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Chapter 2
Autopoiesis

Humberto R. Maturana

A system is autonomous if the relations that characterize it as a unity involve only the system itself, and not other systems. Thus defined, autonomy can be viewed as a central characteristic of living systems. Yet, since autonomy is not necessarily a feature exclusive to living systems, any attempt to explain the organization of living systems must show how they are autonomous and how all the phenomena proper to them arise as a result of their autonomy. It is in this context that I maintain that the notion of autopoiesis fully characterizes living systems as autonomous entities in physical space. It is also in this context that I maintain that the notion of reproduction does not enter into the characterization of living systems as unities and that the phenomenon of sequential reproduction by cellular division (or any other kind of partition into equivalent unities) is necessary only for the phenomenon of phylogenic evolution.

F. Varela and I have published these notions in a small book and in several articles (Maturana and Varela 1973; Varela, Maturana and Uribe 1974; Maturana 1975; Varela 1978). I now wish to review them and clarify some aspects of the theory of autopoiesis as I see it today.

2.1 Autopoiesis (αυτόσ = self; ποιενιν = production)

We maintain that there are systems that are defined as unities as networks of productions of components that (1) recursively, through their interactions, generate and realize the network that produces them; and (2) constitute, in the space in which they exist, the boundaries of this network as components that participate in the realization of the network. Such systems we have called autopoietic systems, and the organization that defines them as unities in the space of their components, the autopoietic organization.

We also maintain that an autopoietic system in physical space (i.e., an autopoietic system whose components we define as physical, such as molecules) is a living system, and, therefore, that a living system is an autopoietic system in physical space.

2.2 Implications of Autopoiesis

The autopoietic organization of an autopoietic system is necessarily an invariant. This is obvious, of course, because these systems are defined and realized as unities by being autopoietic. What is not immediately obvious, however, is that all that happens to them must happen while they are autopoietic and through their being autopoietic; otherwise they disintegrate. Autopoiesis, therefore, results in the stabilization of autopoiesis through its operation as the configuration of relations that must remain invariant through the history of change of an autopoietic system.

An autopoietic system is, from the point of view of its dynamics of states, a system that, while autopoietic, only generates states in autopoiesis; that is, with respect to its states, an autopoietic system is a closed system that only generates one kind of states—states in autopoiesis. Obviously, this is a reformulation of the previous point. However, it is necessary to restate it in these terms because the notion of closure is essential for the understanding of the operation of living systems as systems.

Nothing is said in the characterization of living systems as autopoietic systems about the operational constraints under which their autopoiesis must be realized. This is because whatever constraints must be satisfied, they are determined by the properties of the components, and they are implied when it is said that an autopoietic system exists in the space in which its components exist. Thus, autopoietic systems in the physical space must satisfy thermodynamics and must be materially and energetically open, even though they are necessarily closed in their dynamics of states.

The notion of autopoiesis also says nothing about the nature of the components that realize the system as a network of productions. In fact, the components of an autopoietic system can vary infinitely so long as they have the properties that permit them to constitute it in the space that they define. Furthermore, the components of an autopoietic system are specified by its autopoietic organization, which determines which properties must have the entities that, as components, realize it in a given space; an observer cannot identify the components independently of the autopoietic system that they integrate.

There is no restriction on the space in which an autopoietic system may exist. The physical space in which living systems exist is only one of many. In fact, living systems exist in the physical space as the space defined by their components. Accordingly, we have chosen to identify living systems with only autopoietic systems in the physical space because this is the space in which we exist, and because for that reason this space constitutes for us a peculiar limiting cognitive space. Otherwise, the properties of autopoietic systems as autopoietic systems must be isomorphic in every space.

An autopoietic system exists as a system in the space of its components, but as a unity it defines a space through its operation as a whole.

The unity of an autopoietic system is the result of the neighborhood relations and interactions (interplay of the properties) of its components, and in no way the result of relations or interactions that imply the whole that they produce. In other words, nothing takes place in the operation of the autopoietic network with reference to the unity of the network. Therefore, notions of regulation and control that may be used to describe what may take place in an autopoietic network, pertain to the metadomain in which the observer describes the system as a whole; they do not characterize the interactions of its components.

Reproduction is not a constitutive feature of autopoietic systems in general, nor of living systems in particular. Reproduction is secondary to the constitution of the unity to be reproduced; therefore, reproduction does not enter into the characterization of living systems.

2.3 Comments

My comments will center on the following:

1. The basic notions of unity, organization, structure, space, and the domains of perturbations.
2. The biological phenomena of reproduction, heredity, and adaptation.
3. The distinction from other systems.

2.3.1 Basic Notions

In what follows, the word "entity" refers in the most general manner, and without further qualifications, to anything that may be distinguished.

Unity. The basic cognitive operation that we perform as observers is the operation of distinction. By means of this operation we define a unity as an entity distinct from a background, characterize both unity and background by the properties with which this operation endows them, and define their separability. A unity thus defined is a simple unity that specifies through its properties the space in which it exists and the phenomenic domain that it may generate through its interactions with other unities.

If we recursively apply the operation of distinction to a unity, so that we distinguish its components, we redefine it as a composite unity that exists in the space that its components define; it is through the properties of its components that we observers can distinguish it. Yet we can always treat a composite unity as a simple unity that exists not in the space of its components, but in a space that it defines through the properties that characterize it as a simple unity. In this context, then, if an autopoietic system is treated as a composite unity, it exists in the space defined by its components; but if an autopoietic system is treated as a simple unity, the distinctions that define it as a simple unity characterize its properties as a simple unity and define the space in which it exists as such a simple unity.

Organization and Structure. The relations between components that define a composite unity (system) as a composite unity of a particular class constitute its organization. In this definition of organization the components are viewed only in relation to their participation in the constitution of the unity (whole) that they integrate. For this reason nothing is said about the properties that the components of a particular unity may have, other than those required by the realization of the organization of the unity.

The actual components (all their properties included), together with the actual relations that concretely realize a system as a particular member of the class of composite unities to which it belongs by its organization, constitute its structure. Therefore, the organization of a system, as the set of relations between its components that define it as a system of a particular class, is a subset of the relations included in its structure. It follows that any given organization may be realized through many different structures, and that different subsets of relations included in the structure of a given entity may be abstracted by an observer (or its operational equivalent) as the organizations that define different classes of composite unities.

The organization of a system, then, specifies the class identity of the system, and must remain invariant if the class identity of the system is to remain invariant: if the organization of a system changes, then its identity changes and becomes a unity of another kind. Yet since a particular organization can be realized by systems with otherwise different structures, the identity of a system may stay invariant while its structure changes within the limits determined by this same structure. If these limits are overstepped—that is, if the structure of the system changes so that its organization is destroyed—the system becomes something else, defined by another organization.

It is apparent that only a composite unity has both structure and organization. A simple unity does not; it only has properties that are defined

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by the operations of distinction through which it becomes separated from a background. It is also apparent that as soon as a composite unity is treated as a simple unity any question about the origin of its properties becomes inadequate because the properties of a simple unity are given through its distinction as a simple unity. Yet it is also apparent that although the properties of a composite unity arise from its organization, they are realized through the properties of its components. Accordingly, while two simple unities interact through the simple interplay of their properties, two composite unities interact in a manner determined by their structure through the interplay of the properties of their components.

Space. Operationally, a simple unity defines its space, that is the domain in which it can be distinguished as a unity. A simple unity, therefore, exists in a space that it defines. A composite unity, however, exists in a space defined by its components because it is through the properties of its components that it can be distinguished as a unity. Yet a composite unity treated as a simple unity defines a space as a simple unity and exists as a simple unity in such a space. According to this, although we have said that living systems are autopoietic systems in the physical space, strictly speaking the physical space is defined as the space in which living systems exist as autopoietic systems and interact as composite unities. Therefore, the physical space is necessarily a limit space for living systems because they cannot undergo interactions that are not mediated through their components, and the components define the physical space.

The specification of a space goes together with the specification of a phenomenic domain. As soon as a unity is defined, a phenomenic domain is defined. Accordingly, if a composite unity operates as a simple unity, it operates in a phenomenic domain that it defines as a simple unity, and that is necessarily different from the phenomenic domain in which its components operate. Therefore, the emergence of a phenomenic domain, as the result of the operational distinction of a composite unity as a simple unity, makes phenomenic reductionism (and, hence, explanatory reductionism) impossible. Furthermore, the dynamics of the establishment of unities through operational distinctions that specify their properties results in all phenomenic domains being necessarily realized through the operation (interplay) of the properties of the unities that generate them; that is, through relations of contiguity. Given that a component *A* interacts with another component *B* in such a way that the changes in *B* through its interactions with *C* result in the reduction of the production of *D*, an observer may say, by considering the whole, that *A* controls the production of *D*. *A*, *B*, *C*, and *D*, interact through relations of contiguity, but the relation in which *A* controls the production of *D* is not a relation of contiguity in the phenomenic domain defined by the components. Relations such as regulation, control, or function, therefore, are not relations of contiguity, but referential relations specified by the observers putting themselves in a metadomain of descriptions, by using their view of the whole as the reference for their description of the participation of the components that they describe in the constitution of the composite unity.

"Everything said is said by an observer . . ." (Maturana 1970), so everything said is a description in the observer's domain. Yet by defining a unity in this domain of descriptions, the observer specifies a reference description that may constitute the basis for a metadomain of descriptions of descriptions, and can do this recursively. Thus, although a characterization of a system as a composite unity, without reference to the whole in terms of neighborhood relations only, and a functional description in terms of relations between the components and the whole, are both descriptions made by an observer; they are operationally different because they take place in different descriptive domains. The first points to a system that would operate in the described manner if its components existed as described; the second points to how the relations and interactions of the components of such a system would appear to an observer who considers them in relation to the whole that they are observed to constitute. These two descriptions are complementary in the cognitive domain of the observer.

Domains of Perturbations. All that happens to a composite unity, whether in relation to its internally generated dynamics of structural change or in relation to its interactions and the structural changes that these trigger in it, is determined by its structure. Or, in other words, in every instance the structure of a composite unity determines both (1) its domains of structural changes without loss of identity (domain of states) and with loss of identity (domain of disintegrations) and (2) its domains of interactions that trigger its changes of state (domain of perturbations) and that trigger its disintegration (domain of destructive interactions). Or, in still other words, at every instance, the structure of a composite unity specifies which structural configuration of the medium in which it operates may perturb it, and which may trigger its disintegration. This is the case regardless of the composite unity considered; it therefore applies to autopoietic systems in any space. As every biologist knows, this is obviously the case for living systems.

Yet, although the structure of a composite unity specifies which configuration of the structure of the medium may perturb it, the actual perturbations that take place are determined by the structure of the medium. However, since the domain of perturbations of a composite unity such as an autopoietic system may change along its ontogeny (individual history) as a result of the structural changes triggered in it by the perturbations or by its internal dynamics, the actual sequences of perturbations and changes of state that a given composite unity actually undergoes is always a function of both the structure of the unity and the structure of the medium. As a consequence, the sequence of perturbations that a system undergoes selects along its ontogeny a path of structural changes that result in its structural coupling to its medium. If the composite unity is a living system, then this structural coupling appears revealed to an observer as a behavioral complementarity in which the conduct of the system is congruent with the changes of state of the medium in a manner that permits it to continue in its autopoiesis. Of course, if a destructive interaction takes place, then the process is interrupted and the system disintegrates.

2.3.2 Biological Phenomena

We maintain that a given phenomenon is a biological phenomenon only to the extent that it implies the realization of the autopoiesis of at least one living system. In other words, we maintain that all biological phenomena necessarily arise as a result of the autopoietic operation of a living system or of a group of them, and that this is their only peculiarity.

Reproduction. Reproduction takes place whenever a composite unity gives origin to another unity of the same class (same organization) through a process of fragmentation, and not through processes of construction or mapping, as would be involved in the phenomena of production or copy. Therefore, in reproduction the new unity should originate as an operationally independent entity. Defined in this manner, reproduction is a frequent phenomenon in nature. It takes place whenever a composite unity whose organization and the components that realize it are uniformly distributed throughout its expanse, with no component in a single dose or compartmentalized, undergoes a fragmentation that does not exclude any of the necessary components or processes from any of the fragments. This obviously takes place in the fragmentation of a crystal when the plane of fracture separates collections of unit cells. The same thing happens, in principle, in the fragmentation of an autopoietic unity, regardless of how the fragmentation is triggered, if its components are uniformly distributed and are not compartmentalized or in a single dose with respect to the plane of fracture. In contemporary eucaryotic cells the process of mitosis transforms a compartmentalized autopoietic unity that has some of its components exclusively in the nucleus, into a noncompartmentalized unity in which a plane of fracture can separate two unities with equivalent (but not necessarily identical) sets of components and the same organization. In procaryotic cells where there is no compartmentalization but some of the components are in single dose, reproduction takes place only after these components have become multiple.

It follows from all this that reproduction is independent of whether the fragmentation arises triggered by the interactions of the unity or through its internal dynamics or both. Accordingly, the fact that present-day mitosis is the result of evolution does not contradict the notion that in cellular reproduction there is nothing else but the fragmentation of an autopoietic unity in a process that is not exclusive to the living systems. What is peculiar to the reproduction of autopoietic systems is that the organization of the unities that reproduce is the autopoietic organization and that the process takes place, in principle, without interruption of their autopoiesis and through the realization of their autopoiesis.

Heredity. Heredity is also a universal phenomenon in nature and takes place whenever reproduction takes place regardless of the class of unities reproduced. In other words, heredity is a necessary result of reproduction, and as such it is a trivial consequence of the distribution of the components when the fragmentation takes place. Furthermore, it is obvious that similarity and difference in the unities produced in reproduction is determined by the same process of distribution of components. In fact, to the extent that the autopoietic organization allows for structural plasticity (structural change without loss of identity), variation is possible through the differential distribution of components, and, to the extent that certain components are necessary for the realization of the autopoietic organization of the unities resulting from reproduction, variation is restricted. If some components have properties that determine a particular feature of their participation in the production of other components, the former may determine some particular restriction in the domain of structural variability compatible with the autopoiesis of the unities involved in reproduction. Yet all of this occurs within the set of phenomena we already described.

Modern nuclear genetics is therefore not the study of heredity; rather it is the study of hereditary phenomena associated with the particular structures (components and relations) and productions that depend on the properties of the nucleic acids. In fact, all of the components of the cell participate in the cellular phenomena of heredity and genetics, albeit with different penetration in the succession of generations.

I have not used such notions as coding, message, information, or transmission of information, because they do not refer to the processes that generate the phenomena of reproduction, heredity, or genetic variation. They refer to relations in a metadomain of descriptions, and do not determine relations of contiguity between the components of the composite unity described. Their value, therefore, pertains to a metacognitive domain where the observer beholds the cell simultaneously as a simple and as a composite unity, and where he establishes a relation between these two otherwise independent entities.

Adaptation. In the history of interactions of a composite unity in its medium, both unity and medium operate as independent systems that,

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by triggering in each other a structural change, select in each other a structural change. If the organization of a composite unity remains invariant while it undergoes structural changes triggered and selected through its recurrent interactions with its medium, and if there are structural configurations of the medium that participate as recurrent selective features in the history of interactions of the unity, then the outcome of this history of interactions is the selection by the medium of a sequence of structural changes in the composite unity that results either in its adaptation to the recurrent features of the medium (as its operation without loss of class identity in relation to them) or in its disintegration. In other words, if a composite unity is structurally plastic, then adaptation as a process of structural coupling to the medium that selects its path of structural change is a necessary outcome. In this process the configuration of constitutive relations that remain invariant in the adapting composite unity determine the matrix of possible perturbations that the composite unity admits at any instance and hence operates as a reference for the selection of the path of structural changes that takes place in it in its history of interactions. Defined in this manner, adaptation is not peculiar to living systems. On the contrary, adaptation is a universal phenomenon that takes place whenever a plastic composite unity undergoes recurrent interactions with structural change but without loss of organization, and may arise in relation to any recurrent structural configuration of its domain of interactions. Furthermore, this domain of interactions could be anything with which the composite unity interacts as if with an independent entity or system, including its own configuration of internal states. Accordingly, all that is unique with respect to adaptation in living systems is that in them the autopoietic organization constitutes the invariant configuration of relations around which the selection of their structural changes takes place during their history of interactions.

If adaptation takes place during the individual history of one autopoietic unity, the phenomenon is ontogenic adaptation and corresponds to what is usually called learning. If adaptation takes place through a succession of generations in which each reproductive step offers an additional dimension of variability through the diversity produced in the offspring in each generation, the phenomenon is phylogenic adaptation, and the outcome is evolution.

2.3.3 Distinction from Other Systems

An autopoietic system is defined as a unity through relations of production of components, not through the components that compose it, whichever these may be. An autopoietic system is defined as a unity through relations of form (relations of relations), not through relations of energy transformation. An autopoietic system is defined as a unity through the specification of a medium in its realization as an autonomous entity, not through relations with a medium that determines its extension or boundaries. An autopoietic system is defined as a unity as a closed network of productions of the components that recursively, through their interactions, realize the network that produces them and constitute its boundaries by realizing the surfaces of cleavage that separate it as a composite unity in the space in which they exist.

It is the configuration of relations that defines the class of autopoietic systems, not the processes or components through which this configuration is realized. The only thing peculiar to autopoietic systems is their autopoietic organization. Yet since there are many systems that may have components of the same kind as the components of a particular subclass of autopoietic systems, or that may be defined by relations of form, or that may be realized as networks of productions—but are not autopoietic—the recognition of an autopoietic system may be difficult. This is particularly so if one forgets that the system that one intends to consider is realized in the space of its components, and, hence, one loses view of its boundaries.

In general, an observer who beholds a composite unity, and thus defines it as such, may assort its components in several different manners and claim that the composite unity may at the same time belong to a manifold of different classes of unities: an apple may at the same time appear to an observer as an apple and as a projectile. However, in the strict operational sense, different unities are defined by different operations of distinction that specify which relations define their different organizations and, hence, which relations are necessary and which are superfluous. Strictly, then, an apple is not a projectile, even though the same components may be organized as an apple or as a projectile. This, of course, is not new, but a mistake can be produced if one forgets that a unity is defined by its organization and not by its components. Thus, for example, in an autopoietic system identified as a separable entity in the physical space through the identification of its boundaries and components, an observer may describe dissipative processes, both from the energetic and material points of view, and claim that an autopoietic system is a dissipative system. However, a dissipative system is not an autopoietic system. A dissipative system is defined by relations of stability under flow, and, therefore, it is defined as a system by relations to another entity or system with respect to which it is supposed to exhibit stability. Accordingly, although the observer who calls an autopoietic system a dissipative system may direct another observer to an entity that includes the boundaries of an autopoietic unity, the direction is to a different system; the other observer is directed to a system defined by relations different from those that determine the boundaries of an autopoietic system. The structures of the two systems intersect, but they are operationally entirely different systems because they are defined by different organizations.

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2.4 Epistemology

"Everything said is said by an observer to another observer that could be himself" (Maturana 1970).

The fundamental cognitive operation that an observer performs is the operation of distinction. By means of this operation the observer specifies a unity as an entity distinct from a background, and a background as the domain in which an entity is distinguished. An operation of distinction, however, is also a prescription of a procedure that, if carried out, severs a unity from a background, regardless of the procedure of distinction and regardless whether the procedure is carried out by an observer or by another entity. Furthermore, the prescriptiveness of an operation of distinction implies a universal phenomenology of distinctions which, through the specification of new procedures of distinction or through their recursive application in the reordering of the distinguished entities, can, in principle, endlessly give rise to new simple and composite unities, and, hence, to new nonintersecting phenomenic domains. In these circumstances, although a distinction performed by an observer is a cognitive distinction and, strictly speaking, the unity thus specified exists in the observer's cognitive space as a description, the observer defines a metadomain of descriptions from the perspective of which a reference is established allowing speech to occur as if a unity, simple or composite, existed as a separate entity that can be characterized by denoting or connoting the operations that must be performed to distinguish it as a separate entity.

From the perspective of a metadomain of descriptions, the distinction between the characterization of a unity and the observer's knowledge of it should be clear. In fact, knowledge always implies a concrete or a conceptual action in some domain, and the recognition of knowledge always implies an observer that beholds the action from a metadomain. Therefore, an observer who claims knowledge of a system also claims the ability to define a metadomain from the perspective of which the observer can simultaneously behold the system as a simple unity and describe its interactions and relations as a simple unity. In these circumstances, it is legitimate to distinguish between the characterization that an observer makes of a unity—by pointing either to its properties, if it is a simple unity, or to its organization, if it is a composite one—and the knowledge about a unity that the observer reveals, by describing either its operation as a simple unity, if it is a simple unity, or both its operation as a simple unity and the operation of its components as components, if it is a composite entity. In either case, however, the knowledge an observer has of the unities so distinguished consists in handling these unities in a metadomain of descriptions with respect to the domain in which they are characterized. In other words, an observer characterizes a unity by stating the conditions in which it exists as a distinguishable entity, but perceives it only to the extent that a metadomain is defined in which it can be treated as the characterized entity. Thus, autopoiesis in physical space characterizes living systems because it determines the distinctions that we can perform in our interactions with them, but we know them only as long as we can both operate with their internal dynamics of states as composite unities and interact with them as simple unities in the environment in which we behold them. The fact that the characterization of an entity is also a description made by the observer, and as such also belongs to the observer's descriptive domain (Maturana 1970), does not invalidate the operational effectiveness of the distinction of distinctions in the metadomain of descriptions in which the cognitive statements are made. The entity so characterized is a cognitive entity, but once it is characterized the characterization is also subject to cognitive distinctions valid in the metadomain in which they are made by treating the characterization as an independent entity subject to contextual descriptions. Therefore, complementarities such as system–environment, autonomy–control, and so on (Goguen and Varela 1977; Varela 1978) are complementarities in our cognition of the system that we observe in a context that allows us to establish such relations, but they are not constitutive features of the system because they do not participate in its organization through the interplay of the properties of its components. Accordingly, that one should not be able to account for or deduce all biological phenomena from the notion of autopoiesis alone is not a shortcoming of such a notion. On the contrary, this is to be expected because such a notion only refers to the characterization of a system in a domain of descriptions in which it is distinguished as a composite unity. In order to have a biological phenomenon a background must be involved and, hence, a metadomain of observations must be generated so that the phenomenon may be distinguished and described. For a biological phenomenon to take place, an autopoietic system must operate in a context; the processes that take place in the realization of the autopoietic network of productions are not biological phenomena. What is involved here is the dynamics of constitution of a composite unity and the cognitive distinction of a unity. A composite unity is constituted when a set of relations between components specifies a surface of cleavage that operationally defines a background with respect to which it delimits the related components as a simple unity. The unity thus constituted does not participate in its own constitution, because it is only with respect to a background that it has operational existence. The components and the unity that they compose exist in nonintersecting spaces.

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2.5 Summary

My fundamental claims are the following. (1) Autopoiesis in the physical space is the necessary and sufficient condition that makes a system a living system, and as such, an autonomous entity. (2) A given phenomenon is a biological phenomenon only to the extent that its realization involves the realization of the autopoiesis of at least one living system. (3) Although everything takes place in living systems through the realization of their structurally determined autopoiesis, the actual occurrence of any biological phenomenon is always a function of the historical contingencies under which the participating living systems realize their autopoiesis. (4) Any phenomenon that may be involved in the autopoiesis of an organism may participate without contradiction in the domain of biological phenomena.

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