete reproduction, either of the organization of the unity or of the mechanisms and processes that generate the phenomenon to be explained.

Organization. This word comes from the Greek term *opyavov* (organon) that means instrument, and by making reference to the instrumental participation of the components in the constitution of the unity, it refers to the relations between components which define a system as a unity. So, in order to define a system as a unity it is necessary and sufficient to point to its organization. From the cognitive point of view, the organizations of a unity specifies the concept which defines the class of unities to which it belongs.

Structure. This word comes from the latin verb *struere* that means to build, and by making reference to the process of construction as well as to the components of a construct, it refers to the actual components and to the actual relations which these must satisfy in their participation in the constitution of a given unity. An observer may recognize a known system by identifying 'its components, but an unknown system cannot be defined by pointing to its structure.

Organization and structure, therefore, are not synonyms. The organization of a composite system constitutes it as a unity and determines its properties as such a unity, specifying a domain in which it may interact (and be treated) as an unanalyzable whole. The structure of a composite system determines the space in which it exists and can be perturbed, but not its properties as a unity. An unanalyzable unity can be identified by a concept, but it does not have an organization, nor does it have a structure, it only has properties as a fundamental element that exists in a space which these properties specify. It follows that two spatially separated composite unities may have the same organization but different structures and that a composite unity (system) remains the same only as long as its organization remains invariant: whenever the organization of a unity changes the unity changes, it becomes a different unity; whenever the structure of a unity changes without change in its organization, the unity remains the same and its identity stays unchanged. It also follows that when the organization of a unity is to be explained it is a mistake to reproduce its structure, it is necessary and sufficient to reproduce its organization and, thus produce one of the kind; yet, when a particular unity is to be reproduced, both its organization and its structure must be reproduccd.

Furthermore, since a composite unity interacts through the properties of its components, and an unanalyzable one through its constitutive properties as a unity, all interactions between unities, including interactions with the observer (observation), are necessarily structural interactions in the space of the components. Therefore, when an observer refers to the organization of a cornposite unity, he refers to the relations which realize the concept that defines the c1ass of unities to which the observed composite unity belongs.

State-determined system. A state-determined system whose changes of state, defined as structural changes without loss ofidentity (defining organization), are determined by the stIucture of the system and not by an independent perturbing agent. This is a universal constitutive feature of dynamic systems.

Consensual domain. A consensual domain is a dornain of interlocked (intercalated and mutually triggering) sequences of states, established and determined through ontogenic interactions between structurally plastic state-deterrnined systems. A consensual domain can become established only when the plastic interacting systems are homeostatic systems that maintain constant their essential variables through their mutual interactions. Living systems do establish consensual domains through the maintenance of their living organization.

Phenomenological domain. Domain of interactions specified by the properties of the interacting unities, regardless of whether these unities are simple or composite. Therefore, when a unity is defined, through the specification of its organization or by pointing to its properties, a phenomenological domain is defined.

Purpose

After these preliminary considerations, and given that living systcms exist and that sorne of them have a nervous system, the two aims of this article can now be preciseiy stated as follows.

(a) To explain the organization ofliving systems by describing the organization that constitutes a system as an autonomous unity that can, in principie, generate *al! the phenomenology* proper to living systems if the adequate historical contingencies are given.

(b) To explain the organization of the nervous system by describing the organization that makes a neuronal network, integrated as a component subsystem in an organism, a system that can generate *al! the phenomenology* proper to a nervous system.

Tbeory

AUTOPOIESIS (**αὐτόσ** = self; **ποιειν** = to make)

Living systems are given and they generate a specific phenomenoiogy, the phenomenology of living systems. Therefore, in order to explain living systems it is necessary and sufficient to point to the organization that defines a class of unities that generates a phenomenology indistinguishable from the phenomenology proper to living systems. Such an organization can be described as follows.

There is a c1ass ofmechanistic systems in which each member ofthe c1ass is a dynamic system defined as a unity by relations that constitute it as a neto work of processes qf production of components which: (a) recursively participate through their interactions in the generation and realization of the network of processes of production of components which produced them; and (b) constitute this network of processes ofproduction of components as a unity in the space in which they (the components) exist by realizing its boundaries.

Such systems 1 caIl *autopoietic systems:* the organization of an autopoietic system is the *autopoietic organization.* An autopoietic system that exists in the physical space is a living system (Maturana & Varela, 1973; Varela, Maturana & Uribe, 1974).

As a result of their organization, autopoietic systems operate as homeostatic systems that have their own organization as the critical fundamental variable that they actively maintain constant. In an autopoietic system aH its (dynamic) states are states in autopoiesis and lead to autopoiesis. In this sense, autopoietic systems are closed systems, and, as a result ofthis, aIl the phenomenology of autopoietic systems is necessarily subservient to their autopoiesis, and a given phenomenon is a biological phenomenon only to the extent to which it involves the autopoiesis of at least one living system.

NERVOUS SYSTEM

The nervous system is given as a network of interacting neurons that generates a phenomenology subservient to the autopoiesis of the organism in which it is embedded. Therefore, in order to explain the nervous system as a system, it is necessary and sufficient to point to the organization that defines a neuronal network that generates a phenomenology indistinguishable from the phenomenology proper to the nervous system as it exists as a constitutive component of an autopoietic system. Such organization can be described as foIlows.

The nervous system is defined as a unity (that is, as a system) by relations that cOllstitute it as a c10sed network of interacting neurons such that any change in the state of relative activity of a coIlection of neurons leads to a change in the state of relative activity of other or the same collection of neurons: aH states of neuronal activity in the nervous system always lead to other states of activity in the nervous system.

A closed neuronal network does not have input or output surfaces as features of its organization, and although it can be perturbed through the interactions of its components, for it, in its operation as a system, there are only its own states of relative neuronal activity, regardless of what the observer may say about their origino Given a closed system, inside and outside exist only for the observer who beholds it, not for the system. The sensory and the effector surfaces that an observer can describe in an actual organism, do not make the nervous system an open neuronal network because the environment (where the observer stands) acts only as an intervening element through which the effector and sensory neurons interact completing the closure of the system.

If the observer, either experimentally or conceptually, were to open the nervous system at sorne synaptic surface, and describe the transfer properties of the system thus obtained in terms of input and output relations, he would have an open network, but not a nervous system. This is what in fact happens when the observer describes the organism as a system which has independent sensory and effector surfaces for its interactions with the environment: he opens the nervous system and destroys its organization, leaving only an open neuronal network that can be described in terms of hierarchical transfer functions which are relevant only for the descriptive system of references introduced by the observer, who describes the changes of state of the nervous system by mapping them upon the changes of state of the environment (observable medium). As a elosed neuronal network, however, the state-determiued system that the nervous system is operates by generating relations of neuronal activity determined by its structure, regardless of environmental circumstances. The observable effectiveness that the relations of neuronal activity generated by the nervous system have for the realization of the autopoiesis of the organism under environmental perturbations results from the structural correspondence that actual!y exists between nervous system and organism, and between these and the medium in which the autopoiesis of the organism is realized.

IMPLICIT REQUIREMENTS

An autopoietic system is a state-determined composite dynamic unity. Therefore, although the characterization of an autopoietic system does not require any statement about the characteristics of the medium in which the autopoiesis is realized, the actual realization of an autopoietic system in the physical space requires of a medium that provides the physical elements that permit the processes of production of components to take place. This medium ineludes al! that is operational!y different from the autopoietic unity, that is, al! that at sorne instance may constitute a perturbation, even components of the systern itself. It is, then, an implicit constitutive condition for autopoiesis that the autopoietic unity exists in a medium within which it interacts, and within which an observer can see it interchange elements with an environment.

PLASTICITY AND STRUcrURAL COUPLING

The interactions of a composite unity in the space of its components are interactions through its components, that is, are structural interactions. If as a result of a structural interaction the components of a unity, or their relations, change, the structure of the unity changes, and, if these structural changes occur without a change in the organization of the unity, the identity of the unity remains invariant. A unity whose structure can change while its organization remains invariant is a plastic unity, and the structural interactions under which this invariance can be sustained are perturbations. Since the changes of state of an autopoietic system are determined by its structure, the perturbations under which the autopoietic unity undergoes its changes of state (changes of structure without loss of identity) constitutes only triggering events that couple the sequence of the changes of state of the autopoietic unity to the sequence of the changes of state of the medium that constitute the perturbations. Given that it is a constitutive feature of an autopoietic unity to homeostatically maintain invariant its organization under conditions of structural change, the realization of the autopoiesis of a plastic autopoietic unity under conditions of perturbations generated by a changing medium, necessarily results either in the establishment in the autopoietic unity of a structure that can generate specific changes of state that can be triggered by specific perturbing changes of state of the medium, or in its disintegration. The result of the establishment of this dynamic structural correspondance, or *structural coupling,* is the effective spatio-temporal correspondance of changes of state of the organism with the recurrent changes of state of the medium while the organism remains autopoietic.

The same arguments can be applied to the nervous system whose organiza. tion must be invariant, but whose structures needs not be so and may be plastic, with a dynamic of structural change coupled to the dynamic of structural change of other systems such as the organism which it integrates, and, through this, to the medium in which this exists. In fact, if the structUle of the nervous system changes, the domain of the possible states of neuronal activity of the nervous system, and, hence, the domain of the possible behavioural states of the organism itself, change too. Therefore, if as a result of the structural changes of the nervous system the organism can go on in autopoiesis, the new nervous system's structure obtained may constitute the basis for a new structural change which may also permit the organism to go on in autopoiesis. In principie, this process can be recursively repeated endlessly along the life of an organism, and generate a process of continuous structural transformation that specifies the relations of neuronal activity that the nervous system generates in its participation in the autopoiesis. The consequences of this structural coupling are threefold:

(a) while the autopoiesis lasts, the changing structure ofthe nervous system is necessarily that which generates the state of relative neuronal activity that participate in the continued autopoiesis of the organism in the medium in which it exists;

(b) while the autopoiesis lasts, the nervous system operates as an horneo· static system that generates relations of neuronal activity that are subordinated to and determined by the actuallealization ofthe autopoiesis ofthe organism which it integrates;

(c) while the autopoiesis lasts, the structural couplíng of the nervous system to the organism and medium, revealed as a spatio-temporal corres-pondance between the changes of state of the organism and the changes of state of the medium (recursively including the organísm and the nervous system itself), appear to an observer as a semantic couplíng.

In general, then, the reciprocal structUIal coupling of the organism and nervous system, and their simuitaneous structural coupling to the medium in which the autopoiesis is realized, are necessary consequences of the contínued autopoiesis of the organism when these systems have plastic structures.

ONTOGENY AND EVOLUTION

The history of structural changes without loss of identity in an autopoietíc unity is its ontogeny. The coupling of the changing structure of an auto-poietic unity to the changing structure of the medium in which ít exists, is ontogenic adaptation. The ontogenic adaptation of the nervous system ís learning; or, in other words, given that the structure of the nervous system is plastic and that the nervous system ís subservíent to the autopoiesis of the organism which is íntegrates, the determínatíon through structural coupling along the ontogeny of the organism of the relatíons of neuronal actívíty that the nervous system generates or maintains invariant, is the phenomenon of learning. In general, then, due to the homeostatic nature of the autopoietic organízation that ensures that this organization is actively maintained con-stant, while the structure of the organism changes, ontogenic adaptation, and learning if there is a nervous system, are necessary consequences of ontogeny: if ontogenic structural coupling of organism, nervous system and medium do not take place, the autopoietic system disintegrates. The same argument applies to the history of structural change of reproductively generated autopoietic activities. Such a history is organic evolution

DESCRIPTIVE FALLACY

The process of structural coupling between two or more state-determined systems, one of which, at least, is autopoietic, as a historical process leading to the spatio-temporal coincídence between the changes of state of the coupled systems, arises as a necessary spontaneous consequence of the mutual operative restrictions to which the state-determined systems submit to each other during their interactions without loss of identity. This spatio-temporal coincidence in the changes of state of the coupled systems, however, is usually described by the observers as a semantic coupling, that is, as if it were the result of the cornputation by the autopoietic systern (the organism) of its own adequate changes of state after gathering the proper information frorn the environrnent; in other words, as if the changes of state of the autopoietic systern were deterrnined by the environment. Such a description, though, does not reflect any phenomenon actually taking place among state deter-rnined systerns: (a) because the notion of inforrnation is valid only in the descriptive domain as an expression of the cognitive uncertainty of the observer, and does not represent any cornponent actually operant in any rnechanistic phenornenon in the physical space; and (b), because the changes of state of a state deterrnined systern, be it autopoietic or not, are deterrnined by its structure, regardless of whether these changes of state are adequate or not for sorne purpose that the observer rnay consider applicable. Therefore, any description which irnplies a sernantic coupling between structurally coupled state·determined systerns, and which is not intended as a mere rnetaphor, is intrinsically inadequate and fallacious.

Implications

The fact that, as the previous characterizations show, an autopoietic system in the physical space, and the nervous system that may be one of its cornpo-nent subsysterns, are closed systerns, determines the occurrence of three distinct phenornenologicaJ dornains that can be described as follows:

(a) the domain of the internal changes of state of a systern in which all state transitions occur without the systern losing its identity;

(b) the domain of perturbations of a systern in which the system can inter-act through its cornponents in the space in which it exists as a unity and, as a result, undergoes changes of structure without loss of identity; and,

(c) the dornain of interactions of a systern as a (non-cornposite) unity in the space which its properties as a unity define, regardless of how these pi operties arise.

The first phenornenological dornain is the dornain of realization of a systern as a systern; in the case of an autopoietic systern this domain is the dornain of its autopoiesis to which everything in it is subordinated as a necessary con-dition for its existence; in the case of the nervous system this domain is the dornain of its operation as a closed neuronal network. The second phenomen-ological dornain is the dornain of structural coupling of the organisrn and the nervous systern to each other and to the rnediurn in which the autopoiesis of the organisrn is realized, and, therefore, the domain in which the structural phenornena that we describe as adaptation and learning occur. The third phenornenological domain is the dornain where cognition takes place as a phenomenon of observable rnanipulations of an environrnent, and where the observer arises as a systern that can rnake descriptions, and alwaysrernain external to its circurnstances by treating descriptions as objects of further descriptions.

The following are sorne general irnplications of this.

(a) If the autopoiesis of an autopoietic unity is realized through a distributed structure that ensures a distributed autopoiesis, a simple rnechanical fragrnentation of the autopoietic unity (self-division or self-reproduction) produces at least two new autopoietic unities that rnay have identical or difIerent structures according to how uniforrn was the cornponent's distribution in the original unity. Heredity of organization and structure with the possibility of hereditary structural change is, therefore, a necessary consequence of distributed autopoiesis. If there is difIerential realization of autopoiesis arnong structurally difIerent autopoietic unities due to disuniforrnities in the rnediurn in which they exist, evolution is a necessary consequence if the autopoietic unities are generated through self-division.

(b) AII the states that an autopoietic systern can adopt are states in autopoiesis, and are necessarily deterrnined by its organization and structure, not by the perturbations arising in the rnediurn in which it exists. Cognition, at whatever level of concreteness or abstraction, as a phenornenon of operation of the organisrn (as a unity) in its rnediurn, also necessarily consists at the level of the internal dynarnics of the unity in the actual realization of its autopoiesis. Therefore, in a strict sense, for any organisrn its cognitive dornain is its actual dornain of autopoiesis.

(c) Iftwo plastic autopoietic systerns interact, and their structures becorne ontogenetically coupled as a result of these interactions, a consensual dornain of conduct is developed between the two organisrns as a dornain of conduct in which the participation that the conduct of one organism has for the realization of the autopoiesis of the other organisrn becornes determined during the interactions through their structural coupling. Such a consensual dornain of conduct is a linguistic dornain, and as such it is a dornain of descriptions in which the conduct of one organisrn can be taken by an observer as a description of the consensual conduct which it elicits in the other organisrn.

(d) If an organisrn is capable of consensual conduct and of recursively interacting with its own states (through internal interactions of its closed nervous systern), and applies the descriptive operation to itself by developing a consensual dornain with itself through interactions with its own consensual states, a new phenornenological dornain is generated that is indistinguishable from that which we call our dornain of self-consciousness.

Comments

THE OBSERVER

Everything said is said by an observer to another observer; furthermore, the observer can always recursively be an observer of his observation and stay external to the description of his circumstances. This he can do because everything he does is mapped in the same domain: the domain of relative neuronal activity in his closed nervous system. Interactions of the nervous system with its own states of neuronal activity allow, in principIe, for infinite recursion with continuous behavioural change. The domain of descriptions in which the observer arises when in the course of evolution the nervous system becomes able to recursively interact with its own states, is also a closed domain.

THE THEORY

The purpose of this thoery is to give the fundamental set of necessary and sufficient notions capable of explaining all the phenomenology of living systems. Therefore, no attempt has been made to explain any particular biological phenomenon; aH particular phenomena should be explainable by the theory if the proper contingent circumstances of their realization are taken into consideration. AIso, 1 have made no attempt to give this theory a mathematical formalism, first, because 1 am incompetent to do it, and second, because 1 consider that such formalism is necessarily secondary to the complete conceptual statement of the theory which 1 have here presented.

Basic requirements that the theory satisfies are as follows.

(a) To use only simple operative concepts of immediate validity to any observer as a natural and as a scientific persono

(b) To state only necessary conditions that cannot be taken for granted. Thus, when talking of processes of production of components (such as molecules, polymers, etc.) no statement is made about their physical or chemical legality, obviously because in nature there only occur those chemical reactions or physical processes that can occur. Therefore, if a given set of components cannot generate the processes that constitute an autopoietic system, they do not constitute an autopoietic system, without this invalidating the notion of autopoiesis. A truism is implicit: autopoiesis takes place whenever it can take place.

(c) To specify only the conditions which generate phenomena that are isomorphic with the phenomena to be explained, and not with the description of the phenomena as they appear to the observer.

(d) To provide a mechanistic explanation for al! biological phenomena, that is, to show that all biological phenomena arise from the interactions of the proper components, and not as an expression of the properties of sorne components.

(e) To point to conditions that can be realized through neighbourhood relations without invoking organizing principIes of any kind which pretend to subordinate the components to the whole. The unity, the whole, is the result of the interactions of the components through the reaJization of the organization that defines it, and not an operant factor in the interaction of the components that generate it. For the purpose of communication, an observer that behoIds simultaneousIy the unity and its components may describe the latter with reference to the former, but this is merely a descriptive metaphor and not a refiection of the constitution of the unity. A unity if composite, is fully specified by specifying its organization.

To the extent that these basic requirements have been fulfilled, the theory reveals living systems as having a fundamentally simple organization which can arise spontaneousIy, and inevitabIy, in any part of the universe when certain conditions are given. AII the structural compIexity of present-day living systems is the result of their evolutionary and ontogenic histories, and, therefore, irrelevant to the description of their organization.

POINTING TO A UNITY

The basic operation that an observer perforrns (although this operation is not exclusive to observers) is the operation of distinction; that is, the pointing to a unity by performing an operation which defines its boundaries and separates it from a background. The observer, then, aIways specifies the unity that he observes through sorne expIicit or implicit operation of distinction, and always implies by his observation an organization in it that is compatible with its implied or specified boundaries if it is a composite unity. This is a fundamental point for three reasons.

(a) Given an operation of distinction that separates a unity by specifying its boudaries, usually there are many organizations that could define a unity with such boundaries as partiaI boundaries, but which would strictIy specify different unities. There is, therefore, a communicative ambiguity in pointing to a unity if no explicit reference is made to its organization or to its being indicated through a total distinction, and two observers may disagree because through unspecified boundaries they may imply different unities, even though they may perform identical overt operations of partiaI distinction under the belief that they refer to the same unity.

(b) Different operations of total distinction separate different kinds of unities because they define different kinds of boundaries and, therefore, imply different organizations.

(c) The organization and structure of a unity specify all the operations of distinction through which it can be separated from the background.

It follows that it is always the task of the observer to specify the organization of the unity that he observes, or to imply it unambiguously through a complete operation of distinction.

THE PHYSICAL SPACE

I have said that living systems are autopoietic systems that exist in the physical space. Strictly, however, I should say that the physical space is the space in which living systems exist, and that this determines its singularity. In fact, since autopoietic systems are closed homeostatic systems that maintain constant their organization, all their changes of state are changes of state in autopoiesis and they can only be perturbed through the interactions of their components. Therefore, the domain of perturbations of an autopoietic system is defined by the domain of interactions of its components, and exists as a domain of perturbations only in the domain in which these components exist. This necessatily applies to us too, and, unless we explicitly suppose something different, this also applies to our cognitive processes. It follows that if cognitive processes are operations in autopoiesis, the space of our components is a limiting space outside of which we cannot step through cognition.

The physical space defined as the space in which living systems exist, then, is both ontologically and epistemologically singular; it is ontologically singular because it is constitutive to the phenomenology of living systems, and it is epistemologically singular because it defines the operational boundaries of our cognitive domain.

STRUCTURAL COUPLING

Two plastic systems become structurally coupled as a result of their sequential interactions when their respective structures undergo sequential changes without loss of identity. Therefore, the structural coupling of two independent structurally plastic unities is a necessary consequence of their interactions, and is greater the more interactions take place. If one of the plastic systems is an organism and the other its medium, the result is ontogenic adaptation of the organism to its medium: the changes of state of the organism correspond to the changes of state of the medium. If the two plastic systems are organisms, the result of the ontogenic structural coupling is a consensual domain, that is, a domain of behaviour in which the structurally determined changes of state of the coupled organisms correspond to each other in interlocked sequences.

To an observer, the states of adaptation between organisms and environment, or between organisms in a consensual domain, appear as states of correspondance between plastic systems that can be described in terms of functional relations, that is as semantic couplings. The statements go like this: the function of such and such a structure in the organism is to cause such and such a change in the environment; or the meaning of the state of system A for system B is what determines the state to which system B passes as a result of the interaction of the two systems. Such a description in terms of functional relations is a description in terms of a semantic coupling because the structural correspondance between the interacting systems is considered without reference to its origin, and the changes of state of the coupled systems are treated as if they were determined externally by the perturbations, and not internally by the respective present structures of the interacting systems. If the fact that the mutual perturbations constitute only the historical instances under which the structurally coupled system undergo internally determined changes of state is neglected, four fundamental phenomena are ignored.

(a) That the result of the structural coupling of two or more systems is the structural determination of an interlocked order in the respective changes of state of the systems that is realized in the form of ordered sequences of mutually triggering perturbations.

(b) That if it were not the case that perturbations only constitute triggering circumstances for internally determined changes of state, inadequate behaviour, that is behaviour that for an observer appears out of context, would never take place.

(c) That semantic interactions, that is, interactions in which the perturbing agent determines the new state attained by the perturbed system, do not take place in the phenomenological domains of state determined systems, but only occur in the domain of description.

(d) That the domain of descriptions arises as a metadomain from the establishment of consensual domains by structurally coupled plastic systems (Maturana, 1970). Although the structural coupling is a historical process, that is, each structural innovation arises as a modification of a pre-existing structure and constitutes the basis for the next one, the structurally coupled unities always correspond to each other in the present. The history of a system may reveal how *its* structure arose, but it does not reveal how it operates in the present: the operation of a system is always the result of its present structure, not of its history, however, significant or complex this operation may seem in a historical perspective.

The nervous system operates in the present as a dosed neuronal network that maintains constant, under continuous external (changes in the medium) and internal (its own states of neuronal activity) perturbations, certain relations of neuronal activity (describable either as internal neuronal correlations or as sensory-effector correlations) that have been specified or become specified through its structural coupling with the organismo If one considers the complexity of the things that people are able to do, such as talking, abstract thinking or ethical and political decisions, such a description of the nervous system seems insufficient. This insufficiency, however, is only apparent because the ethical, sociological or philosophical complexity of these human operations lies in their historical significance, not in the nature of the operations themselves.

The historical significance and, hence, the contextual complexity of any behaviour, is put in the descriptions by the observer who defines the domain of re1evance of the observed behaviour in his domain of description. Re1evance, meaning, function, significance, then, are terms which refer to the observable domain of interactions of the autopoietic unity as a unity ,and not to its internal autopoietic changes of state. Therefore, the actual complexity of the operation of the nervous system is, exclusively, the complexity of an homeostatic elosed neuronal network that generates, or maintains constant, relations of neuronal activity that may be continuousiy changing through the structural coupling of the system to the medium (which may recursively inelude the nervous system itse1f) in which it exists.

SELF-REPRODUCfION

If the organization of an autopoietic unity and the structure which realizes it are uniformly distributed across the expanse of the unity through a uniform distribution of components, self-reproduction is a trivial consequence of a simple mechanical fragmentation of the autopoietic unity, and heredity a necessary consequences of the uniform distribution of the components. In modern cells there are molecular components that are usually not uniformly distributed across the cell due to its internal compartmentalization, and must become uniformly distributed (through the dynamics of mitosis) before cellular fragmentation takes place. However, once the uniform distribution of components is obtained, everything occurs as stated above. No copying takes place, and no notion of program, of coding or of transmission of information is necessary in order to account for the phenomena of self-reproduction and heredity.

Since it is the autopoietic organization that determines the unity of a living system, and since it is its structure that determines its mode of realization, it is intrisically inadequate to consider anyparticular component as responsible of the properties of the system, and, least of all, of its hereditary characteristics. Notions such as program, coding or transmission of information do not apply to the operation of state-deterrnined systerns. These notions are useful, though conceptually rnisleading, as rnetaphors in the dornain of description in which a rnapping is rnade of the observed phenornenon upon the dornain of purposeful design of the observer. An autopoietic unity, as is universally the case with every state-deterrnined systern, undergoes only the changes of state deterrnined by its structure. The viral DNA that is sornetirnes referred to as a genetic rnessage, does not specify what the host cell will do; the changes of state that the cell undergoes are deterrnined by the structure of the cel1 under viral perturbation, but not by the viral DNA.

DESCRIPTIONS

A consensual dornain ontogenically established through the structural coupling between two or more organisrns appears to an observer as an interlocked dornain of distinctions, indications or descriptions, according to how he consideI s the behaviour of the observed organisrns. If the observer considers every distinguishable behaviour as a representation of the environmental circurnstances which trigger it, he considers the behaviour as a *description,* and the consensual dornain in which this behaviour takes place as a dornain of interocked *descriptions* of actual environrnental states. What we do as observers when we rnake a description is exactly that, we behave in an interlocked rnanner with other observers in a consensual dornain ontogenically generated through our direct (rnother-child relation) or indirect (rnernbership in the sarne society) structural coupling. Yet, if the observer forgets that the interlocked adequacy ofthe rnutually triggeringchanges of state ofthe rnutually perturbing systerns in the consensual dornain is the resuit of their ontogenic structural coupling, he rnay *describe* the consensual dornain as if it constituted an intrinsicdescriptive systern in which the descriptive interactions gave inforrnation to the organisrns to compute the *ad hoc* states needed to handle the described environrnent.

The establishment of a dornain of *descriptions* is not exclusive of autopoietic systerns. Any col1ection of systerns that can undergo ontogenic structural coupling can establish a consensual dornain as a closed dornain of interlocked interactions and, therefore, can participate in a dornain of *descriptions* in which every *description* is a *description* only within the consensual dornain. Futherrnore, if a systern that can rnake *descriptions* can be perturbed by its own states within the dornain of *descriptions,* and thus generate *descriptions* of a rnediurn that includes its *descriptions,* a second-order consensual dornain is produced through the recursive application of *descriptions* on *descriptions,* and an observer is operationally generated. For this to take place, however, it is necessary that aH perturbing agents, including the *descriptions,* should belong to the same class, so that the operation of *description* could be recursively applied to the product of its application. This is possible in organisms with a nervous system because the nervous system is a close neuronal network in which all states of activity are states of relative neuronal activity that only lead to other states of relative neuronal activity, independently of the circumstances of interactions of the organism in which these states of activity arise, a condition which necessarily results in the nervous system becoming recursively structurally coupled to its own structural changes. Since internally and externally generated states of relative neuronal activity in the nervous system are indistinguishable for the dynamics of states of the nervous system, the interactions of the nervous system with its own states that its closed organization implies, become, in the domain of interactions of the organism, descriptions of descriptions.

LINGUISTIC DOMAIN

A linguistic domain is a domain of consensual behaviour, ontogenically established between at least two structurally plastic organisms, that is usually described as a domain of semantic interactions. Yet, the semantic value of an interaction, in whatever domain, is not a property of the interaction, but a feature of the description that the observer makes by referring to it as if the changes of state of the interacting systems were determined by their mutual perturbations, and not by their respective individual structures. Therefore, the problem of establishing a linguistic domain is not the problem of establishing an operational semantic coupling, but the problem of establishing an ontogenic structural coupling that generates a consensual domain in which the coupled plastic systems can undergo an unending series of interlocked alternating changes of state. In other words, linguistic behaviour is structurally determined behaviour in ontogenically structurally coupled organisms, in which the structural coupling determines the sequential order of the mutually triggering alternating changes of state. Semantics exists only in a metadomain of descriptions as a property projected upon the interacting systems by the observer, and valid only for him.

Descriptions as linguistic behaviour are no exception to this. The semantic value of a description exists only in a recursively-generated metadomain of descriptions of descriptions, not in the domain of operation in which a description is realized as an actual behaviour. The same happens with self-consciousness as a subdomain of self-descriptions in a domain of descriptions of descriptions (Maturana, 1970). In these circumstances, the changes of state of the nervous system that lead to self-description would not be different from other changes of state that lead to other descriptions, but would differ only in the consensual domain in which the descriptions arose and are applied.

It is the recursive application of descriptions in a domain of self-descriptions as the expression of a recursive structural coupling of the nervous system with its own structure in the sequential changes of state of a single system, that gives to self-consciousness its uncanny quality of a process which transforms a single system into two: the changes of state ol' a single system appear to an observer as if they were taking place through interactions with another. Otherwise, as occurs with any other behaviour, the determination of self-consciousness is structural and not semantic.

Conclusions

Although the fundamental conclusions are already contained in the previous sections, it may be worthwhile to summarize them in the following formo

(a) The constitutive feature of a living system is autopoiesis in the physical space; the constitutive feature of the nervous system is its condition of being a closed neuronal network.

(b) AlI changes of state in the living system and in its nervous system are subordinated to the realization of the autopoiesis of the living system, if this does not occur the autopoiesis stops and the living system disintegrates.

(c) If the organism and its nervous system are structurally plastic, the continuous realization of the autopoiesis of the organism necessarily results in a structural coupling of the organism and nervous system to each other, and to the medium in which the autopoiesis is realized.

(d) The result of this structural coupling is that although the organism operates only in autopoiesis, and the nervous system operates only in generating internal relations of neuronal activity, each determined by its own structure, the changes of state of the organism and the nervous system, and the changes of state of the medium, mutually trigger each other in a manner that leads to continued autopoiesis. As a result, if an organism were to be taken out of the medium to which it is structurally coupled, it would go on in its structurally determined changes of state regardless of their inadequacy to the changes of state of the new medium, and, eventually, disintegrate.

(e) Descriptions in terms ofinformation transfer, coding and computations of adequate states, are fallacious because they only reflect the observer's domain of purposeful design and not the dynamics of the system as a state-determined system.

(f) The observable complexities of the domain of interactions of an autopoietic unity as a unity, are complexities proper to the historical circumstances in which the changes of state of the unity take place, not to the processes that constitute the internal changes of state of the unity itself, the nervous system included. The organization and structure of an autopoietic unity do not include operational elements proper to the domain in which it interacts as a unity.

(g) Any recursive operation in an organism, or in its nervous system, is the application of the same operation on different states of a structurally changing system with invariant organization, that can take place only because the results of the application of the repeated operation belong to the same class of phenomena as the object on which the operation is applied. This is what obviously takes place in the nervous system which, as a closed neuronal network, only adopts states of relative neuronal activity that lead to new states of relative neuronal activity. Such a recursion in the descriptive domain is necessary to generate self-consciousness as a new phenomenological domain.

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