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A NATURALIZED ACCOUNT OF THE INSIDE-OUTSIDE DICHOTOMY[1]

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ABSTRACT

The first form of the inside-outside dichotomy appears as a self-encapsulated system with an active border. These systems are based on two complementary but asymmetric processes: constructive and interactive. The former physically constitute the system as a recursive network of component production, defining an inside. The maintenance of the constructive processes implies that the internal organization also constrains certain flows of matter and energy across the border of the system, generating interactive processes. These interactive processes ensure the maintenance of the constructive processes thus specifying a meaningful outside. Upon this basic form of identity, the evolutionary and historical domain is open for the emergence of a whole hierarchy and ecology of insides and outsides.

1. Introduction

An inside-outside[2] dichotomy suggests the existence of something (a self

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[2] We will use the terms "inside-outside" and "in-out" as equivalent in this article.

or identity) in relation to which something stands in or out. We commonly assume that a certain *part* of reality constitutes a system (a set of elements and relations among them) and the *rest* is the "environment", the outside. Nonetheless, the description of something as being a system (and, hence, the introduction of a dichotomy between what is "inside" and what is "outside" of it) is usually the result of the adoption of a particular point of view. It suffices to change the classifying criteria of the observer, and what was considered before to be the outside becomes the inside and vice versa. Now, as Hoffmeyer (1998) has pointed out, nature is replete with systems (living beings) having (different) points of view.

Can we approach the origin of the in-out dichotomy detached from the intrinsic relativism of each subject with his or her respective way of partitioning the world? In fact the relativist position must step back in the face of the very existence of subjects, namely, systems that create their own world of distinctions. For in any case, we have to recognize that there are systems that result from our distinctions and other systems that create their own distinctions. Hence, the fact that there are systems capable of establishing distinctions points towards a solution to the problem. In order to overcome relativism and "objectivize" the question, we shall begin with those systems whose identity is somehow self-generated and not just the result of a choice made from a particular point of view.

Which could be the most basic system capable of generating its own identity, i.e. capable of generating the distinction between itself and the rest of the world? Let us begin with the example of a star. Stars are systems formed when gravitational forces concentrate a critical mass in a relatively small region of space. As a consequence, the enormous pressures produce thermonuclear reactions in the nucleus, generating a long sustained and stable organization during a considerable amount of time. The stability in the star is the result of a specific set of initial conditions and it is maintained through the continuous dissipation of energy in the surrounding space, which acts as a sink. A star is, thus, a system whose identity lies in its dynamic organization. Let us take another example, a candle flame, which manifests a short-term stability and persistence, but only as long as fuel and oxygen are inputs to the process. Except for cases like stars, usually the maintenance of far-from-equilibrium processes requires transactions with the environment, otherwise they would move toward equilibrium and their organization would cease.

What we see in these examples is the generation of a certain kind of identity — which consists, in fact, in a more or less stable kind of dissipative cohesion. This identity is not the result of external descriptive criteria but a consequence of a set of far from equilibrium processes that, given certain boundary conditions, are maintained stable. Significantly, in this kind of systems, the identity is the result not just of external constraints but also of the dynamics of the system itself. In these examples we can see a form of *self*-constitution of the very identity of the system, because this latter is nothing but a pattern which, given the adequate initial and boundary conditions, recursively contributes to its own maintenance. The pattern of collective order established must remain as such because it plays a direct *causal* role in the dynamics responsible for its maintenance. In the example of the candle flame, as Bickhard (2000) points out, the flame is a 'self-maintained' system, for itself contributes to maintaining the conditions of distance from equilibrium that continuously make it possible (particularly, high temperature and the constant oxygen uptake). The candle flame melts down the wax allowing it to be absorbed by the wick and to ascend through it in order to keep the flame going whose heat will keep the wax melting down etc, etc. On the other hand, the heat of the flame propels the air to rise, creating an ascending flow of oxygen that permits the combustion of the flame, which feeds-back the flux of air. This continuous feed-back and recursivity between the flame combustion and its boundary conditions (oxygen intake and wax) is self-reinforcing and it is robust in the face of disturbances (whenever they are not of an excessively aggressive character, of course).

Now, is the formation of a self-generated identity, as we see in these examples, sufficient to speak about a genuine creation of the in-out dichotomy? What we see in the aforementioned examples is the creation, in certain far from equilibrium conditions, of a self-sustaining organization, hence, a self-maintaining distinction between the system and its environment. However, a true in-out dichotomy only arises when the system is able to create its own external world, not merely as something that does not belong to the organization of that system, but in the sense of a world of interactive processes driven by the system itself. In this sense, the in-out dichotomy suggests that the organization of the system, in order to be understood as "internal", must have operational consequences beyond the system it constitutes. Although these consequences, in some sense, take part in the maintenance of the very system, they can be considered external to it. Thus, unless we understand it in a trivial sense, the inside-outside dichotomy does not only express the process of separation between a system and its environment while the former is self-generated and maintained. The inside-outside dichotomy expresses also a difference between the processes that constitute and build itself and those that the system as a whole maintains in the interaction with its environment. In this sense, none of the examples shown above (stars and candles) displays a true in-out dichotomy. In fact, only living beings (or higher level systems constituted by living beings) manifest this in-out dichotomy.

Given the large distance in complexity between inorganic natural systems and the simplest known living beings, if we want to investigate the origin of the in-out dichotomy, we must situate ourselves in the hypothetical scenario of prebiotic evolution.

2. The origin

We can imagine that, given the adequate environmental conditions, a great variety of chemical systems would have appeared on the primitive Earth (or on other similar planets). Among these systems, some would be autocatalytic networks. Certain complex autocatalytic networks have the property of closure, namely, they are systems where all components and component aggregates (directly involved in their organizational dynamics) must be products of a reaction network that constructs itself (Kauffman 1986). Such kind of systems could have appeared on special places of the Earth's crust during the period of chemical evolution that took place when the planet got cooled down. However, it is difficult to conceive further increases in the complexity of such autocatalytic networks because they become more vulnerable to external perturbations as their complexity increases. The solution to this problem requires that the organization of the system should be capable to modify (at least in a minimal sense) its external conditions so as to keep its organization going. In other words, the following step would require systems capable of modifying their own self-maintaining processes in order to adjust to those environmental changes, which jeopardize their "survival".

How to achieve such performances? Which are the conditions that a chemical system must satisfy for being capable to actively maintain its identity? The system has to generate a set of conditions for their components differing from those of the environment, and for that it has to create a clear separation (an asymmetry) between itself and the environment. Wächsterhäuser (1988) argues that the existence of a mineral surface could have played this role of separation in a first stage of prebiotic evolution. According to this author, under these conditions the system could "act" on the environment establishing a buffering of pH or bringing down the tendency towards hydrolysis in its surroundings. Nonetheless, in this kind of systems the capacity for self-modulation will be highly limited because the system depends on the existence of an external, fixed constraint[3]. In addition, in this example the mechanism of differentiation between the system and its environment is restricted to a bi-dimensional organization. But this solution limits severely the evolutionary capacities of these systems.

Thus, the only solution with more open capacities to increase its complexity is that the very system generates a flexible constraint that affects globally the network, allowing the creation of an internally selected environment. This constraint cannot be other than a selectively permeable membrane, since only a physical boundary can differentiate the organization of the system (the set of relations that constitute it as a distinct unity) and the environment, where different interactions occur. This way, a clearly distinct inner medium is created: a space where not just the concentrations but even the components will be different from the "external" medium. But the most important issues is that, since it is a boundary mechanism generated by the very system, it can be modulated by it. That is why it becomes crucial for the boundary to be produced by the internal dynamics of the system (i.e., that it be an integral and integrated part of the metabolic network) and not a mere "wall" whose properties are externally defined.

[3] Wächstershäuser defends that the first 'organism-environment dichotomy' is established on the interface 'solide phase (mineral surface) – liquid phase (water)' on which its "surface metabolic network" is situated (displayed in a layer of molecular depth). But he recognizes that the *holism* characteristic of a metabolic sytem is produced only when the cellular stage is established.

Obviously, the construction of this global constraint implies a substantial change of the very organization that generates it. Now the (internal) organization will appear as much more integrated and complex in respect to its environment than the autocatalytic network without physical border. The membrane allows the relations between the components of the system to be produced in much more favorable and stable conditions (regulation of concentrations, selection of kinds of components, etc.). This way the generation and stability of more complex systems becomes possible. At the same time, the requirement of a selectively permeable membrane produced by the very system raises the necessity of an increase in the complexity of the whole organization of the system. These systems could be considered as autonomous systems (Ruiz-Mirazo & Moreno, 1998, 2000).

3. Constructive and interactive closure

The appearance of cellular systems produced a fundamental change (other than the increase in the organizational complexity of the system): the existence of a physical border built by the system itself draws a net distinction between an "in" and an "out". From this fundamental event on we can distinguish between those processes happening in the interior side of the physical border (including those of construction and maintenance of the boundary itself) and those that, although they appear organizationally as prolongations of the system, occur outside its physical boundary. These processes, although governed by the internal organization of the system, show specific features: since they occur outside the physical boundaries of the system they do not share the conditions of the inner medium and are less integrated and constrained by the global organization of the system. We find, then, an asymmetry between both kind of processes: the internal-constitutive and the external-interactive ones. Although both are shown to be mutually dependent, the internal-constructive ones are more fundamental. Interactive processes are thus less fundamental than constructive ones, because they are the result of the existence of a strongly holistic network, much more integrated and complex than the interactive processes performed by the system on its environment. It is this inner organization, taken as a whole, that functionally controls certain flows of matter and energy between the environment and the system so as to ensure its maintenance (Collier, 2000). In most of the present-day living beings, the interactive processes can even be disrupted and recovered thanks to the internal organization, which induces a new interactive process capable of maintaining the internal organization. That is what defines the "in" of the relation in-out: a robust and recursively self maintaining (in)side.

Thus, what allows for the creation of a genuine in-out dichotomy is the existence of a system with two kinds of recursive relations, both mutually dependent but asymmetric in this relationship. On the one hand, the "constructive" or internal relations, organizationally differentiated from the rest of its environment and defining the identity of the system as a material entity. On the other hand, the "interactive" or external relations, which are the set of relations that the system must hold with its environment in order to persist and that are controlled by the internal organization of the system.

How can we distinguish them? After all, we are talking in both cases of processes of self-maintenance for the system. The "constructive" processes could not be maintained without the interactive ones being realized, and, in turn, the interactive ones require the internal organization of the system in order to be carried out. As we have seen, at a basic level, the only thing that allows for such a distinction of processes is the existence of a physical border that somehow makes the internal relations homogeneous in the face of external conditions. Thus even if a set of elements and energetic flows of the environment are governed by the system (becoming thus part of those interactive relations necessary for the maintenance of the system) they are not homogeneously constrained. Therefore, its participation in the maintenance of the system requires the previous existence of a globally integrated (internal) organization.

In this sense the (self) generation of an inside is ontologically prior in the dichotomy in-out. It is the inside that generates the asymmetry and it is in relation to this inside that an outside can be established. Although the interactive processes/relations are necessary for the maintenance of the system, they presuppose it (the system) since it is the internal organization of the system that controls the interactive relations. For example, active transport in cells is possible because there is a specific organization of internal chemical reactions that, in addition to providing energy to carry out that work, synthesizes specific molecules with the appropriate catalytic functions. In order to do so, it is necessary for the complex chemical organization to be able to self-enclose itself in a selectively permeable membrane, creating an asymmetric relation between interior and exterior. This way the internal world is that in which constructive processes take place, the exterior that in which interactions occur and the membrane is the place where both processes connect.

4. The nature of the in-out frontier

So then, the physical border of an autonomous system must play an active role, which is fundamental for the interaction with the environment, as an indispensable device for managing the flow of energy and matter through the system. This is precisely what makes the self-production and robust maintenance of the system feasible. Therefore, rather than a boundary produced and reproduced as a consequence of an autocatalytic reaction happening within it —as is formulated in the autopoietic approach in the research of minimal autonomous systems (Varela et al, 1974, Varela 1979, Fleischacker 1988)—, the membrane of these hypothetical primitive systems was a physico-chemical interface capable of regulating interactions with the environment and controlling (however minimally) matter and energy exchanges with it. In other words, such an interface needs to be a semi-permeable structure where coupling mechanisms (particularly energetic transduction and active transport mechanisms), which are basic for the complete self-construction, are anchored (Ruiz Mirazo and Moreno, 2000 and 2004). The membranes of all known cellular living beings show this kind of mechanisms and through them a fundamental interactive part in the constitution and maintenance of any metabolism is carried out.

Accordingly, the membrane must consist of an aggregate of structures much more complex than that of a mere physical boundary. We are talking about a global envelope of selective permeability (which must facilitate transit of some substances, such as water, and prevent the diffusion to the outside of others, such as polymer chains), which at the same time acts as the controller of matter and energy flow through the system. This implies the existence of a topologically closed surface where some components are inserted: some carry out local tasks (for instance mediated transport or catalysis) and others are able to capture energy from some external source and transform it. Therefore, in order to achieve an adequate flow of energy and matter through the system, a basic autonomous system requires a set of macrocomponents some of them inserted in the boundary structure and the rest in the inside of the system.

Thus, the recursive process of self-construction should be deeply entangled with the recursive process of self-maintaining interactions with the environment. Functional interactions become possible only insofar as there exists an inner medium ensuring a holistic network more complex than the inside-outside interactive loops. It is this inner organization, taken as a whole, which controls functionally the interactions between the system and its environment, so as to achieve both constructive and interactive closure.

This interactive dimension of the system is of fundamental importance. The self-constructed identity will be strongly linked to its capacity to define (by its own) the domain of interactions (or dependencies) that it will establish with its environment; this in turn will show a distinctive behavior (Ruiz-Mirazo and Moreno 1998; 2000).

5. Agency: the conquest of the outside by the inside

A system is an agent if it does something in the environment and this action is not merely a physical interaction, because its own viability is affected by it (Moreno and Etxeberria, 2005). An autonomous system must be an *agent* because it has to perform certain interactive processes on its environment in order to ensure its viability as a self-constructing organization. The nature of these interactive processes will always be different from that of mere physico-chemical reactions happening all the time in both directions (and which are, in fact, present in all kinds of systems, from the simplest to the most complex). Since the action has an (direct or very relevant) effect on the self-constructing dynamics established in the system, it would constitute a functional loop of the system itself: i.e. it constitutes an environmentally mediated loop, but with a clearly asymmetric[4] component. An example of a very basic form of agency, which we can see even in the most primitive forms of life, is the mechanism of active transport, which is a flow of matter in/out against gradient, driven by the internal organization of the system[5], as described in the sections above. Thus, agency involves a functional action on the environment, modifying (and later controlling) a very important *environmental condition* for the system's dynamics.

From the external point of view the evolution of agency appears as a set of increasingly complex actions that the organism performs, transforming physical domains into biological ones. Along the evolution of life, the external action performed by each organism will be maintained and reinforced, forming complex interactive webs among living beings and with his or her environments. Therefore we shall distinguish between an outside affected by the internal organization of the system and an outside more independent and distant. Biological evolution is the process of self-organized material construction under the pressure of natural selection. Living beings are self-assembled systems whose components modulate the flow of energy coming from diverse sources in order to produce work. In other words, organisms constrain the energy flow available in their environments in the form, intensity and direction required for their self-maintenance and production. As a consequence the evolution of life is a process of colonization of all possible domains where life can be sustained. This process of colonization has created a friendly environment for the organisms; without it the long-term maintenance of life would become impossible[6]. Probably, from the very beginning this process of colonization of the physical environment came hand by hand with agential actions between organisms constituting genuine ecosystems. Thus the most significant part of the outside of organisms has become that of specifically biological interactions and, with

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[4] Asymmetric in the sense that the environment cannot establish such recursive interaction processes with the agent, unless we are speaking of an ineractive coupling between two agents.

[5] This mechanism probably appeared even in prebiotic forms of cellular organizations because it is required in order to avoid an osmotic crisis, which would lead to the burst of the cell (Peretó 1994).

[6] Of course, this friendly environment is absolutely crucial for the appearance and propagation of more complex forms of life.

the evolution of animals, that of cognitive interactions. In this sense, the history of evolution is the history of the conquest and codefinition of "outsides" progressively wider, more flexible and complex. To this "conquest" we shall add the "construction" of a world of collaborative interactions between organisms and the construction of environmental structures (nests, dens, etc). These external constructions (inter-organismic and structural), in virtue of their recursive functional integration, can become higher levels of organization with their respective insides and outsides. The evolutionary process generates new forms of life, which in turn, constitute the necessary environments for new and more complex living systems.

From the internal point of view, the development of agency transforms the physical environment into a world of significances (Varela 1992). Any living being —from the simplest bacteria to the human being— establishes in its world a system of distinctions that is only useful for itself (and alike). It is this system of distinctions and partitions that defines the "meaning", what is "good" and "bad" for the organism in question. The origin of new autonomous systems with adaptive capacity involves and implies a fundamental event: the creation of interpretative-evaluative domains (Di Paolo, 2005). Adaptive action cannot be carried out without a certain "perceptive" capacity: i.e., a capacity to differentiate certain environmental states (that potentially affect the maintenance of the system) and to normatively bind the detection of these environmental variations to the appropriate functional interactions that assure the maintenance of the system. Therefore, adaptive action can be considered from a double perspective: the "external" one and the "internal" one. The adaptive interactive dynamic of an autonomous system with its environment implies a radical differentiation between two kinds of relations: functional and dysfunctional; i.e. on the one hand, those interactions which are integrated in the processes that contribute to the self-maintenance of the system; and on the other hand those that in some way hamper this maintenance processes. There is also a third group of relations, which are those that are indifferent to the maintenance of the system. Thus, the system constitutes its environment (its outside) as a world of evaluative interpretations, as an *Umwelt* (Uexküll 1982) and ignores the rest of interactions. The perceptive world of the system is constituted as a function of its internal normativity. This way from the perspective of the system that generates the in-out dichotomy, the outside does not appear as an undifferentiated physical space but as a set of possibilities and dangers for its self-maintenance. It is in virtue of this constitutive interactivity of every organism that the outside is perceived (at all) by the inside, and thus, comes into existence from the phenomenological side (the inside) of any autonomous system.

6. The in-out dichotomy in higher levels of organization

We have focused on the origin of the in-out dichotomy because of two fundamental reasons: a) the in-out dichotomy is an ontologic primitive, a ground of the subject/object duality, that arises from a previously undifferentiated world of processes in which a difference, a boundary, is only an epistemological separation made by an observer; and, b) because it shows the most fundamental form upon which other levels of in-out dichotomy are sustained.

Thus the case of a basic level of in-out differentiation and identity formation is the naturalized condition of possibility of further generations of in-out dichotomies at higher levels of organization. It is upon this basic level that other forms of in-out appear in nature; new ensembles, recombinations, aggregations, etc. but also new systemic processes hierarchically grounded on them: multicellular systems, nervous systems, immune systems, symbiotic systems, colonies, even whole ecologies and societies. All these systems constitute higher levels of organization that generate their respective identities distinguishing themselves from their surrounding dynamic processes.

We have seen that the self-generation of a physical boundary becomes a necessary element for the in-out dichotomy in the basic level of organization where internal and external components belong to the same interactive level (physico-chemical). The physical boundary also plays a central role at higher levels of biological organization since it is a key element for defining the concept of organism. Sterelny and Griffiths emphasize "the importance of physical cohesion and the existence of a physical boundary between the organic system and the rest of the world. Physical boundaries are important in two ways. First a physical boundary gives us a clear and natural segmentation of an evolutionary process (...) [The second is that] as a physical boundary develops, the units within the boundary become increasingly important to one another. They become the dominant element of one another's environment." (Sterelny and Griffiths 1999: 175—176). But in those higher levels of organization composed themselves of complex adaptive systems, new forms of identity differentiation and in-out dichotomies can be generated that do not require a physical boundary. In particular, the creation of new types of components can be a source of maintenance of the in-out dichotomy: this happens when the components within the system are such that they allow for specific interaction processes different from those happening between the system and the environment, and between the components of the environment. This differentiation of constitutive components can be produced in different ways. For example, certain changes in the environment can induce processes of genetic expression or suppression that lead to cellular differentiation (as it happens in developmental processes), thus leading to a differentiation of subsystems in the organism and their respective in-out dichotomies. In such cases the boundary between the inside and the outside of the subsystem is not so much produced by a physical barrier but by the specificity of the kind of cells and tissues that constitute the system. The nervous systems serves as an example of a system that maintains a somewhat separated identity with the rest of the systems in the organism. In the nervous system specific cells (neurons) instantiate a specific kind of component interaction (neural signaling) which is not possible between other kinds of cells in the organism. A similar case of inside-outside distinction can be found between human beings and animals. Humankind establishes new forms of internal relations (based on language, tools, etc.) that cannot be established between humans and other animal species nor between other species themselves.

But the specificity of constitutive components alone is not a sufficient condition for the establishment of a genuine in-out dichotomy (although it might be a necessary condition when a physical boundary is not present), nor is the existence of a boundary alone a sufficient condition. As shown by the examples above (multicellular systems, colonies, cultures, etc.) all the new higher levels of in-out distinctions are associated with new levels of identity formation through self-organized and self-maintained cohesive processes. In other words, what is maintained invariant in all those levels of organization in which the in-out dichotomy appears is an asymmetry between the constructive closure of a self-maintained system and their interaction processes; an asymmetry in which the latter are less cohesively integrated and require the former. This is the case of multicellular organism, colonies, or even subcultures in which internal cohesion and functional integration in the generation of meaningful practices and symbols are the source of social in-out dichotomies.

On the other hand, in complex biological and cultural systems other intermediate kinds of in-out dichotomies can also be created. For instance in the example of gastrulation in animals a peculiar kind of "outside" can be formed inside of the organism. This "exterior-inside" is a particular medium: connected to the environment through two selectively permeable gates, it is a highly constrained medium (in relation to temperature, pH, chemical composition, etc.). But nonetheless, it is a medium separated by physical boundaries from the inside (strictu sensu) of the organism that is a much more integrated and organized system than the former. In other cases, we observe an evolutionary process of gradual "in-corporation" of initially distinct systems: this is usually achieved through processes of symbiotic association of increasing irreversibility. A paradigmatic case of this kind could be, according to Margulis (1981), the one leading to the origin of eukaryotes, where certain internal structures such as mitochondria could have had their origin in external and completely independent cells (bacteria) that appear now integrated.

To summarize, once the first in-out dichotomy appears in nature the way is open to a whole range of in-out aggregations, integrations, compositions and recombinations and to the emergence of new levels of organization in which the abstract pattern of in-out generation is repeated: a self-organized process of identity generation, functionally integrated and robust to internal and external perturbations (whether a physical separating boundary is present or a component specificity is sufficient).

7. Concluding remarks

The minimal basis for the creation of an in-out dichotomy is the constitution of autonomous systems. As we have seen, the crucial step in this transition is the process of self-encapsulation by an active physical border, fully integrated in the organization of the system. This transition gives rise to a new kind of systems constituted by two kinds of complementary but asymmetric processes:

(a) Constructive processes, which physically constitute, in a recursive way, the system as a network of component production which produces a physical border creating inside (a part of) the conditions for the maintenance of the very network. The maintenance of the constructive processes implies that the internal organization also constrains certain flows of matter and energy across the border of the system, generating:
(b) Interactive processes, which modulate the external conditions of the system in order to ensure the conditions for the recursive maintenance of the constructive processes. Adequate interactive processes are required in order to generate/control the necessary conditions for the recursive realization of the constructive ones.

Once these basic and minimal conditions for the appearance of the in-out dichotomy are met, the way is open towards higher levels of organization showing an in-out dichotomy (which is not necessarily based on physical barriers). Upon this basic form of identity formation, the evolutionary and historical domain is open for the emergence of a whole hierarchy and ecology of insides and outsides which mutually subsume and collaborate in the maintenance of that essential in-out dichotomy that defines the conditions of possibility of the subjects and the worlds they generate.

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