



**HAL**  
open science

## From physical to biological individuation

Paul-Antoine Miquel, Su-Young Hwang

► **To cite this version:**

Paul-Antoine Miquel, Su-Young Hwang. From physical to biological individuation. Progress in Biophysics and Molecular Biology, 2016, 122 (1), 10.1016/j.pbiomolbio.2016.07.002 . hal-04039234

**HAL Id: hal-04039234**

**<https://hal.science/hal-04039234>**

Submitted on 21 Mar 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# From physical to biological individuation

Paul-Antoine Miquel<sup>a,\*</sup>, Su-Young Hwang<sup>b</sup>

<sup>a</sup>Université de Toulouse 2, 5 Allée Antonio Machado 31058 TOULOUSE Cedex 9

<sup>b</sup>Hongik University, Department of Liberal Arts and Science, Sejong-Ro 2639, Jochiwon-eup, the New city of Sejong, South Korea

---

## Abstract

In this paper, we insist on stressing the epistemic and metaphysical difference between individual and individuation, a distinction originally developed by Gilbert Simondon. Individuation occurs in complex physical systems by the coupling ( $R_1$ ) between the system and its outside conditions. As such the system is not well defined by its sole constituents. Let's characterize ( $R_2$ ) as follows: the system is not entirely defined by its structure at a given time because this structure will change and global emergent properties will appear, as in the paradigmatic example of phase transition. Thus physical individuation is defined both by the coupling of a physical system with its environment ( $R_1$ ) and by its diachronic dynamics taking place ( $R_2$ ). We interpret biological individuation as a second order one, i.e. as a recursive procedure through which physical individuation is also acting on "its own theatre". We represent this procedure like a mapping through which ( $R_1R_2$ ) are applied to themselves, so that:  $R_N = (R_1R_2)^N$ . We highlight the relation between this assumption and the concept of extended criticality developed by Bailly, Longo and Montévil.

*Keywords:* Biological individuation, Extended criticality, Plasticity, Robustness, Normativity.

---

If Substance is not the right word to characterize the Being, it is possible to conceive the relation as a non identity between the Being and the Being itself.

Simondon, 1964, p 30

*Special thanks, to Cheryl Michaelson, Ana Soto, Mael Montévil, Carlos Sonnenschein, Giuseppe Longo, Matteo Mossio, Nicole Perret, and Arnaud Pocheville that read or revised the manuscript.*

## Introduction

In this issue Longo and Soto discussed the differences between physical objects and biological ones, particularly on the genericity of physical objects and on the specificity of biological ones, and on the ability of biological objects to initiate action and even create their own rules, as remarked by the French philosopher G. Canguilhem. These distinctions bring us to the idea of individuation. In the current paper, we explore the concept of «biological individuation» which was introduced by another French philosopher: G. Simondon, in his doctorate thesis initially defended in 1958

and entitled «l'individuation à la lumière des notions de formes et d'information » (2013).

Following Simondon, individuation is characterized by the fact that a «structural potential» (2013, p 77) is generated. A «structural potential» is the ability of the system to change its structure in contrast to the ability for a physical system to change states through the same determinative structure. Strictly speaking, individuation is not a simple change in physical state. Instead, it is the state that expresses the limits of a determinative physical structure. To further explain this subject, Simondon selects the example of a first order phase transition: i.e. crystallization.

Simondon also says that we go from physical to biological individuation through a recursive procedure (recurrence of causality, "réurrence de causalité"). He assumes that, when such a procedure is applied, we are moving away from a simple singular event of individuation in a physical system towards a system in which all biological events are singular and occur in a so called "theatre of individuation" (2013, p 162). We will interpret this typically French image as the fact that in biological systems, criticality is not point wise. We will assume that biological systems move in a space of criticality. Then, we will compare Simondon's assumption to the concept of "extended criticality" developed by Bailly/Longo/Montévil.

## 1. Physical individuation

1.1 Even in physical systems, «individuation» has an origin and can be explained not merely as a "principle", but

---

\*Corresponding author

Email addresses: [pamiquel@univ-tlse2.fr](mailto:pamiquel@univ-tlse2.fr) (Paul-Antoine Miquel), [hsy62@yahoo.co.kr](mailto:hsy62@yahoo.co.kr) (Su-Young Hwang)

• Published as: Paul-Antoine Miquel, Su-Young Hwang, From physical to biological individuation, *Progress in Biophysics and Molecular Biology*, Available online 16 July 2016, ISSN 0079-6107, <http://dx.doi.org/10.1016/j.pbiomolbio.2016.07.002>.

also as an “operation” that depends on certain conditions. As an ontological principle, “individuation” is not the same as “individual”; Simondon’s starts from a critical analysis of Aristotle’s physics and metaphysics:

“Knowing the individual through individuation instead of knowing individuation through the individual” (Simondon, 2013, p 24).

Following Aristotelian physics, Nature is not Art, since Nature generates itself and has its principle in itself (Aristotle, 1973, 192b 15). However, Nature is firstly *matter*: (Aristotle, 1973, 192b). In Aristotelian philosophy, as a logical and also an ontological “subject,” matter is something *on which* all predicates depend since the subject is precisely not a predicate (Aristotle, 1974, Z, 3, 1029a). Matter is co-predicated to all predication. As such, matter is also a “substance”, or a quasi “substance”. For instance a tree has a location, a length. It also has leaves and flowers. But every quality describing a tree is related to the tree as “subject” (ὑποκειμένων).

However, matter, as an ontological principle, is not enough to characterize Nature *as such* (καθ’ αὐτό). What a tree *potentially* is, as leaves, or flowers, is not a tree in its own nature. Thus, a tree as principle from which leaves and flowers become *actual* is the Shape or Form (ἡ μορφή καὶ τὸ εἶδος). And the way Form is emerging in the subject, is also *an Aim*, or in other words, a final cause (Ἐπι τὸ ὅ ὕενεκα καὶ τὸ τέλος τῆς αὐτῆς) (1973, 193b 15). For Aristotle, an individual (σύνολον) has *an essence* which is characterized through its matter, its form, and its final cause. And also, for Aristotle, individuation is just the process through which the individual emerges as such. There is no direct description of ontogenesis and individuation is not an ontological principle.

1.2 By contrast, in Simondon’s philosophy, the operation of individuation, from which the individual comes to existence, is precisely *an ontological principle*, and the individual would be grasped as a certain phase of reality that depends on pre-individual conditions; the individual *doesn’t exist on its own*. Philosophy is also not moving *directly* from common sense to the ontology of Nature, like in Aristotelian metaphysics. Philosophy starts as a reflection on complex physical systems analyzed and explained by science. Ontology comes from the way by which a scientific explanation is *related to* physical systems and physical operations. There is no ontology per se, no “*Ding an sich*”, no Final causes, like in traditional metaphysics. Ontology, as a “relational” concept merely comes from and after the systemic approach that characterizes science as such (Simondon, 2013, p 83). Conversely, it means that science is not ontologically free. There is always some ontological commitment in scientific theories that cannot be reduced to empirical observations, which a philosopher has to analyse. Individuation as a process and as a principle is therefore not an empirical fact. It is an ontological entity revealed through and by scientific explanation, and not without it. And thus, even in theoretical sciences, scientists always deal indirectly with a metaphysical expe-

rience.

1.3 Individuation starts when a “structural potential” is constituted (Simondon, 2013, p 77). The concept “structural potential” expresses the limits of “structural stability”, rather than this stability itself. (Simondon, 2013, p 77). “Structural potential” is unrelated to the classical concept of “potential energy” in physics. In a more contemporary vocabulary, it means that we deal with an open thermodynamic system (for a review, Halley J, Winkler D, 2008). Not surprisingly, Simondon takes the example of crystallization to elaborate on this subject.

In classical physics, “structural stability” is associated with “symmetries” (Van Fraassen, 1990). Symmetries form a set of transformations that has a group structure. Basically, it means that such a set contains a transformation, which doesn’t change anything and conversely, that for every transformation there is a transformation, which reverses its effect. As such, symmetries play a *theoretical role* in classical physics (Longo, Montévil, 2014). When a theoretical system can be explained through symmetry groups, the *states* of the system will change all the time, but these changes fully depend on the structure of the determination of the system. In other words, we have a structure of determination at a certain level of explanation. Thus, a level is not simply a scale, i.e. a purely quantitative relationship between the measurement of an object and the measurement of its representation. At a certain level, a state is not simply related to an observer; it is also related to a structure.

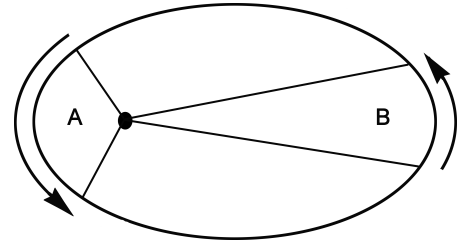


Figure 1: *Second Kepler’s Law.*

Starting with the classical example of the second Kepler’s law (*Figure 1*), positions and velocities characterizing initial conditions are related to final ones through the conservation of energy that can be formally *deduced* via Lagrangian operators from the minimization of action, by variational calculus<sup>1</sup>. In this example, conservation of mechanical energy is expressed through the equal surfaces of triangles swept out by the planet turning around the sun in equal intervals of time. The position and velocity form the physical state of a system and they vary continuously while the surface is always the same for a given interval of time. Finally, such a system is *closed* because an *order relation* between states and structure will *completely*

<sup>1</sup> The equation of motion through the Lagrangian operator (L) is:  $d(\partial L/\partial v)/dt + \partial L/\partial q = 0$ ; v and q are positions and velocities.

characterize all physical states of the system<sup>2</sup> (Nicolis, Prigogine, 1989). And it is **conserved** because the state of the system varies while the structure stays **invariant**. It doesn't depend on time<sup>3</sup>. All states **depend on** the structure; however, the structure is not changed by the states. We call such an anti-symmetrical relation, "**physical determination**".

1.4 By contrast, crystallization starts when a thermodynamic flow is open between inside and outside, through control parameters, like pressure and temperature. In Simondon's example, at a critical point the physical system changes of "state of matter", and entropy decreases (2013, p 74). Following Prigogine and Nicolis (1989), control parameters ( $\lambda$ ) are nothing but *external constraints* that can be inserted in a flow equation, like:

$$dX_i/dt = F_i(X, \lambda)$$

It means that under certain boundary conditions, through a thermodynamic flow and at a critical point, the structure ( $X$ ) of a physical system ( $S$ ) is irreversibly changed. However, a system  $S$  traversed by its thermodynamic flow of energy, or of energy and matter, is not an object, since it is not completely defined by the relation between its physical states and its structure. And we cannot say that such an object is submitted to a thermodynamic flow, like the motion of the ball is externally constrained by the inclined plane, because through this action, the object is **susceptible** to change its structure. **This susceptibility** depends on what we would call: **an inside/outside relation**. As Simondon explains, such a system is "*not identical to itself*"<sup>4</sup>, since *what it is* depends on *the relation between what it is* and *where it is*. The system is **individuated**, it has an "itself". That is the expression of a circular relationship between *it* and *its* boundary conditions. In this case, of course, there is no matter exchanged with the outside. Nevertheless, relationships between physical *states* and *structure* also depend on the *open shape* of this system symbolized by the thermodynamic flow of energy. That is why Simondon calls *this open shape* a **topological constraint**. One could counter-argue that all possible phases are included in the system  $S^*$  because a phase space can be set up (See Part 1 Soto/Longo). But  $S^*$  is not  $S$ .  $S^*$  is **an extension** of  $S$ . In  $S^*$ ,  $S$  cannot be described as a closed system, like a planet turning around a star. It is an open one. And even if the possible phases of  $S^*$  are known, the phase transition of  $S$  in the phase space is emergent and not predictable in  $S^*$ . The possible phases of the system are known, but the complex dynamic of  $S$  in  $S^*$  is non linear and unpredictable when a phase transition occurs, because fluctuations occur at each scale. We will call  $R_1$  this first circular inside/outside relationship<sup>5</sup>, through

which the system  $S$  is also an *element of itself* (Figure 2).  $R_1$  doesn't mean: what is outside of the system, like if one could clearly delineate "inside" and "outside".  $R_1$  means "its own limits", or in more technical terms "its boundary conditions" inasmuch as they are required to describe the system itself.

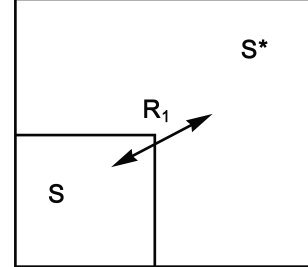


Figure 2: *The topological constraint ( $R_1$ )*. ( $S$ ) is the system. ( $S^*$ ) symbolizes the system  $S$  plus external conditions represented by control parameters in the flow equation.

Let's insist now on the most important point. Namely, ( $S$ ), as a physical system placed in a thermodynamic flow, is not only an object, it is also "an agent" in Simondon terms (2013, pp 82, 190), **since its structure is also the result of its interactions with its boundary conditions**. Then, when physical boundary conditions vary up to a critical point, an emergent property suddenly appears and ( $S$ ) drastically changes.

In a way, there is some causal relationship between the conditions before this change and the result. But there is no implication, or no deduction in this relationship, because the emergence of the global constraint that will act downward on all ( $S$ ) components cannot be predicted at the beginning. This constraint is the diachronic and constructive result of the relation between what ( $S$ ) *is*, and what ( $S$ ) *does*. The "being" of ( $S$ ) will not define this relationship. On the contrary, this relationship defines the being of ( $S$ ). We will call this second circular relationship through which  $S$  is element of itself,  $R_2$  (Figure 3).  $S$  **is also what it does**, and no formal description of  $S$  at an instant ( $t$ ) would be complete. It is expressed in the formal calculus by the high level of non-linearity of the flow equations that cannot be directly integrated (i.e. solved exactly).

There is a strong ontological commitment here. It means that ( $S$ ) is also a process. **Its becoming cannot be reduced to its being**<sup>6</sup>. In more formal and mathematical terms, it means that ( $S$ ) has to be characterized recursively, as the result of its own operations, but this

<sup>2</sup> Thus, the equation of motion is given by the Hamiltonian  $H$ , when «  $q$  » is position and «  $p$  » velocity:  $\partial H/\partial p = dq/dt$ ;  $-\partial H/\partial q = dp/dt$ .

<sup>3</sup>  $dH/dt = 0$

<sup>4</sup> « Il est possible de concevoir la relation comme non identité de l'être par rapport à lui-même » (2013, p 32)

<sup>5</sup> «La relation est ici observable comme une limite active, et son

type de réalité est celui d'une limite. Nous pouvons en ce sens définir l'individu comme un être limité, mais à condition d'entendre par là qu'un être limité est un être polarisant, possédant un dynamisme indéfini de croissance par rapport à un milieu amorphe" (2013, p 93).

<sup>6</sup> «Le devenir ne s'oppose pas à l'être; il est relation **constitutive** de l'être en tant qu'individu» (2013, p 91).

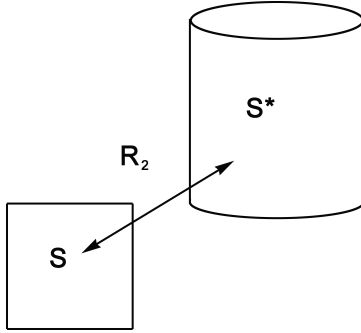


Figure 3: *The chronological constraint ( $R_2$ ).* (S) is the system. ( $S^*$ ) symbolizes the global pattern emerging under certain external conditions.

point is not really elucidated by Simondon. The French philosopher will call  $R_2$  a “chronological” constraint, while  $R_1$  is a “topological” one (2013, p 227). What the system *is* afterwards is not what it *was* before, since its shape has irreversibly changed, through and by a *temporal symmetry breaking*. Even at the level of a physical system traversed by a thermodynamic flow, we need chrono-topological constraints. And what we call “constraint” doesn’t act only at a local level. An architectural constraint is a *specific relationship*, which expresses that (S) is also *an element of itself*: it is where it is, and it is what it does. Of course in a simple phase transition, like crystallization, the topology is reduced to this “inside/outside” relationship ( $R_1$ ), and the chronology to this “before/after” one ( $R_2$ ).

To sum the situation up,  $R_1$  corresponds to the coupling of the system with its outside (boundary conditions) inasmuch as this coupling defines the behavior of the system so that this coupling is fundamental to its very definition (in physics, typically, this is the writing of the equations of its behavior). Instead, ( $R_2$ ) corresponds to the idea that the system is not entirely defined by its structure at a given time because this structure will change since global emergent properties will appear, for example, in the paradigmatic example of phase transition. As such the system is not well defined by its sole constituents. Instead, it is defined both by its coupling with its environment ( $R_1$ ) and its diachronic taking place ( $R_2$ ). Thus, these complex systems are not understood just on the basis of their constituents at a given time (S) but as  $S^* = R_1 R_2 S$ .

## 2. Biological individuation.

Following Simondon, individuation of the living is never achieved in a definitive way. It constantly “amplifies itself without being stabilized” (2013, p 152). Whereas at the level of organization, the living is in continuity with matter, vital individuation takes place extending the critical states of material individuation before it doesn’t attain its stable equilibrium. Then, “the living conserves within itself a permanent activity of individuation” (2013, p 27). It is “not only the result of individuation, like the crystal

or the molecule, but it is the theatre of individuation: not all of the activity of the living is concentrated at its limit, such as with the physical individual» (2013, p 27). Within the living, there is “a regime of internal resonance” that requires “permanent communication” and *through which individuation is acting on itself*. Thus, a living thing is obviously not a mere machine, since in biology there is a second order individuation, or better said “an individuation by the individual” (2013, p 28). Vital individuation “is doubling by perpetual individuation, which is life itself” (2013, p 27). We will call this, *the doubling condition*.

There is also a *specific condition* that explains how physical individuation would be a so-called “pre-individual” through which individuation by the individual is performed. It is a *recursive procedure* (“récurrence de causalité”; 2013, p 162). It indicates that *the structure* of living system is also *the result* of the operations through which biological individuation is coming out from its physical pre-individual conditions. Then, in a way, *biological individuation could be naturalized*, provided that we accept the *ontological specificity* of physical individuation.

2.1 Simondon was not the first thinker to imagine such a “doubling” condition. The French philosopher Maine de Biran introduced the same term (“redoublement”) to capture the mind-body problem in its specificity (1804). But the real scientific origin of the “doubling” condition is perhaps found in *What is life?* (1944). In this prophetic book, Erwin Schrödinger first invented the concept of “order by disorder”, which means that an open thermodynamic system, for example in a phase transition, produces negative entropy. But in principle, a crystal is an indefinite iteration of the same shape, and there is no internal resonance between the beginning and the end of the operation, so there is no communication across. The same pattern is repeated again and again, like in “ordinary wallpaper” (1944, p.5). A living organism is “a masterpiece of embroidery, say a Raphael tapestry” which shows “an elaborate, coherent, meaningful design” (1944, p 5).

Following Schrödinger, there is nothing in biology that cannot be explained by physics, but physics needs to be *extended* to “the principle of *order by order*”. So we find here again, and in a different context (not only in the mind-body problem), the doubling assumption. The concept that the “hereditary code-script” included in the chromosomal structure also determines the phenotype of an organism does not imply that biological features cannot be explained by physics (1944, p 21). On the contrary, “the aperiodic crystal” in which semantic and functional properties of the living organism could be “miniaturized” was just an illustration of the principle of order by order.

2.2 A comparison can also be drawn in autopoietic systems between “biological individuation” and “organizational closure”. Following Francisco Varela (1980, 1981), an autopoietic system like a cell is also the result of its own interactions with its environment so that its organizational unity is preserved, as a fixed point of a given equation:

$F = \phi F$

Nevertheless, the meaning of  $F$  is not very clearly explained by Varela himself. Taking into account the distinction between two causal regimes of circularities in physics and in biology by Rosen (1972), neovarelians have introduced the concept of “closure of constraints” (Mossio, Moreno, 2010). In the shape  $F$ , not only material elements ( $M_1, M_2 \dots$ ) but also specialized regulation devices ( $C_1, C_2 \dots$ ), like bio-catalyzers, are continually replaced, so that  $F$  can be preserved by this replacement.

They also define “constraints”, as entities, which, while acting on physical processes or chemical reactions, remain unaffected by them (Montévil, Mossio, 2015). Nevertheless, through such a definition of constraint, the origin of a second order regime of circularities remains a mystery. More precisely, there is no biological closure within the organization, without specialized regulation devices in “mutual dependence”. Through organizational closure, when a local constraint regulates a chemical reaction at a short time scale, this constraint is also altered and repaired by another one at a longer time scale, etc. . . Finally the same set of constraints  $F$  is preserved. But the question remains: **from where is this set of constraints emerging?** In other words, how can we understand the transition between a first and a second order regime of circularities? There is no clear answer to such question within the classical neovarelian position.

2.3 Following Simondon’s approach, a constraint is a global property emerging in a complex physical system and through which a system is individuated, like crystallization. But the emergence of a global constraint first requires the presence of a structural potential, and of ( $R_1$ ) ( $R_2$ ).

( $R_1$ ) can be called **an architectural constraint** by which the system  $S$  cannot be fully determined by its internal structure **because what is outside  $S$**  also characterizes it. “Where the system is”, is also a necessary part of its own definition. “What it is” depends on the relationship between *where* it is and *what* it is. Such a system is already an individual **because** it is individuated. Individuals are just phenomena. They are just the result of specific process at work in circular individuated systems. Individuals are not metaphysical entities. The internal relationship between a physical system and its limit ontologically commits us, when the shape of this system is open.

And we are also committed by the fact that under specific and critical conditions of pressure and of temperature, a new constraint of crystallization is emerging in a system  $S$ . This constraint can be called “a contingent cause” exerted by “specific structures or dynamics” (Montévil, Mossio, 2015), but such a constraint can already be understood as a property of a system  $S$  **that is also the result of its own operations**. By this property,  $S$  is circular again, since the relationship  $R_2$  between  $S$  and  $S^*$  defines  $S$  (see the sum up, part 1). By  $R_2$ , there is no complete description of  $S$  (even a *per se* description) because

**$S$  is also the result  $S^*$  of the relationship between its structure and its operations** ( $S^* = R_1 R_2 S$ ).  $S$  is not an entity anymore; and we switch from an ontology of entities to **an ontology of process** in which time is acting, because what the system is depends on what the system does (see also Dupre, 2012).

2.4 As a mere assumption, we propose that under certain conditions, coupled operators  $R_1 R_2$  are indefinitely applied to themselves (we will not describe them exhaustively). Under those conditions, we can get the **mapping**:

$$R_N = (R_1 R_2)^N.$$

By this mapping, we philosophically assume that “an extended criticality” between  $S$  (a physical system) and  $B$  (the biological situation) could be generated, since each iteration symbolizes a critical transition through which a new global constraint emerges. Such an assumption is fully coherent with the idea that the origins of life are nothing but multiples. Each *singular step*, starting from dissipative structures, like Benard’s convections, to kinetic control and self-catalysis, metabolic pathways, mixed type of membranes, molecules storing memory, like DNA or RNA, could be symbolized as *one step* in this recursive equation.

2.5 At the same time, let’s imagine, that, like we had in  $S^* = R_1 R_2 (S)$ , at a self-organized physical level,  $R$  will be characterized by the relationship between  $R^*$  and  $R$  at a biological level. In other words, through iterations of  $R_1 R_2$ , a self-similarity relationship between  $S/S^*$  and  $R/R^*$  is expressed, so that instead of  $R = \Phi R$ , like in neovarelian modelling, we get the following relationship characterizing the biological system  $B$  as such:

$$R^* = \Phi_1 \Phi_2 R$$

But what could be the meaning of  $\Phi_1$  and  $\Phi_2$ , which are biological counterparts of  $R_1$  and  $R_2$  respectively? The first philosophical intuition as for  $\Phi_1$  is connected with the concept of **level entanglements**. The second one,  $\Phi_2$ , is related to the concept of **permanent temporal symmetry breaking**, proposed by Bailly and Longo (2008), and then by Longo and Montévil (2014) to characterize what they call: “extended criticality”. Let us now expand on these two aspects of biological individuation.

\*  $\Phi_1$  corresponds to an intuition that is also not very far from Pradeu (2010) and Gilbert’s (2012) characterization of an organism as “fundamentally heterogeneous”, and from Pradeu’s insistence to see the immune system as the right level to characterize what an organism is. In the immune system, there is no clear distinction, no clear boundary between the “self” and the “non-self”. Through “immune-tolerance”, foreign entities like bacteria can be integrated into the self, and reciprocally, through “immune reactivity” dying self-cells are eaten by macrophages.

**Let’s call  $\Phi_1$  a set of constraints  $R$  (theater of individuation<sup>7</sup>) with an open shape**, so that a  $B$  system is **not identical to itself**, because it has **an open shape**

<sup>7</sup> Simondon uses this image, to assist the reader in understanding that biological individuation is like an actor that plays a role, and is also the theater in which the role is played.

of constraints, and not simply an open structure, like in physical individuation. At the same time, this open set of constraints will regulate the activity of all physical and chemical processes, and of all regulatory devices, *because it is also regulated*. Thus, there is no functional integration in B without any functional decoupling. In the last section, we will provide an example.

\*\*  $\Phi_2$  is quite similar to what Bailly and Longo (2008), and Montévil and Longo (2014) call “extended criticality”, i.e. the idea that in a biological system, criticality is not *point wise*, like in ferromagnetism, or in crystallization. Criticality becomes a ubiquitous property. A very analogous insight is present in Longo, Montévil, Sonnenschein and Soto’s assumption of “proliferation with variation” and motility as the default state for cells in an organism (1999; 2011, 2015). One could also find it in the Darwinian “principle of descent with modifications” (1859).

By  $\Phi_2$ , the set of constraints R is also the result of its own operations, so that it has a propulsive shape. A propulsive shape is co-constituted by its own dynamics in a virtuous circle of constraints that never stops. Such shape is never temporally closed. If new constraints emerge in such a set of constraints, this constraint will also change the shape of the set, so that new constraints will come again and again, and so that the process through which an individual results from an individuation process, is continually delayed.

It should be noted that such a characterization is also not very far from the concept of “generative entrenchment” proposed by Wimsatt (2007). New “constraints” emerging in a short time scale that will also change the shape of the theatre in a long time scale can also be understood as “engines”. Finally, such a characterization of a B system is also already present in Simondon: “the individual is like a crystal that would grow up without stabilizing itself” (Simondon, 1964, p 152).

### 3. On the emergence of novelty in a biological organism.

If there is some self-similarity relationship between S and B, it also means that for certain “super-critical” values of  $\Phi_1$ , the system becomes propulsive by  $\Phi_2$ , as in the case concerning the relationship between  $R_1$  and  $R_2$ . It also means that we can connect two properties that are usually separated in the semantic grammar of systems biology.

3.1 We will call “plasticity” the ability of the B system to integrate  $\Phi_1$  in a specific way.

It means that such a system is *plastic* only if its functional description is such that this system is not a regulatory one at a lower level without also being regulated at an upper one, so that *it has* an “identity” because *it is* a “co-construction”, as emphasized by Lewontin (1983). The more its space of constraints is open, the more the B system will have *the potential to change* without

being deleted. A real change can be characterized as a *global redistribution of biological functions*. This definition is compatible with the traditional characterization of phenotypic plasticity, as the ability of an organism to change its phenotype in interaction with environment (West-Eberard, 2003, p 32). However, as we will see, it could also involve changes in genome (Radman, 1999). More generally, plasticity is not simply a *passive reaction* to environmental changes. It is an ability to change that is present in the organism *for intrinsic reasons*. This ability is due to the openness of its space of constraints (figure 4), and not simply to the environment.

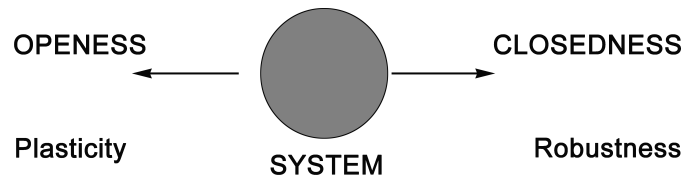


Figure 4: The relationship between plasticity and robustness.

Second, a biological system is not only plastic. It is always a compromise, a *modus vivendi*, between activity and passivity, between plasticity and robustness (figure 4), because a biological system has also an identity symbolized by an organizational closure (Montévil, Mossio, 2015). By *robustness*, we mean a specific regime of stability in a biological system that reduces instability and variations, in interaction with environmental conditions. Using Canguilhem’s vocabulary a robust system is a “normal” one. It is not “normative” (Canguilhem, 1943). For instance, at the genetic level, the Hox genes, their chromosomal arrangements and expression patterns can be called a robust regulatory device, which is well conserved and present in very different species (Duboule/ Wilkins, 1998). The space of constraints is not *closed*, but it is *stable*, through various types of shifting balanced equilibrium. The more genes are functionally connected, the less changes or combination of changes are possible. Variations are canalized in the same functional structure. A robust B system will not easily change, even if continually submitted to external perturbation and internal variation. However we argue that an organism is robust, *because* it is less open. It is not robust because it is completely closed. There is never complete closure of the space of constraints characterizing an organism, because to realize closure, the organism also depends on constraints that are external ones, resulting from the interaction with the environment (See Montévil, Mossio, 2015, p 8). Again, it means, that even if an organism is polarized, even if it has two regimes of existences (identity and co-construction), we can understand identity as *a specific variety of co-construction*. An organism stays identical to itself, when it is less open.

*Third*, since an organism is plastic, it is also adaptive, because plasticity gives it a potential to change and to successfully resist to changes in environment. The French philosopher Georges Canguilhem (1943) called this ability:

“normativity”. However, he used the word “normativity” in a sense that is not common in the English and American literature. Normativity is not simply the ability to *follow rules*, in interaction with environment. Normativity is not normality. It is the ability to change and to invent new rules, in interaction with environment. Such ability initiates “a *dynamic polarity*” (1943, pp 77, 137, 155) between health and pathology. Life is a “dynamic power of overcoming pathology” (1943, p 72). An organism “normal” or “well adapted” is paradoxically not healthy.

**3.2 If our assumption is correct, in various circumstances, plasticity can also be understood as a condition to “propulsivity” so that the open biological system will induce a dynamic of change in the space of constraints.** Canguilhem already opposed “propulsive” and “repulsive” “constraints” (“*constantes propulsives*” et “*répulsives*”) 1943, p 137). He took as a typical case of propulsive constraint the immune reaction, because when the immune system reacts to an external or endogenous antigen, the second time the response is usually faster and more efficient than the first.

We provide two examples of this. First, at the molecular level, Radman and his team (1999a) have shown that in the case of serious damage of the bacterium genome due to UV radiations, a specific regulatory device is at work: the SOS Box. A gene Lex A usually represses the activation of RecA, and of SOS Box. But when the bacterium is stressed by UV radiation, RecA becomes a co-protease RecA\* that will cleave Lex A. At the same time, RecA\* will induce DNA repair when polymerases 4 and 5 are also expressed by mutator genes present in the SOS Box, so that bacterium division can restart.

The plasticity condition ( $\Phi_1$ ) is present because the activation of the SOS box is not simply regulated by a gene, or more generally by a regulatory device. This condition also depends on an epigenetic relationship between the organism and its environment that plays an active instructive role, as if the milieu were a part of each organism. SOS box appears exactly as a genetic regulatory system that is also regulated at an upper level, so that it has *the potential to change*, through this recursive regulatory operation. Such an ability is precisely integrated into its structure, because this epigenetic regulation occurs through a genetic mechanism: the repression of the repressor Lex A by the protein RecA. As mentioned by Radman (1999b), this mechanism cannot be explained within the limits of neodarwinian assumptions, since the milieu doesn’t act passively, as a mere filter.

If, by UV radiation, we let DNA damage go up to “a super critical value”, targeted and non-targeted mutations are suddenly introduced into the bacterium genome by mutator genes during the repair process, so that the level of genetic diversity is increased, without too much genetic mutational cost. Plasticity, then, is connected with “propulsivity” ( $\Phi_2$ ). The changes produced are open in the sense that they are not specified or regulated by the mutator genes, instead any kind of changes in the func-

tioning of the bacterium can be obtained as a result. That is, the mutator apparatus forms a propulsive constraint. The *open regulatory device* mentioned below acts as a global flexible constraint that will induce, by the presence of mutator genes, a self-amplification process. Mutator genes can be understood in a short time interval as constraints and over a longer time interval as engines that will give a propulsive shape to the space of constraints. Mutator genes create new constraints  $R_{1n}$ ,  $R_{2n}$ , that will lead to the creation of other constraints  $R_{1n+1}$ ,  $R_{2n+1}$ , so that the set of constraints itself is continually changing, through continuous symmetry breaking. When the bacterium ceases to be stressed, the regulatory device comes back to its initial position.

At a population level, Erez Braun, an Israeli biophysicist, gives a second spectacular example of such a connection between plasticity and what we call propulsivity thanks to the dynamics of yeast cells facing “an unforeseen challenge” (Braun, 2015). Braun mimics an event of “genome-rewiring” by detaching the gene HIS3 (coding for an enzyme essential to the expression of histidine) from its usual regulatory place, and puts it under the promoter of the Gal regulatory device. In glucose medium, the Gal system is repressed. Under these new artificial constraints, it would be the same for HIS3; massive cell death would be expected. To the contrary, fast-inherited adaptation through a global reorganization of gene regulation is observed, as an average population responds in 10/30 generations in a chemostat, without any significant mutations. Thus, this adaptation cannot be due to natural selection of rare phenotypes. Adaptation is a metastable populational property. Measurements show that new cells appear continuously, which are unable to propagate the adapted phenotype. Adaptation appears, as a “transgenerational memory” (Braun, 2015) and through a rich spectrum of metastable states. Mutations occur after 30 generations, as a result of the dynamic, and not as a real engine. Finally, each global pattern of gene expression resulting from exposure to such drastic conditions is unique. It depends on each specific transgenerational memory, even when populations are grown under the same historical conditions. Of course, such transgenerational memory would not be possible if multiple alternative trajectories to adaptation were not present in such systems. But at the same time, there is a “one to many degeneracy” in such systems, so that “practically identical configurations may give rise to seemingly different macroscopic dynamics and functions” (Marom & Braun, 2015). We understand this non-trivial transgenerational memory as the result of a propulsive process that is not simply depending on *traditional causality*, and on *initial conditions*. It is linked we *the plasticity* of biological organization. Without to assume this plasticity, it would be very difficult to explain how such transgenerational memory could appear.



#### 4. Conclusion

The *doubling condition* assumption (R) is a philosophical one. It is a conceptual scheme, and not a scientific hypothesis. But this proposal provided by a philosopher can help the scientist to better understand the difference between adaptability and robustness in biological systems. It is triggered by the idea that the space of constraints characterizing an organism is always an open one, depending on a milieu that plays an active role on the organization.

Under certain conditions, the functional decoupling played by the environment leads to a stable functional integration: that is robustness. But adaptation is a compromise as well, a so-called *modus vivendi* between functional integration (normality, robustness) and a self-organized dynamics leading to organizational changes (normativity). In the first case (robustness), adaptation coincides with *stabilization through variations*, and *not with invariance*. In the second one, and using two very different examples, we show that adaptability is related to the presence of specific regulatory devices at all levels of organization, from the molecular to the population level. These reactions will induce a *propagative dynamics* through which the space of constraints characterizing all regulatory devices in an organism is continuously changing in a specific and/or in a non-specific way (See also Kauffman, 2000).

One challenging enigma remains in this way of thinking; it is the understanding of the relationship between adaptation, on the one hand, and pathology, disease and death on the other. This means the relationship between adaptive pathways and evolutionary ones.

#### References

- Aristotle (1973) *Physique*, édition bilingue. Les belles lettres, Paris.
- Aristotle (1974) *La Métaphysique*. Vrin, Paris.
- Bailly F, Longo G (2008) Extended critical situations. *Journal of Biological Systems* 16(2): 309–336.
- Braun E (2015) The Unforeseen Challenge: From genotype-to-phontype in cell populations. *Report on Progress in Physics*, 78.
- Canguilhem G (1943) *Le normal et le pathologique*. PUF, Paris.
- Darwin Ch (1859) *On the origin of species by means of natural selection*. John Murray, London.
- Duboule D, Wilkins A, (1998) The evolution of bricolage. *Trends in Genetics*, February, Vol 14(2), 54-58.
- Dupre J (2012) *Processes of Life: Essays in the Philosophy of Biology*. Oxford University Press, Oxford.
- Gilbert S et alli (2012) A symbiotic view of life. *The quarterly Review of Biology*, Vol 87, n°4, pp 327-341.
- Halley J, Winkler D (2008) Consistent concepts of self-organization and self-assembly. *Willey Periodicals, Inc, Vol 14, N2*.
- Kauffman S (2000) *Investigations*. Oxford University Press.
- Lewontin R C (1983) Gene, organism and environment In D. S. Bendall (Ed.) *Evolution from Molecules to Men* pp. 273–285 Cambridge University Press.
- Longo G, Montévil M, Pocheville A (2012) From bottom-up approaches to levels of organization and extended critical transitions. *Frontiers in Physiology* 3: 1-11.
- Longo G, Montévil M (2014) *Perspectives on organisms. Biological time, Symmetries Singularities*, Springer.
- Longo G, Montévil M, Sonnenschein C, Soto AM In Search of Principles for a Theory of Organisms. *J. Bio-sciences*, 2015
- Maine de Biran P (1804) *Mémoire sur la décomposition de la pensée*, Paris, edited by Ernest Naville, 1859.
- Marom S. & Braun E. (2015). Universality, complexity and the praxis of biology: Two case studies. *Studies in History and Philosophy of the Biological and Biomedical Sciences*, 53: 68–72
- Montévil M, Mossio M (2015) Biological organisation as closure of constraints. *Journal of theoretical biology*, 372: 179-192.
- Mossio M, Moreno, A (2010) Organisational closure in biological organisms. *History and philosophy of life sciences* 32: 269-288.
- Nicolis G, Prigogine I (1989) *Exploring Complexity*. Freeman, New York.
- Pradeu T (2010), [What is an organism? An immunological answer](#). *History and Philosophy of the Life Sciences* 32: 247-268.
- Radman M (1999 a) Enzymes of Evolutionary Change. *Nature*, 401: 866-69.
- Radman M et al (1999b) Evolution of Evolvability. *N.Y. Ac. Of Sc*, 870: 146-155.
- Rosen R (1972). Some relational cell models: the metabolism-repair system. In: Rosen R. (Ed.), *Foundations of Mathematical Biology*. Academic Press, New York.
- Schrödinger E (1944) *What is life?* Cambridge University Press.
- Simondon G (2013) *L'individuation à la lumière des notions de formes et d'information*, Paris, Jérôme Milion.
- Sonnenschein C and Soto AM (1999) *The society of cells*. Bios, Oxford.
- Soto AM and Sonnenschein C (2011) The tissue organization field theory of cancer: A testable replacement for the somatic mutation theory. *BioEssays* 33, 332-340.
- Van Fraassen B (1990) *Laws and symmetry*. Oxford University Press.
- Varela F (1980) *Principles of Biological Autonomy*. North Holland/Elsevier, New York.
- Varela F (1981) Autonomy and Autopoiesis, Self-organizing systems - autopoiesis.com.
- Wimsatt, William (2002), Functional Organisation, Functional Inference, and Functional Analogy? In : A., R.

Ariew, R. Cummins and M. Perlman (Eds.), *Functions*, Oxford, Oxford University Press, p. 174-221.  
Wimsatt, W. (2007). *Re-engineering philosophy for limited beings*. Cambridge: Harvard University Press.