

The robot and the forest

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- Le robot et la forêt. La recherche hors-série n°12. Le corps humain. Juillet 2003.

- Une onde d'abeilles. "L'évolution" coauthored with Isabelle Stengers. Mot à mot. EDP Sciences 2003.

Biology has long been under the influence of the animal-machine metaphor. Today's reference machine is no longer a clock but a robot. Accordingly, living cells are but individual spare parts in charge of the smooth functioning of the robot. Now what if the living body were compared to a forest? Ecosystems do not evolve under the tutelary guidance of some central programming biased by the search of a best collective interest, but rather by the conjunction of the particular interests of each of its individual inhabitants. That body-forest would arise not from a prefigured plan tending to a preconceived goal but merely from its history. Among the crop-full of questions that such a proposal might at once feed stands the following: how could specialized physiological functions such as say defense against infections which implicates the cooperation of multiple cell types could emerge from that organization?

Programming the living robot

The correct functioning of a robot is dependent upon a program and its execution. The program contains information that rule on the robot's performance: «*Move forward!* », «*Stop right there!* » and the likes. That is to say the robot's actions are triggered by commands. In the language of cybernetics, centralized control programs bears on the issue of communication¹ : to acquire the correct information and transmit the right orders. Without ever taking notice that the robot metaphor encompassed the issue of its creator, biology and medicine have since the 1970s made routine the use of the first cybernetics principles founded by Norbert Wiener² and John von Neumann: a genetic program both constructs the living robot and coordinates its functioning. In that context, a given genetic disease may be seen as resulting from a default in the program, and genetic therapy aimed at correcting the defect may be conceived of as organism «*reprogramming*».

The cybernetics order has established its rule in research and biology: understanding the activities of a cell falls down to identifying the incoming orders allegedly received by that cell. Each incipient event capable of affecting the living cells would have its specific information counterpart akin to a command that a signal-molecule would transmit. Such conception of the body takes biology to the brink of caricature: why does a given cell undergoes proliferation? Because it has received a proliferation signal! Why does that other cell differentiate? Because of a

¹ 1958 Listener 18 Sept. 413 The claim of cybernetics is that we can treat organisms as if they were machines, in the sense that the same methods of synthesis and analysis can be applied to both. (Oxford English Dictionary, II edition)

² 1948 N. Wiener Cybernetics 19 We have decided to call the entire field of control and communication theory, whether in the machine or in the animal, by the name Cybernetics. (Oxford English Dictionary, II edition)

differentiation signal! Why does the cell now die? Because it was given a death signal! The transposition from linguistics to biology of a resonant « *book of life* », enciphered in our chromosomal DNA under a « *language of genetics* », to be decoded à la Champollion, was eventually overextended into the idea of “*molecular signal*”, which represents no less than a « *verbal command* ».

The signaling system both ensures the proper functioning of the body and defines its functional and individual autonomy. Like a robot, the body follows the order of the program, all in all making up to a whole. Implicit in the application of cybernetics to the body however is that the making of the robot as well as its behavior both emanate from a project, the actual harmonious unfolding of which must recursively be pre-enclosed in that very programming. The program concept was proposed in the 1960's as a solution to describe biological function without requiring final causes. The term of teleonomy was coined to distinguish such “causality by a preexisting program” from Aristotle teleology, i.e. “causality from a final goal/project”. The programming activity was attributed to chance, rather than the will of a programmer. Such conception of biology was widely popularized, for instance in Jacques Monod famous book “*Le hasard et la nécessité*” published in 1970. Despite these efforts, advancing under the disguise of modernity and information theory, the living body programmatic metaphor from its inception onwards would hardly hide an archaic panglossian finalism³.

For Candide's tutor: « *noses were made for the portage of spectacles; and so we have spectacles. Legs were instituted to be gartered, and we do have garters. Stones were formed to be chiseled for the construction of castles; and so his grace has this very beautiful castle...* » Along that line, brain would clearly be made to think, with the genetic program ensuring that this will be executed to its best. Whatever the machine, the man-machine representation understates the pre-existence of a doer-constructor. In a robot, autonomy bears at the level of the whole completed machine, the constitutive parts of which stay fit under the rules of one same program.

Before its completion, the parts only obey to the project constraints. Within such conception of life, recurrent controversy aroused whether the robot becomes free, or remains forever trapped in its programming. The genetic determinism used to explain the body-robot construction is embarrassing when the body-robot is completed at birth. Will programming suddenly switch off to allow for body freedom, and when? The question was often asked for the whole living robot, but not for its parts. At difference with the completed robot situation, the individual spare part has no autonomy of its own. Freedom is firmly denied for molecules or cells that make the robot. The molecule or cell has to obey, not to live for itself. It becomes “alive” only indirectly through the whole robot when the final project has been fully completed. So the spare part is build before the robot itself within the framework of the robot-project. The finalized robot justifies the beforehand construction of its spare parts. In following with that metaphor, body physiology can hardly break away from finalism wherein the

³1976 Nature 18 Mar. 1962 The old Panglossian fallacy (has it) that natural selection favors adaptations that are good for the species as a whole, rather than acting at the level of the individual. (Oxford English Dictionary, II edition). Voltaire derides Leibniz by having his character «Candide» (1759) tutored in «*metaphysico-theologico-cosmolo-estupidology*» by Pr Pangloss (from *pan*, all, and *glossa*, tongue/language) who teaches that «*all is for the best in the best of all possible worlds* ».

development of an embryo for instance is sustained by the project of a global organism. To escape the pitfalls of finalism, the ubiquitous chance factor generally resorted to as a solution should be endowed with miraculous powers. Will science be contented with such a factor especially when dealing with low probability events?

Altruistic suicide

Mechanistically conceiving of the body may carry other outlandish consequences. Within the living robot construction, cells are not taken as full-fledged animals. As already underlined, they are like standing spare parts complying with centralized commands to ensure the normal order of the whole. Translated into Darwinian language, the survival of the individual cell does not take precedence over that of the body, and when the supreme interests of the latter stands against that of the cell, the cell undergoes the supreme sacrifice and lays down its life. Suicide though has been quite uncommon in the animal world. Altruistic suicide in the name of collective interest has been even less frequent. Can we contemplate the simple cell, of all animals we know the most derisively primitive, being endowed with such elaborated skills ?

Let us take one example from immunology. By their allotted capacity to recognize substances foreign to the organism, our lymphocytes like good-willed little soldiers on watch are readied to part and attack our enemies. To the contrary, those lymphocytes liable to dangerously harming organism constituents are (fortunately) to be eliminated. Current theory has the latter lymphocytes negatively selected for by their elegantly committing suicide during ontogeny. The immune system would existentially learn to tell that which belongs to our body – the “*self*” – from that which pertains to the outer world – the “*non-self*”. Pushed by the ideas of cybernetics, sophisticated systems dedicated to that discriminative education - and subsequent cell life or death activation - have been proposed: during their being made, lymphocytes would recognize each others through the exchange of complex signals dedicated to guarantee the hypothesized recognition. Such explanation of our individuality is somewhat circular. Indeed, the system must know what is self and non-self prior to decide which cells must live and which cells must die. Thus cell life and death results from self definition and do not build the definition. To escape this problem, it was proposed that everything present before birth is self, whereas the rest is non-self. However the question of what distinguishes the organism before and after birth remains unanswered. It cannot be resolved without tautologically inverting cause and effects of the self non self discrimination. Is might be impossible to build a coherent theory of immunology, if based on the idea of specific recognition of distinct categories of elements.

Finally, the mechanisms by which our “self” individuality would eventually be distinguishable down to the molecular level from the non-self by the immune system remain suspiciously complex when not irreconcilable with irredentist “auto-immune” phenomena⁴. To its contrary, the immune system stays off certain foreign substances. This may not always turn out as unfavorable: think of the fetus, «foreign» if any body within that of the mother ...

⁴ following a non-immunological tissue attrition like an ischemic visceral (cardiac, renal) infarct for instance.

On an evolutionary basis, one may wonder how cells at first autonomous would acquire such a refined collective know-how, up to the ultimate sacrifice. Could natural selection favor « altruism » at the level of a given cell? As a first approximation, the answer would straightforwardly be no: Darwinian selection has retained survival, not sacrifice. Or else, selection would have to operate both one way and its opposite. It certainly would make good to us had selection retained sacrifice for the cells - negligible quantities – while on the other hand favoring the body as a whole - that which really counts... This would amount to portray cells as capable of cooperating to the point of sacrifice in the name of the group.

A Matter of Viewpoint

But would it not be a somewhat awkward and embarrassing coincidence that the group elected in that natural selection process be the one we would most prefer, that is, our “*personal residence*” as expressed by Stephen Jay Gould⁵? There are multiple numbers of other possible groups. An organ is also made of a group (of cells); a cell itself is made of a group of molecules; molecules are made of groups of atoms.

Matter will cease sub-elementary groupings at a length of 10^{-35} meters (Planck's length) ... So for the sake of which of these groups should the sacrificing element lay itself down? The answer generally borrows to genetic thinking: cells would adopt a collective behavior extending to altruism down to the ultimate sacrifice because of, or in relation to the sameness of the participants' genes. To define the identity of the group by its genetic characteristics would rightly fall within the robot metaphor: as the robot obeys the program, all its constitutive elements share the same program. By extension, all the cells that share a common genetic program could be considered part of one robot.

Taking a closer look at this circular explanation shows that it is creating as many problems as it is meant to solve. Indeed, the flagship cells of the immune system (lymphocytes) are made so as *not to* express a unique genetic program, but rather the contrary. In effect, the lymphocyte genes become reshuffled in the course of embryonic development into particular genetic scaffolding specific to immune cells⁶. And so, while they derive from a common genitor, the lymphocytes of a given individual genetically differ between each others. That very diversity lays at the foundation of immune obligations, i.e., being able to foray upon a vast diversity of microbes. The cells purportedly equipped with the utmost capacity to define the self-subject while picking out the “strange ” microbe foreign to the so defined genetic collectivity, those cells are precisely the ones for which genetic differences are best and most documented !

As humans, evidence for our functional unity seems hardly debatable. We live under the impression of our ability to speak, and to do so in an autonomous way. Speaking and expressing oneself however takes no less than two persons. Similarly, to fulfill the very physiological function of reproduction, it also takes two elements. And even more so for the most vital nutritional function basically sustained by plant

⁵ Stephen Jay Gould and Elizabeth A. Lloyd. “Individuality and adaptation across levels of selection: how shall we name and generalize the unit of Darwinism ?” PNAS, oct 99, vol 96, n°21, p. 11904.

⁶ The so-called re-arrangement of the DNA stretches that encode the specific immunoglobulin-type surface receptors of T and B lymphocytes.

photosynthesis of the glucids we consume. At its lowest reference levels, a human being consists in a highly diversified society of thousand billions of cells, plus a vast population of digestive bacteria which are indispensable for his/her survival. In such a respect, our so-called *autonomy as an individual* appears as highly subjective.

Let us portray for a moment cells as drawing their food from a nutritive milieu. That milieu may be considered as external to them, with cells acting as autonomous individuals. Now the whole cell colony may altogether be seen as one individual entity, with the nutritive milieu becoming interior to the group. Cells are now said collectivists and potential altruists. This example underlines that notions of group, interior, exterior, or even altruism, totally depend on the selected viewpoint. However, natural selection requires the definition of a given *individual* to be selected or counter selected by a given *environment*. The choice of a different individual and environment will heavily condition the predictions of the theory.

Important categories on which rely biological theories appear relative to the observer's viewpoint. In preferred terms of physicists, biological theories are not relativist. A human watcher may consider he/she is an "individual" supplied with his/her own "milieu intérieur". Cells would obviously see it differently, with our inside out theirs, and the rest of the body as their societal environment. Why should our subjective point of view prime over that of our cells? Should we consider our cells as full-fledged animals and not any longer as spare parts at the service of a superseding whole? Can one validly describe the living being independently of the observer's choices? Beneath the technical problem of the individual unit on which to base the Darwinian selection theory hides another classical question about how breaking down a given continuum into discrete entities. Was the universe but a network of connections in space and time, from the big-bang onwards, where should individuals of reference on which to base our theories stand?

Space and time

To approach these perplexing questions under a different angle, let us turn to viruses. Imagine a virus favored by selection for its high multiplication rates so much that it will cause death of its animal carrier and by the same way drives the viral population extinct. The apparent opposition between the individual's interest (personified in the virus) with that of the group (= the whole viral population) is also a temporal one. The virus advantage in the short term (= high multiplication rates) is contradictory to its advantage in the longer term (low multiplication rate allowing survival of its host and population). The "social" issue appears linked with that of time, in regard of which the individual versus group issue may be abandoned in favor of that of space and time.

An advantage in favor of a given individual will at once take its local effect, whereas an advantage to the group will travel in space and be delayed in time. So, more time is required for interactions to unfold within the group and inside the space occupied by the group –more spread than that occupied by the individual. A centrally coordinated system may function through signaling processes at a distance, i.e., not instantaneously. In addition, the capacity to interpret such signals must be present before the emissions of these signals. But such anticipation cannot be handled in the framework of natural selection, because of its acting strictly here and now. For

selection there can be no consideration for the notions of extended group, future or signals. Following the long term advantage in spite of the short term advantage is not accessible to natural selection. The long term choice implies the existence of a project. Thus, as long as it tries to explain the body by referring to groups of cooperating elements, biology will be trapped into the issue of finalism.

Well integrated harmonious groups do exist in nature. To account for their existence within the theoretical framework of evolution, must we force our imagination and contemplate the possibility of *selective advantages paradoxically both instantaneous and group-determined*? When a group phenomenon arises, it can only result from the simultaneousness or *coupling* of local interactions. This corresponds to the very meaning of the term *emergence*⁷ or *auto-organization*. Within the latter concept, interactions from a distance are not to be entirely eliminated, but they cannot override the consequences of local interactions. For the philosopher Isabelle Stengers, the issue of emergence is that of « *the significance taken by a phenomenon in the midst of a story which it does not account for* ».

A number of collective behaviours, such as the building of a bee-hive are apprehended in this manner⁸. In the build-up of a hive, locally concurring interactions intervene *prior* to the completion of the construction. If one does not resort to the final cause concept, in no way can the hive itself or its projected build-up father the constructing local interactions. Pure chance is often invoked as the *ad hoc* explanation. Local interactions would have appeared by chance and would have been maintained/selected for because they *eventually* would lead to the build up of a functional hive. This would come down to explaining hardly anything while leaning entirely on a combination of chance and the *final* usefulness of the hive. A story where bees and hive get to build up together neither by chance nor to follow a pre-existing plan may then be told. For example, bees producing an excess of wax would lay it down for the simple reason of «overflow». When a sufficient number of bees do *try* (= diversified attempts = *noise factor*) to avoid and stay the farthest away possible from the wax dump laid by its neighbors, wax depots may follow an organization pattern as would seem to be dictated from a blue printed plan. The putative wax excess would stem from accruing «unconsumed resources» in well-fed bees, and not by chance or worse, from some « need for wax » for some hive-making «purposes».

However, a certain dose of random, unavoidable in many respects, is to be called in. Were bees to behave in a completely homogenous manner hive construction would not go along. *Variations* in the behavior of bees will allow them to *try* a variety of possibilities. Some variations will make construction progress within the local conditions, while others won't. Collective emergence is necessarily based on *noise* within the set of individual behaviors. That very noise, by creating diversity, produces

⁷ *The emergence of a new quality from any level of existence means that at that level there comes into being a certain constellation or **collocation** of the motions belonging to that level, and possessing the quality appropriate to it, and this collocation possesses a new quality distinctive of the higher complex.* S. Alexander, 1920, *Space, Time, & Deity* II. iii. ii. 45.

⁸ 1932 *Discovery* Apr. 108/2 One of the salient features in recent etiology (i.e. evolution lore) has been the recognition of the more or less open secret expressed in the term “emergent evolution”. It has become evident that the Ascent of Life has been a succession of “emergent” steps, novelties that are creative rather than “additive”, such as birds from ancestral reptiles.

a wealth of behaviors⁹. The need for behavior variations does not however imply that the ability to build a hive takes place at random. If chance does set its mark, it does so only punctually, at times of *bifurcations*, i.e., *choices*.

The emergent body

If we ponder our individual view point and adopt that of our cells or of our molecules, we may approach the representation of the body under a new angle. Each organism reveals the unique story of a society of elements. In this respect, our cells do not behave differently from the billions of bacteria that populate our digestive tract, and if these get to proliferate locally, it is because they must find favorable conditions. They are indispensable to our digestion without having been programmed to this end. Gene therapy may be considered not as a reparation process by a good and omniscient genetic program aiming at the re-establishment of a previously established harmony. Within the framework of an evolutionary and historical perspective, genetic therapy should be thought as intervening upon the course of a body history with its attempting to elicit a new one. Within this theoretical framework, finalism which insidiously lurks in the concept of genetic program is voided: organism logic is not necessary for setting organs in their places. The panglossian finalism built in the physiological discourse is no more required: the purpose of the kidney is no longer to urinate, nor is heart meant to beat, or brain to think and congratulate itself about it.

Defending against infections may collectively result from a multiplicity of local actions by “immune system” cells. The latter denomination corresponds to a global viewpoint, a sight order that does not help us understand the activities of the participant cells. At the level of each lymphocyte, the viewpoint would be different. When we are defended against infections, our cells are doing something different. For example, when we consider that they defend our “self”, they might simply eat microbes. *Their* food is *our* enemy, *their* meal *our* protection. They are consuming whatever resource is available to them. Micro-organisms may be taken as such, but at times tissue constituents if and when available also. If the collective phenomenon tagged *Immunity* eventually emerges from these activities, it will not have been their founding purpose. Fixed categories such as self and non-self are replaced by dynamic properties: self results from a balance of tissue production and renewal/consumption.

In fact, the white cells of our immune system do not at all spare our « self». Actually, our white cells do consume our own cells and tissues but just and only in proportion of the “normal” life and death turn-over rates of these cells, and far more so when in tissue attrition makes those resources massively more available. The dynamic equilibrium normally realized could account quite simply for the apparent stability of the system, feeding the impression that nothing perturbing is going on in the “normal self”. The immunological consequences of such a process will essentially depend on consumption-reproduction dynamics, and not on some particular structural characteristics of the cell constituents. The same type of rule would apply to infectious agents. Be it destroyed faster that it may reproduce, it will be eliminated, and all is well: the foreign microbe has been evicted, and the body integrity

⁹ On the role of noise in auto-organization, see for instance Henri Atlan, « *Entre le cristal et la fumée* » Seuil 1979.

respected. In that account the classical « self » and « non-self » would stand where the theory see fit, as do even more so our dearest wishes.

There are cases where the destruction of an infectious agent hardly compensates its reproduction as in the case of AIDS or chronic hepatitis with their respective ever persistent viral infections. The «foreign body» now dwells within ours and the self and non self notions do not any longer fit reality, with the theory being just as sick as the person.... The body-robot implicates a simplistic conception of disease: « *When all is well, the will of the program is respected. Our Self corresponds to what we wish it to be. When things turn awry, it is because the program has been unsettled* ». The body is not a global and harmonious set defined in a tautological manner by a would-be program that should define it. Body normality pertains to our dreams, not reality. Disease is no longer astray from the norm: it becomes a plausible alternative equilibrium of the collective interactions among societal elements of the body.

What about brain functions? From a neuronal point of view, cerebral functioning is a group activity, as is the making of the hive from the bee point of view. Thought activities (=thinking) emerge from the set of local brain cell activities. Neurophysiology today does depict these matters that way. Yet evolutionary interpretations have not followed through and final group functioning still forms the basis of interpretations for brain evolution. This is not coherent: a collective emergence cannot be accounted for by the role it *will* play when completed.

If brain function emerges from local cell interactions, one must only identify the local reasons for the cells to be involved in these local plays. To state it differently, If neurons are now thought as not guided by a brain project, what is it that makes them connect via nerves at the onset? That question evidently concerns the “first ever brain” that will have appeared in evolutionary times but also *upon each single brain formation* taking place in the forming embryo. One possible answer would have the following: the filamentous neuronal continuations (=nerves) emitted by brain cells – quite distant from the primary sources of gases and nutrients in the embryo – are sent out to their remote feed as roots do for trees. The numerous “signaling” exchanges which characterize the nervous system would fall equivalent to *alimentary chain swapping* among cells, now estranged from those signals that were meant to guarantee the *future* quality of thoughts *to come*.

Conjunction of interests

On a general basis, in the course of embryo development, cells will have to specialize (=differentiate) and we surmise that they do so depending on their positioning along metabolic resources accessible to them¹⁰. As a consequence, the processes by which *the first embryo developed* are the very same through which *again and again* each embryo *must* evolve. Each organism tells a “new” story, based on the interactions of cells adapting to an environment built on billions of quasi-likes

¹⁰ JJ Kupiec has proposed to apply the concept of natural selection to cells and so account for the embryonic development on a metabolic basis. Initially presented in *A probabilist theory for cell differentiation, embryonic mortality and DNA c-value paradox*. Specul. Sci. Technol. 1983, Volume 6, No 5, p.471-478, his darwinian theory of embryonic development is exposed in details in chapter 4 of « *Ni Dieu ni gène* », By JJ Kupiec et P Sonigo, editions du Seuil, Paris, 2000.

that altogether must specialize in their quest for resources lest they not survive. No individual egg may escape this developmental scenario; making good for its potential vagaries, with each developmental course starting anew. Contrarily to the vision of genetics, the quasi-exact reproduction of a developmental story from generations to generations is no proof either of a blue-printed organism project or of its transmission. It says that given similar conditions, cell societies will follow similar paths and tell similar stories. Biological history will not have been *written* in solid-gold: should conditions vary, (hi)story will also vary¹¹, and *so may evolution eventually unroll*.

Cells do not obey a common genetic blueprint, made to impose collective interests at the expenses of that of the individuals. Cells must adapt and specialize (= differentiate) as it is the most favorable to them as a function of their history and environment. In that situation, there can be no conflicts between the body and its composing cells, but only conjunction of interests. It is no longer necessary to impose the interests of the group via *the force of the program*. There are no more hierarchies between the whole and its parts. Molecule, cell, organ, the whole is one part equivalent to other parts. The collective interest prolongs the individual interests from which it emerges. When all interests converge towards the same direction, the arbitrary choice of a given level of observation does not condition theoretical predictions about the system. To picture that new representation of the body, the ecosystem metaphor may be useful. In ecological thinking or economy, the individual actor's goal is not bent on constructing the global equilibrium of a system which he cannot globally behold or fully understand. Let us conceive of the body organism as forest inhabited by free and autonomous animals. A forest is a collectivity of living beings where each individual pursues its own particular interest. In that forest, no central program exists to define the organization of the whole. The global structure eventually emerges from arrays of individual interactions. Our body would be better pictured as a societal entity where each of the constitutive elements would only have to ensure its best survival.

Can we try and account for the formation of the "first cell"? Its structure as a cell should not result from its eventual cell function. It must emerge from a series of lower "level" local interactions according to their own logics. A collective set of molecules would follow their particular rules, those of chemistry, and not that of a would-be cell or organism project. As much as an organism should emerge from a cell collective, a cell should emerge from the activities of a molecular collective. What to say about the origin of such molecules? Whatever the element, it is always constituted by a series of other, smaller ones. For an entity *not* to emerge from other elements, more proximate local interactions should *not* be possible. The distances between elements would close down to near zero. *Exit*, biology, *Enter*, the elementary particles of physics. Yet there still should be no breach between these laws and those of biology. The historical increasing complexity of our universe would only correspond to vertiginous series of innumerable emergences, from one "level" of organization to the next one up, from Big Bang times to ours...

¹¹ Farge E. Mechanical induction of twist in the *Drosophila* foregut/stomodaeal primordium. *Curr Biol*. 2003 Aug 19;13(16):1365-77 : application of abnormal physical pressure on a developing drosophile embryo alters the expression of developmental genes.