ON BOUNDARIES OF AUTOPOIETIC SYSTEMS

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Introduction

This paper is the development of some reflections posted to the Autopoiesis-Dialognet discussion group on the 23rd. February 2001 (thread : Boundaries again!). At that time, my intention was to contribute to recurrent discussions about boundaries in the context of autopoietic theory. It was a relatively short message (although I thought it was too long for the kind of contributions expected in a discussion group) in which I tried to condense some personal conceptual developments related to the notion of boundary of an autopoietic unit, as implied from the definition of autopoiesis proposed by Maturana and Varela. After reading that post some years later I realized that it was just a collection of shorthand notes about a complex subject that needed some further explanations in order to be understood at all (I had myself difficulties trying to fully understand what I wrote at the time!)

In the following I assume that the reader is familiar with the concept of autopoiesis proposed by Humberto Maturana as an approach to explain what distinguishes living beings from other dynamic systems observed in nature[1]. The extension of the theory of autopoietic systems beyond the biological realm (the domain of existence of molecular autopoietic systems) has led to discussions about the type of distinctions we need to make as observers when confronted to the task of identifying a suspected autopoietic system existing in any given phenomenological domain. This is a theoretical problem which asks for the definition of a general set of rules formulated in the domain of distinctions in which observers participate in languaging.

The problem

This theoretical problem is tantamount to specifying the preliminary distinctions necessary to bring forth a composite unit of dynamical objects or entities existing in a generalized phenomenological domain and describing the frontiers of the composite unit embedded in the environment in which it behaves as an emerged dynamic system capable of organizational conservation. Maturana and Varela proposed in very general terms some basic rules that specify the operation of distinction leading to the identification of an autopoietic unit[2]. But many difficulties have been encountered when applying these rules to some particular domains in which the existence of autopoietic systems has been suspected. This is specially the case of the social or economical domains. Discussions have concentrated often on the question of identifying the boundaries of would be autopoietic systems as a way of separating the observed composite units from the background and decide if they are indeed members of a particular class of entities showing autopoietic behavior.

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[1] I use the term "observed" in the sense used by Maturana in his paper "*Ontology of Observing, The biological foundations of self consciousness and the physical domain of existence*", Humberto R. Maturana, Conference Workbook: Texts in Cybernetics, American Society For Cybernetics Conference, Felton, CA. 18-23 October, 1988. (available on line at http://www.inteco.cl/biology/ontology/index.htm)

[2] Maturana H.R. and F.G. Varela (1973) "De máquinas y seres vivos", in English "Autopoiesis: the organization of the living", in Autopoiesis and Cognition by Maturana H.R. and F.G. Varela, Reidel 1980.

Many authors have proposed to tackle the task of identifying the “boundary” of such observed systems in order to bring them forth as units clearly separated from their environment and analyze its conservative properties. This task is approached by specifying an operation of distinction, based on observations and leading to the identification of separated classes of dynamical entities (components): those that do belong to the suspected autopoietic system as such and those that do belong to the environment in which the said composite unit supposedly behaves as an autopoietic system. I realized that such discussions became often circular because they usually led to invoke the distinction of an autopoietic behavior of the observed unit in order to specify the distinctions necessary to identify its boundary, which in turn were necessary to explain the existence of the autopoietic unit itself. In my opinion, this was the outcome of some confusion in the use of very general terms as “dynamical system”, “dynamics”, “self-organization”, etc., without pertinent references to the underlying basic distinctions and explanations that provide a distinct operational meaning to those terms. I felt that some lower level explanations were necessary to avoid circularity.

My explanatory approach

My reflections followed the path of avoiding a reference to the distinction of autopoietic behavior as a starting point for my discussion. This distinction should be an outcome of some preliminary explanations, not a premise for these. My starting point is an explanation of what I understand as necessary distinctions allowing an observer to bring forth the description of dynamical objects and of interactions between them. From there I stepped into an explanation of what I understand as the necessary distinctions allowing an observer to bring forth the description of a general composite dynamical system existing in a given phenomenological domain. My aim was to explain through which distinctions we may bring forth the descriptions that are essential to identify an autopoietic behavior in a composite dynamical system being so far unknown as a member of the class of autopoietic systems in that particular domain. In other words, I intended to pinpoint the necessary logical steps that an observer should perform in order to focus on pertinent observations that would allow him or her to bring forth the description of a suspected autopoietic behavior shown by the observed composite dynamical system. All this without assuming anything about its conservational abilities at all.

My approach is to explain how a very general composite dynamical system can be “seen” emerging gradually as an autopoietic system by following an explanatory path in which more basic operations of distinctions are proposed to fellow observers. I impose the requirement that the resulting explanations should be those leading to a pertinent identification of the “boundary”, of the “body” (what is “inside the boundary”) and of the “medium” (what is “outside the boundary”) of the suspected autopoietic system. Then I criticize these distinctions in order to judge on their pertinence or necessity in the task of identifying an autopoietic system.

Ontological considerations

The criteria to be applied to generate the above mentioned operations of distinction are not trivial, but I claim that they can be specified in general for any phenomenological domain, provided that the formal relations used in the languaging domain to describe the links between dynamical objects existing in the observed phenomenological domain express causal[3] interactions, whatever the interaction mechanism may be. In other words, I claim that the identification of a particular

[3]I point out the fact that the causality requirement needs to be explicitly stated in order to choose the most appropriate formal language capable of expressing the operations of distinction.

interaction mechanism is not necessary to make the operation of distinction in the languaging domain. It is just sufficient to identify the causal relationships linking the components of the composite system.

In this sense, the criteria used by the observer to decide whether some entities are components of a suspected autopoietic system or not, define the boundaries of the referred system independently from any observed "(objective) reality". Stated in this way, the operations of distinction should be understood as cognitive statements made arbitrarily by an observer. Whether such distinctions lead to the observation of an autopoietic system in action or not, is essential to judge on the pertinence of the proposed distinctions, but they are not imposed *a priori* by the system's phenomenological domain of existence.

In other words, each possible set of distinction criteria constitutes an hypothetical approach giving rise to interpretations of observable events that can be more or less useful to "detect" the existence of a suspected autopoietic unit in the observed phenomenological domain. In this sense, the "boundary" exists only in the languaging domain: it is the "observer's point of view" allowing him or her to talk about the existence of an observable composite unit, clearly detached from its environment and showing an eventual autopoietic behavior in the considered phenomenological domain. But we need to keep in mind that some operations of distinction may prevent observers from identifying such a composite unit as an autopoietic system at all.

Nevertheless, when an observed phenomenology allows for the description of a "boundary" for a dynamical subsystem in terms of observed interactions with its environment, we are naturally led to consider that it is the composite system itself that "defines" its emerged boundaries (for an observer). This is an outcome of considering the observed unit as a structure determined system. But the particular structure of the system arises (for an observer), only when his or her attention is focused on a particular type of interaction occurring as an observed phenomenon in the system's domain of existence. This might sound in contradiction with the observer's freedom to choose his or hers set of distinction criteria leading to the identification of a composite unit, of its boundary an of its environment.

The contradiction is only apparent because the observer's operations of distinction are only hypothetical approaches existing in the languaging domain and what the observer says about his or hers observations on the interactions of the system with its environment are descriptions of what he or she experiences in the phenomenological domain in which the system behaves as such. It is the confrontation of the theoretical operations of distinctions with the description of observational experiences that allows the observer to claim that there is a formal correspondence between his or hers languaging distinctions and his or hers descriptions of observational experience. If the observer is not able to establish such a correspondence, he or she is free to modify the proposed criteria until a better match can be claimed. When the formal correspondence can be claimed and other observers agree to say that the claim is valid, "objectivity in parenthesis"[4] allows us to say that the observed system (objectively) defines its emerged boundaries, but this is just another way of wording the same claim.

Briefly, causal coupling relations are the base level considerations necessary to describe a proposed theoretical "boundary" for the system. The consideration of a particular type of interaction mechanism allows the observer to define observational protocols devised to verify that the proposed "boundary" coincides with observed phenomena occurring in the system's domain of existence (I reckon that when this is the case we can talk about an "embodied boundary").

Explanations in the biological domain

[4] Humberto Maturana, "*Ontology of Observing*", referenced above.

Let's see how these considerations apply in a particular case. For example, the phenomenological domain of observation for which Maturana and Varela developed their theory of autopoiesis was the biological domain in which living systems are observed as biochemical dynamical systems capable of performing the conservation of their organization in continuous interaction with their biochemical environment. Maturana proposed that:

> *"(...) living systems are dynamic systems constituted as autonomous unities through being closed circular concatenations (closed networks) of molecular productions in which the different kinds of molecules that composed them participated in the p roduction of each other, and in which everything can change except the closed circularity of the concatenation of molecular productions that constitutes them as unities (...).Francisco Varela and I expanded this characterization of living systems by saying : first, that a composite unity whose organization can be described as a closed network of productions of components that through their interactions constitute the network of productions that produce them and specify its extension by constituting its boundaries in their domain of existence, is an autopoietic system; and second, that a living system is an autopoietic system whose components are molecules. Or, in other words, we proposed that living systems are molecular autopoietic systems and that as such t hey exist in the molecular space as closed networks of molecular productions that specify their own limits"* [5]

In my words: the type of interactions considered in the macromolecular domain are those established between complex molecules giving rise to more or less stable macromolecular structures participating in the dynamics of the system that they constitute. These interactions are explained in terms of chemical couplings in which spatial closeness and chemical affinity of the interacting entities -macromolecules- plays a fundamental role. In physical terms, interactions occur according to the manifestation of electrochemical attractive or repulsive forces subject to three-dimensional Euclidean constraints. These constraints are expressed in terms of distances between the interacting entities and of the mutual three-dimensional orientation of their spatial structure.

The resulting structure of a composite system of macromolecules interacting together through biochemical bonds is also a spatial structure occupying a volume in space. Such structures have "natural boundaries" that can be described mathematically in terms of topological surfaces in a three-dimensional Euclidean space. For example, the cell membrane is the embodied locus of the boundary for the most elementary structure of living beings : the living cell described as an autopoietic system. This boundary is (objectively) produced by the cell itself.

But the distinctions made in the biochemical phenomenological domain (i.e. the identification of the basic dynamical entities called macromolecules) need to be stated with caution. For example, the scale of observation is essential to bring forth the appropriate structures to be observed and described. When considering biochemical interactions, everything occurring in the phenomenological domain is a succession of multiple biochemical couplings continuously linking molecules to other molecules. If the scale of observation is not chosen large enough to allow for the observation of the emergence of large scale structures, the identification of structure determined boundaries might become impossible. At a low scale of observation, a cellular membrane would be seen as a sieve and interacting molecules could not be sifted out as being part of an "inside" or of an "outside" volume. On the other hand, if the scale of observation is too large, the observer would not be able to observe interactions between basic components -but only between large scale composite structures- nor explain the emergence of an autopoietic unit as a result of underlying interaction mechanisms.

These examples of operations of distinction which depend on the scale of observation shows how an observer can miss the identification of an autopoietic system and its boundary altogether or be unable to claim an explanatory path for the emergence of such composite unit.

Explanations in a general phenomenological domain

[5] Humberto Maturana, ibidem.

In order to apply Maturana's very general definition of autopoietic systems to other phenomenological domains many authors have discussed about the identification of such units. This is specially the case in the sociological or economical domains. Discussions often concentrate on the notion of boundary for systems being analyzed in terms of autopoietic theory. The operation of distinction performed by the observer in order to identify a possible autopoietic system embedded in the dynamics of the observed agents interacting in a given domain is placed at the core of such investigations. The problem faced by the observer is seen as a matter of decision on which agents should be considered to belong to the candidate autopoietic system and which do belong to its environment.

My purpose is to show that any pertinent operation of distinction that an observer can make in order to propose an hypothetical approach to distinguish the boundary of a suspected autopoietic system relies only on the notion of causal interactions occurring between its components. The description of the nature of the underlying mechanism responsible for such interactions is needed only to verify the pertinence of the operation of distinction through observations carried out in the phenomenological domain of existence of the suspected autopoietic system.

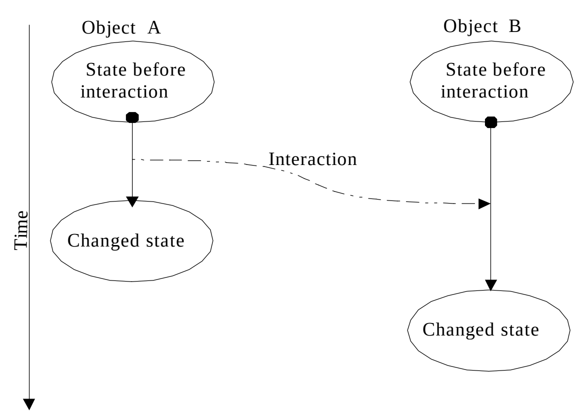
Let me first start by proposing some definitions aimed at a generalization of the notion of causal interaction.

1) I propose to define dynamical objects as entities, agents, components (or whatever we want to name the dynamical objects observed in a phenomenological domain), capable of performing changes of state.

2) I mean by state of a dynamical object the set of parameters or features that the observer can associate to the object at a given time. The values of these parameters should be observable and describable by the community of observers at any chosen time.

3) A change of state (or transition) of a dynamical objects occurs when at least one value of its associated parameter set changes in time.

4) I propose to say that we distinguish a cause-effect coupling between two dynamical objects A and B if a change of state in object A (a triggering transition in A) is the cause of a change of state in object B (a triggered transition in B). I propose to define an interaction between dynamical objects as a cause-effect coupling that links them for us as observers of the evolution of their history of state changes in time.



5) The mechanism responsible for cause-effect coupling between dynamical objects is not considered now, but it is meant to exist as a causal influence of one object on another that

the observer can distinguish as occurring in time (i.e. it is a phenomenon in the given phenomenological domain).

6)The latter means that:

a) in the absence of any other cause-effect coupling between B and any other object different from A, the triggered transition in B does never[6] occur before the occurrence of the triggering transition in A

AND

b) whenever objects A and B are in a specified state and a specified triggering transition in A occurs, the same triggered transition occurs always[7] in B, within a finite time interval.

7)Cause-effect coupling can be represented formally as a relation in a multi-dimensional relational space (with as many dimensions as number of parameters considered in the associated parameter set)

8)We can define a general dynamical system as a set of dynamical objects linked together via cause-effect coupling (i.e. causal interaction). This set can be represented by a network of relations existing in the multi-dimensional relational space whose dimension is defined by the cardinal number of the parameter set associated to dynamical objects.

Up to this point it is important to note that these definitions are applicable to any kind of interaction because nothing is said about the mechanism responsible for the observed fact of cause-effect coupling occurring between dynamical objects. Nothing is said neither about the nature of the "influence" of an object upon another nor about the nature of the dynamical objects themselves. They could be embodied by physical particles, molecules, cells, organisms, individuals, social organizations or even software processes, for example. The interactions could be embodied by physical forces, perturbations flow, information transfer or any kind of mechanism capable of triggering changes of state in a dynamical object which is "sensitive" to it. The only thing being said is that the interaction is causal, in the terms defined above.

An observer may decide to distinguish specific interactions according to the underlying mechanism responsible for the cause-effect coupling occurring between dynamical objects. This choice defines different type of interactions occurring in the same phenomenological domain. Each type of interaction is in correspondence with a particular configuration of cause-effect coupled dynamical objects. In the general case, each causally determined configuration may be independent of all other possible configurations. This means that different type of interactions may produce cause-effect configurations which are causally independent from each other (in this case we talk about "orthogonal configurations")

To advance in my explanation, I will need to develop further definitions necessary to account for observable interaction structures.

9) I propose to say that a chained cause-effect coupling occurs when a change of state of object A triggers a change of state of object B via the change of state of an intermediate dynamical object C linked by direct cause-effect coupling with A and B. In this sense, I propose to say that the interaction between A and B propagates via C.

10)A dynamical structure is a set of of dynamical objects linked together by direct cause-effect coupling or chained cause-effect coupling. In this sense, a dynamical structure can

[6]This is a strictly deterministic definition. We could have said "occurs with a nearly zero probability" instead of "does never occur ".

[7]This is a strictly deterministic definition. We could say "occurs with a non zero probability" instead of "occurs always", but let us stay simple (and classical) this time.

be described as an interaction network emerged in the phenomenological domain as a propagation path for interactions between dynamical objects.

11) An interaction network is isomorphic with the network of relations representing the dynamical structure in an associated multi-dimensional relational space. The linked dynamical objects of an interaction network are represented by the nodes of the corresponding network of relations (a graph).

12) A dynamical object X belongs to a dynamical structure if there are one or more dynamical objects coupled directly or chained to X and all of them are coupled in the same way to each other at a given time. A dynamical object which is member of a dynamical structure is called a component of the structure.

13) A dynamical object Y does not belong to an identified (observed) dynamical structure if there is no direct cause-effect coupling linking Y to any member of the identified structure at a given time. Such an object is said to belong (at a given time) to the environment in which the structure emerges.

14) Dynamical structures arise when delimited subsets of dynamical objects within the global dynamical system emerge as distinct (observable) dynamical objects that can be represented as nodes of a network of relations.

15) We shall note that the emergence of dynamical structures is a "natural" outcome of the propagation of interactions throughout the history of state changes experienced by all the dynamical objects of a phenomenological domain. It is a phenomenon in itself and it does not depend on any observer criterion other than the choice of a particular type of interaction that the observer decides to observe and describe.

16) Components of a dynamical structure may become environmental components if they reach states in which they no longer interact with structure components. Conversely, environmental components may become components of a given dynamical structure if they reach states in which they do interact with at least one structure component. In other words, dynamical objects can enter and leave a dynamical structure in the history of state changes of its components.

17) Dynamical structures may emerge and disintegrate, according to the propagation of interactions throughout time.

The terminology used so far refers to two interlacing languaging domains: one pointing to the phenomenological domain (in which observations are made) and one pointing to an abstract explanatory domain (in which explanations are produced). Some correspondences between terms need to be highlighted:

Terms related to a phenomenological domain	Corresponding terms in an abstract explanatory domain
Phenomenological domain (realm of observable phenomena occurring in time)	**Multi-dimensional relational space** (set of all possible relations linking relational nodes)
Dynamical object (associated to a set of observable parameters)	
State of a dynamical object (set of observable values assigned to each parameter at a given time)	
Interaction (cause-effect coupling between dynamical objects)	**Relation** (relational arrows linking nodes of a graph)
Dynamical system (set of dynamical objects observed as a composite unit of interacting dynamical objects)	
Interaction network (set of dynamical objects acting as agents of interaction propagation within a dynamical system)	**Network of relations** (graph made of nodes and arrows)
Component (dynamical object member of an interaction network)	**Node** (abstract entity defined by the starting or arrival points of relational arrows in a graph)
Global state (the set of all values assigned to the parameters of all components of a dynamical system at a given time)	**Configuration of relations** (topology of the graph of a network of relations at a given time)

Example in the macromolecular domain

In very schematic terms, macromolecules interact through the establishment of chemical bonds between some of the atoms they are made of. The necessary conditions for the establishment of such bonds, which are the outcome of electromagnetic forces that bind macromolecules components together at the atomic level (this is the underlying interaction mechanism), are essentially those of distance and spatial orientation[8]. If they are not close enough and/or not adequately positioned in a three-dimensional mutual orientation allowing for a match between mutually interacting atom structures to occur, the binding or unbinding interaction may not take place. Suppose that at a given time two macromolecules A and B are not interacting in this manner. Their states can be expressed as a set of parameters where we can include their spatial position and spatial orientation at that moment. Suppose that A moves, rotates and folds/unfolds with respect to a previous situation in which no interaction with B occurred. The change of state of A is expressed by changes in the values of its position, its global spatial orientation and internal atoms spatial configuration. That is to say, for example, that some values of its set of parameters change in time in such a way that a) the distance between A and B allows for the attractive or repulsive electromagnetic force to act by inducing a mutual movement, and b) the mutual spatial orientation of the nearest atoms produces a three-dimensional match of atom structures of A and B that facilitates a chemical interaction. The interaction mechanism produces a change of state in B: it

[8]For the sake of simplification I neglect other conditions such as the presence of a substrate environment (liquid water substrate) and of other catalyser molecules involved in complex macromolecular reactions.

may occur, for example, as B moves due to the action of attractive or repulsive electromagnetic forces (its position parameter changes).

After an observable time interval a chemical bond may be established or broken and a binding or unbinding interaction can be accomplished. The interaction described in these terms is reciprocal because we could interchange the roles of A and B and explain the observed phenomenon in equivalent words. This type of interaction may be also reflexive, as a macromolecule can fold or unfold (i.e. change its state by modify the position and mutual orientation of its own atoms) provoking a binding or unbinding interaction between parts of itself. Dynamical interaction structures may arise in such an environment where macromolecules are free to move, rotate and fold/unfold.

It is important to note that the dynamical interaction structure that we are talking about is not to be confused with the spatial structure of the resulting bonded macromolecules. In fact, the dynamical interaction structure is an abstract concept (expressed in the languaging domain) based on the notion of described relations of cause-effect coupling between dynamical objects leading to the identification of a network of relations where the dynamical objects are the nodes: it is an entity existing in a multidimensional relational space that can be mathematically defined only within the languaging domain. The resulting spatial structure of bonded macromolecules is an observable conglomerate of macromolecules existing in the macromolecular (phenomenological) domain and represented as embedded in Euclidean space. Euclidean space is a mathematical construct expressed in the languaging domain, although isomorphic with a system made of observable three-dimensional physical objects, separated by physical distances, oriented in the ordinary physical space of our experience as observers and existing in a phenomenological domain that we call the classical physical domain. For all practical purposes of observation the macromolecular domain is considered usually as a particular case of the classical physical domain, even if quantum mechanical interactions are involved in the underlying interaction mechanisms.

A similar analysis could be applied to the neuronal domain, the social-economical domain or the concurrent software processes domain, etc. The problems left to the theoretician-observer are those of describing the underlying interaction mechanism and defining the adequate state parameters sets that will account for the changes of state which are determinant to explain the occurrence of an interaction between the corresponding basic dynamical objects (neurons, individuals, processor threads, etc.)

Self organized dynamical structures

Let's concentrate now on dynamical structures. A dynamical structure evolves in time as its network of relations (made of changing nodes and time dependent oriented relations), changes. The flow of interactions, driven by the causal laws attached to the underlying interaction mechanism, produces a cascade of state changes in its components. Nothing prevents the corresponding network of relations to reach a “stable” configuration. I mean by this that the network of relations does not “naturally” disintegrate nor split into several separate networks. Two networks can be considered as separate if their respective nodes are not connected by any relational arrow (or, in other terms, the components of each dynamical structure do not interact with the components of the separated dynamical structure).

When a dynamical structure evolves into a stable configuration of relations it doesn't mean that its components are definitively attached to it (we saw that components can enter and leave a dynamical structure). Such interactions may change the structure locally, but without provoking its disintegration as a delimited subset of dynamical objects interacting together.

In despite of the continuously evolving membership of its components, the “stabilized” dynamical structure may continue to exist as an observable interaction network in a sort of dynamical "equilibrium" as a unit. Because of this component membership flow, the topology of the network of relations can change as well (i.e. the relative connections between nodes can be rearranged), but it may do so in such a way that a delimited subset of dynamical objets interacting together continues to be observable throughout time.

Ephemeral nature of "stable" dynamical systems.

The latter is a description of what is usually called a self organized dynamical structure. Whether a self organized dynamical structure can last indefinitely throughout time is another subject of discussion. For now I will settle on the idea that it lasts sufficiently to be observable during a life span much longer than the time necessary for the propagation of the whole cascade of interactions occurring within the network to occur.

Such emerged stabilized configurations of relations correspond to organized sets of dynamical objects. What do we mean by that? Basically, that the corresponding composite units have acquired an emergent property produced by the particular topology of their networks of relations.

This property is the outcome of the particular flow of interactions occurring within the dynamical structure that allows for the composite unit to be observable as a delimited subset of dynamical objets interacting together throughout time. We call this property self organization.

The particular way in which self organization manifests itself is structure determined. By this, we mean that the organization of a dynamically stabilized structure is a causal result of the underlying interaction mechanism responsible for all the interactions occurring within the composite unit and only within the composite unit. It does not depend on any other interactions occurring elsewhere in the phenomenological domain where the stabilized configuration of relations has emerged.

Up to here, my definition of a dynamical structure organized as a stabilized configuration of relations does not lead to a clear idea about the "frontier" or boundary between the unit and its environment. Any component of the system can interact with dynamical objects existing in the environment provided that they reach states compatible with the occurrence of such interactions (which depends on the nature of the underlying interaction mechanism).

The notion of "delimited subset of dynamical objets interacting together" implies that within an observed time interval no system component interacts with other environmental dynamical objects. If this happens to occur at a given moment, the dynamical structure changes, either locally (there is no interaction propagation within the structure) or globally (interaction propagation occurs).

The result may be a new relational configuration in which the new network topology can lead either to a new "stable" configuration of relations or not. An emerged stable configuration of relations corresponds, in this sense, to a transient global state of an evolving dynamical structure during which only internal components interactions occur. The "frontier" between the unit and its environment is made of the whole set of components belonging to the structure during the "stable" period in which no other external interactions with the environment occur.

In these circumstances, the life span of a stable configuration of relations is not structure determined as it may be affected by the presence of environmental dynamical objects that happen to interact randomly with one or more components of the dynamical structure[9]. In other words, the structure determined self-organization property of an evolving dynamical structure can be ephemeral in face of external interactions[10].

[9]Maturana calls this the *"instantaneous domain of the possible perturbations of the composite unity"*, see *"Ontology of observing"*, referenced above.

[10]Maturana's *"instantaneous domain of the possible destructive interactions of the composite unity", ibidem.*

Emergence of long lasting "stable" dynamical systems

Given the ephemeral nature of stabilized configurations of relations it is interesting to analyze the observed fact that long lasting stable dynamical structures do emerge in some observed phenomenological domains. The first approach is to think about homeostatic dynamical structures in which emerged structure determined mechanisms are available to compensate for disruptive external interactions. Which is the homeostatic variable being controlled by such mechanisms? This is a tricky question because we are dealing with a multitude of continuously evolving dynamical objects performing endless changes of state and and in this endless flow of interactions apparently nothing remains constant throughout time. We need to search for a describable property of the dynamical system that remains constant throughout all component's states transitions.

We can imagine some possible ways by which a system may achieve long lasting stability. One way could be, for example, to have just a small number of components capable of interacting with the environment doubled by a feeble propagation of induced internal interactions. External interactions are thus reduced in scope. Their causal effects produce only minor perturbations of the dynamical structure. A minor perturbation is an interaction that modifies the topology of the network of relations only locally, leaving the rest of the structure unchanged.

A dynamical system can achieve a global state in which some of the components reach states in which they do not interact with environmental dynamical objects and some of the components reach states in which they interact with environmental dynamical objects only through local cause-effect coupling. This means that we can distinguish a subset of components which is "specialized" in performing all possible interactions of the whole structure with environmental dynamical objects. Furthermore, these local "frontier" interactions do not induce interaction propagation within the structure itself. In order to better understand how these considerations are related to the notion of boundary I propose the following distinctions:

18) The medium of a dynamical system is the set of all dynamical objects existing in its phenomenological domain that do not belong to its structure (i.e. that cannot be represented by nodes of its network of relations).

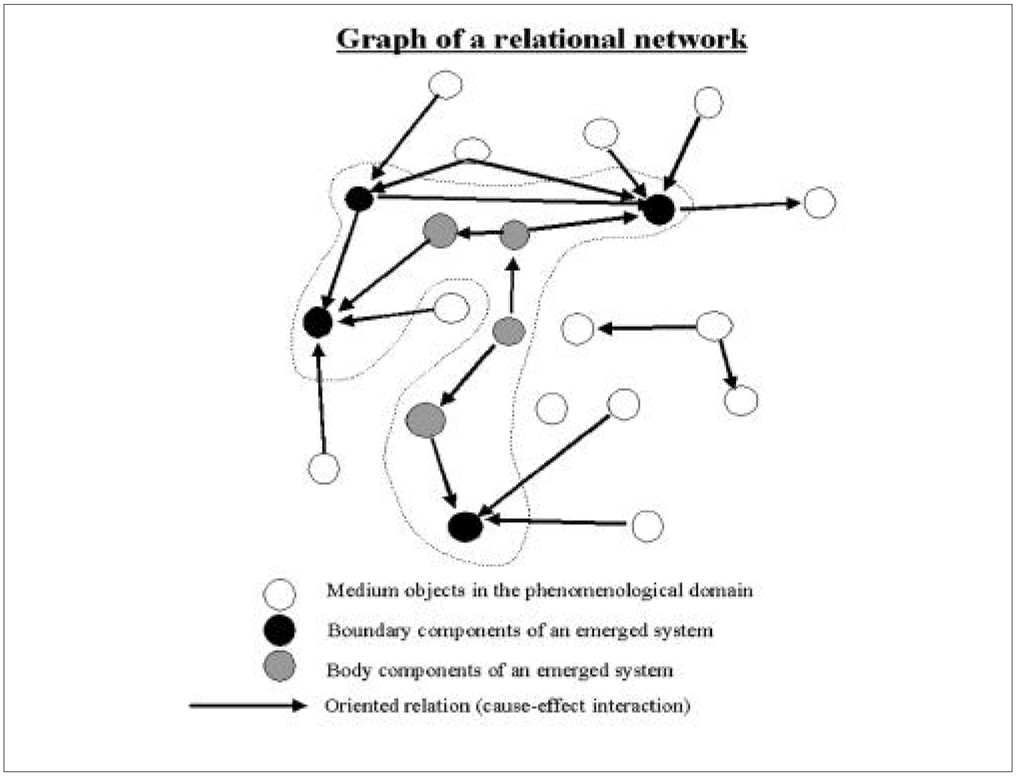
19) A medium component may interact with system components, but the oriented relations representing such interactions must go from the medium component to the system components. In other words, a medium component may trigger transitions on system components but not inversely (otherwise it would be "connected" to the network of oriented relations representing the system and, thus, it would be a system component)

20) I propose to say that a system component interacts with the medium if it interacts with at least one dynamical object of the medium (it is "sensitive" to a state transition occurring in the latter). An interaction of a system component with the medium is called an external interaction. All other interactions affecting a dynamical system component are called internal interactions.

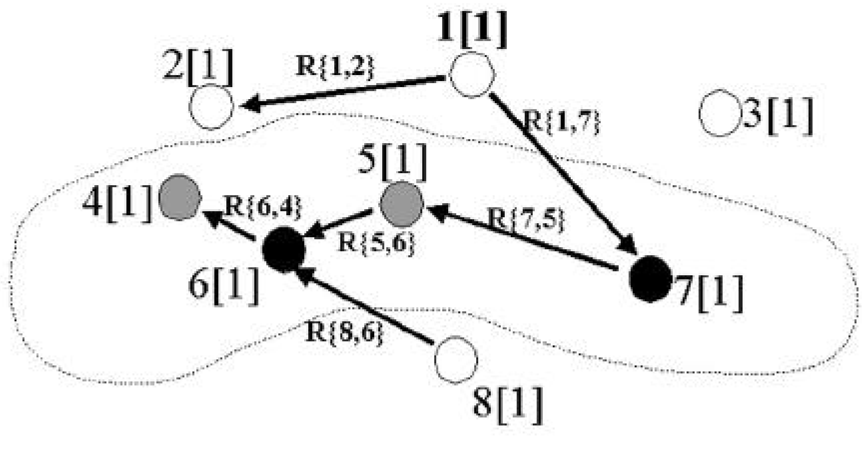
21) The boundary of a dynamical system is a subset of components having reached states in which they interact with the medium. In this sense, boundary components may interact or not with other boundary components.

22) The body of a dynamical system is a subset of components having reached states in which they do not interact with the medium.

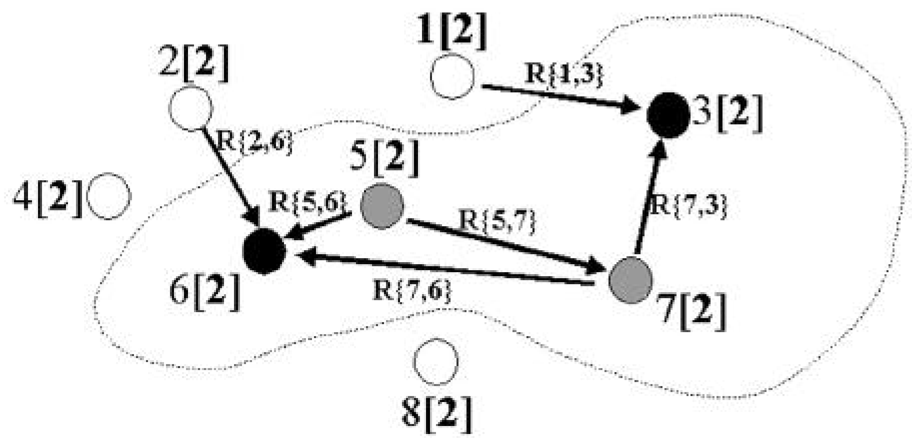
23) A boundary component, as member of the interaction network, interacts with at least one body component, either directly or indirectly via another boundary component.



Example of composite system represented by a network of relations at a specified time: In order to illustrate these definitions, the figure represents dynamical objects of a phenomenological domain in interaction with each other. The arrows represent interactions as oriented relations and the outcome is a network of relations (the closed curve is there just to highlight the interaction network that constitutes an emerged dynamical system at a specified time). Black circles represent boundary components, gray circles body components, according with the above definitions. White circles represent medium dynamical objects. Such a graph is valid only at a specified time (when each component is in a particular state) and the relations connecting components represent the possible cause-effect interactions that a component may trigger on connected components if it changes its state (at a specified time, the arrows of the network represent the potential paths of interaction propagation throughout time)



Network with component 1 in state [1] before a triggering transition to state [2]



Network after the triggering transition of 1 and the consequent interaction propagation

Example graphs of a network evolution in time : when component 1 reaches state [2] the underlying interaction mechanism causes a cascade of transitions in the network. According to the nature of this mechanism, all causally connected components change their states to a state [2]. In its new reached state, each component may interact differently with other components and the network topology may change (compare the graphs). Some components enter the system and other leave; some relations disappear and other are established. Nevertheless, a structure involving basically the same components in state [1] may be still observable after the interaction propagation. The boundary and the body with components in state [1] may loose or acquire components but a boundary and a body with components in state [2] may be still observable as well.

24)I propose to say that a boundary component absorbs an external interaction if after the occurrence of the interaction it reaches a state in which it interacts only locally with body components, i.e. it does not propagate a cascade of interactions to the body of the dynamical structure. Nevertheless, it may induce propagation of a cascade of interactions in the boundary, provided that the propagation does not reach body components.

25) I propose to say that a boundary component transmits an external interaction if after the occurrence of the interaction it reaches a state in which it does propagate a cascade of internal interactions to the body of the dynamical structure.

26) A boundary is said to be tight if all of its components absorb all external interactions.

27) A boundary is said to be porous if some of its components transmit external interactions and is tight elsewhere.

28) A boundary is said to be loose if all of its components transmit external interactions.

By definition, the presence of a tight boundary would prevent the disruption of the configuration of relations within a dynamical composite unit and a long lasting stability could be achieved in this way. If a composite unit is "encapsulated" by a tight boundary, the topology of the interaction network of the body components cannot be changed by interactions with the medium, as all external interactions are absorbed by the boundary, propagating interactions only within the boundary. So, if the boundary does not disintegrate, the only way by which the body could disintegrate is by its own internal dynamical evolution. Disintegration can happen only if the continuous flow of internal interactions leads to global states in which the topology of the interaction network becomes unstable. For the moment I will concentrate on composite units that do not disintegrate spontaneously (i.e. where their self organization mechanism is such that all possible global states reached in the flow of their internal interactions are stable global states).

> As an example, think about an isolated vegetable seed in the biological domain. In the absence of water, the nutrient or toxic macromolecules existing in the medium cannot interact with macromolecules existing inside the husk of the seed. The husk acts as a tight boundary shell that absorbs all external interactions of the seed with the medium. Nevertheless, the internal network of relations of the seed might evolve dynamically according to its specific self organization mechanisms.

Let's examine the case of a composite unit with a porous boundary, that is, a self organized system in which some external interactions can be transmitted to the body. A cascade of internal structure determined interactions can occur leading to a new configuration of relations between the components of the composite unit. Two situations may occur: a) a new stable global state is reached through rearrangement of the topology of its network of relations; b) no stable global state is reached and the interaction propagates indefinitely leading to a breakdown of the topology of its network of relations (i.e. the system's self organizing mechanisms are no longer capable of preserving the existence of the system as a single composite unit). In the first case I propose to say that the system "compensates" for the external interaction, in the second case I propose to say that the system "disintegrates". It is the nature of the interaction mechanism (i.e. the type of interaction) that will determine if the self organized composite unit compensates for it or if it disintegrates.

> As an example, think about the same seed of the previous example placed in a humid environment. The presence of water makes the husk porous, as diluted macromolecules can cross the shell and reach the body of the seed. Biochemical reactions between internal seed macromolecules and incoming macromolecules may occur. If these are nutrient macromolecules, the cascade of interactions may lead to seed growth (non disruptive rearrangement of the topology of the network of relations). If they are toxic macromolecules, the cascade of interaction may lead to the seed's death.

We can say that for a specific type of interaction the ability of an observed composite unit to compensate for external interactions is wholly structure determined: it depends only on the configuration of relations existing at the time of the external interaction occurrence.

These considerations are also applicable to the extreme case of a composite unit with a loose boundary. In this case, external interactions are not absorbed by boundary components: the boundary is not a "protective" shell for the system. The ability of the composite unit to compensate for interactions with the medium will depend exclusively on adequate dynamical rearrangements of the topology of its network of relations by following a path of successive stable global states in which this ability is preserved trough time. The distinction of a boundary is useful only to bring forth the composite unit and separate it from its environment (for an observer), but the presence of a boundary cannot be invoked as an explanation of the ability of the composite unit to compensate for external interactions.

In fact, a tight boundary only avoids disruptive external interactions by "encapsulating" the system and a porous boundary just "filters" some external interactions out. The overall ability to compensate for external interactions is a conservative property of the whole dynamical system expressed through structure determined topological rearrangements of its network of relations. These rearrangements are induced by the cascade of interactions triggered in its boundary and in its body alike.

The rearrangements induced on the topology of a network of relations are outcomes of the flow of interactions between dynamical objects (the nodes of the network). Structural changes occur through such rearrangements (the topology of the network of relations changes). The flow of interactions may result in the lost of some nodes (some components leave the system becoming medium dynamical objects) and the acquisition of new nodes (medium dynamical objects become system's components). Also, some connections between nodes may disappear and others may be established.

The conservation of the self organizing property does not mean the conservation of the members of the set of components nor of the number of components of the composite unit. It does not mean either that the system reaches a global state identical to the global state in which it was before the external interaction occurred. It only means that the flow of interactions produces new topological arrangements of the network of relations in such a way that all reached global states of the system are always stable states, whatever the configuration of relations may be at a given time.

When a composite unit shows such a behavior I propose to say that its structure produces a compensating mechanism (the mechanism responsible for the ability to compensate for a particular type of interaction with the medium). If a compensating mechanism is available after each network rearrangement (i.e. after each structural change) then I propose to say that the composite unit conserves its organization for a specific type of interaction with the medium. This is the constant property (homeostatic variable) that we were searching for.

Among other outcomes, a compensating mechanism can result in a systematic acquisition of new nodes in the interaction network of the composite unit. When a composite unit systematically acquires new dynamical objects (as components) without disintegrating, I propose to say that the composite unit is a self producing system.

I think that the distinctions proposed so far allow for a generative explanation of the emergence of an autopoietic composite unit as proposed by Maturana. A self producing system provided with compensating mechanisms for all the type of interactions involved in the constitution of its network of relations is what Maturana called an autopoietic system. In this sense, an autopoietic system produces its own components in the realization of the conservation of its own organization.

The distinction of boundaries is just a step in the generative process of identifying a dynamical system as an autopoietic unit. Non autopoietic dynamical structures do have boundaries as well and the identification of such a "specialized" subset of components in a composite unit does not guarantee the existence of a compensating mechanism responsible for the conservation of its organization throughout time. Moreover, an autopoietic system can have no boundary at all (as defined above). I mean by this that all of its components may interact with the medium (in which case we could say that the whole system is a boundary without a body) provided that the compensating mechanisms at work are able to conserve its organization throughout time. The only necessary condition for this to happen, is that the flow of interactions within the system leads always to stable global states (in the sense defined above).

Further reflections

A reasonable criticism to this explanatory path could be argued by rejecting its reductionist “flavor”. The above proposed distinctions (meant to help in the task of identifying the boundary and the body of a composite dynamical system observable in a given phenomenological domain) may be operationally useful only if observers are able to fully describe the system's components in terms of their state parameter sets and of the state transitions that they can undergo through cause-effect interactions. Moreover, the underlying interaction mechanism responsible for state transitions in dynamical objects within the observed domain should also be describable as a “valid” explanation of the causal relationships affecting objects in that domain. If observers know little about what happens and how it happens in the entrails of the observed system, these distinctions might appear as helpless. The aim of a reductionist program would be to predict the behavior of a composite unit from the explained behavior of its components and from the deterministic cause-effect relationships in which they participate.

However, this theoretically valid criticism, does not apply to the purpose of my approach . The bottom-up approach of building an understanding of what is entailed by autopoietic behavior by concentrating our attention on the low-level clockworks of its dynamic components (opposed to a top-down approach in which attention is concentrated primarily on the global properties of an observed composite system without detailed analysis of its inner workings) may be of great explanatory value.

In practical terms, the whole description of the dynamics of a complex system in terms of low-level descriptions of components dynamics is an impossible task. This is so for one main reason: the instantaneous state of each single component should be observable and describable (“measured”) at any given time. For systems composed of thousands, millions or even billions of components such degree of precision is unattainable. Even more, there is no need for such a program: specialists of very large and complex systems (i.e. physicians, economists, sociologists, etc.) indulge to dive into low level mechanisms only when they believe that a “critical” partial subset of the global system has been identified as an essential agent that participates in the emergence of a particular global property of the system.

Complete predictability and detailed explanation of the system's dynamics is is not necessarily the purpose of a bottom-up approach. We can just settle for the assumption that for a given phenomenological domain, observers are able to describe the dynamical properties of “typical” objects of that domain in terms of state transitions and produce “reasonable” explanations of the outcomes of causal interactions occurring between them. By “reasonable” explanations I mean the production of partial descriptions of hypothetical networks of cause-effect couplings that can lead to new observations of verification in the phenomenological domain. The aim is to be able to say “what could have happen” within the system, given the “known” properties of its dynamical objects, and devise a way to “show” that the statement is justified by an observational experience.