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Epilogue: Biology is immature biosemiotics

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FUNCTION IN BIOLOGY

One reason why biologists, and scientists in general, so vehemently oppose any claim to the effect that natural selection might not be a sufficient explanation for evolution on Earth, is the belief that the theory of natural selection is the very element that glues biology to materialistic science. The disquieting fact that the creatures of this world so clearly exhibit purposeful behavior has always tempted philosophically minded biologists to claim the existence of peculiar vital forces or principles pertaining to life. It is probably no longer possible to make a career in biology at the university level if you adhere to such vitalist ideas, but biologists still have to somehow cope with the obvious, though tabooed, teleological aspect of life. The prime mode in which this is done in modern biology is by the application of the concept of *function*. Volumes have been produced to solve the problem of how to justify the concept of function inside a non-teleological frame of understanding. And this is where natural selection comes in, for natural selection will tend to optimize the capacity of species to meet the functional challenges of their ecological niche conditions. Functionality is exactly what natural selection is supposed to produce.

The term "function" in biology is understood as the answer to a question about *why* some object or process has evolved in a system. In other words, what is it good for? A function thus refers forward in time from the object or process, along some chain of causation to the goal or success. This inversed arrow of time (future directedness) immediately sets functions apart from other kinds of mechanisms that always refer backward along some chain of causation explaining how the feature occurred. Darwinists, however, are not worried about the teleological character of functions because they believe that natural selection will ultimately account for them through ordinary mechanistic causation. Thus, as often noted by Darwinists, adaptive

traits are *not* explained by the consequences they *will* or *can* have but by the consequences they already *have had* in ancestor populations. The consequences in other words precede the effect they explain, and selection does not therefore challenge the mechanistic paradigm of traditional biology. So, as the explanation goes, the teleology implied by the concept of function is only an "as if" teleology, i.e. a *teleonomy*.

But something feels wrong with this argument¹. There is of course no reason to believe that the flowering apple tree outside my window right now has any purpose in producing flowers. Trees do not have purposes in the human sense of the term. But clearly even apple trees exhibit some kind of *agency* in the sense that they have a capacity to generate end-directed behaviors. The apple flowers serve to attract bees that can pollinate them and thus assure the occurrence of sexual reproduction. But how can a purely mechanical principle (natural selection) produce agency in a world that is not supposed to carry any trace of end-directedness? Our intuitive sense of logic seems to be strained quite a bit here.

We shall return to this problem, but let us first in some more detail consider a clear-cut case of a biological function, the heart: What is the function of the heart? Several answers might be given depending on the level at which the problem is answered. Thus, considering that the heart beats faster in states of emotional agitation one might claim that the function of the heart is to make us aware of states of emotional agitation. A more imaginative answer was put forward by complexity researcher Stuart Kauffman who once observed that our heart beat may reflect the outburst of an upcoming earth quake before it actually hits us. Although this early warning signal is not at present the function of the heart one might speculate that if earth quakes were to become more frequent in the future survivors would tend to possess hearts that have optimized this function of being an early warning system. The beating heart would then have become an example of so-called Darwinian preadaptation (or exaptation (Gould and Vrba 1982)), a non-functional trait which under changed circumstances is recruited by natural selection for a whole new function, in this case a warning signal against imminent earth quakes.

But the main function of the heart is of course to pump blood. The heart is effectively nothing but a muscle and in spite of much prize for it's wisdom it doesn't

¹ Cf. the discussion of teleonomy in Deely 2001: 65-66.

even know we exist. It nevertheless serves us well from the moment it starts beating early in embryonic development, and continues to serve us by beating rhythmically 60 - 80 times per minute without any serious interruptions until the moment we die some 75 years later (on average). In a normal life time the heart will have beaten app. 3 billion times; the heart therefore may well be dumb but it is certainly not lazy².

Pumping blood, however, is only the most proximal function of the heart; for in very small animals, where oxygen can penetrate into the cells from the surface of the animal, there is no need for a heart to pump oxygen carrying liquid around. Pumping blood therefore is only a vital function in animal life because it is a tool for the more central function of providing oxygen to the tissues. So, the real function of the heart, it might be said, is to provide oxygen. But even this function does not hit the "heart" of the matter, for there are plenty of organisms on Earth that do not need oxygen to drive their metabolism, and oxygen may even be toxic to such organisms. The reason oxygen is needed in animals is that the metabolism of animals happens to be based on the burning of food through a series of oxidative processes that use oxygen as the ultimate oxidative source. Therefore oxygen delivery as such is not the core of the matter, rather the core is that organisms need to assure the metabolic formation of energy-carrying molecules (ATP). So the primary function of the heart might be seen as that of assuring ATP production in animal tissues.

Strictly speaking, however, even the function of providing a well regulated source for the production of energy carrying molecules (ATP) cannot be said to be the ultimate function of the heart. For if an organism did not engage in reproduction evolution would not care whether it carried a heart or not. Only because organisms need to reproduce is the heart of importance to evolution. So, seen in a wider perspective the real function of the heart is to make reproduction possible, and so on.

What this mapping of heart functions shows us is that biological functions are contextual and ultimately they depend on the simple fact that life is historical. Life is

² The semiotics of heart function. Heart function is extremely well controlled by the animal body. A subtle semiotic web is in charge of this control. Sensory receptors in the walls of certain blood vessels and heart chambers are sensitive to changes in blood pressure. When stimulated they send messages to the cardiac centers in the medulla of the brain. The cardiac centers in the brain maintain control over two sets of autonomic nerves that pass to the SA node (or pacemaker): Parasympathetic nerves works through a single nerve -- the vagus nerve -- which release acetylcholine, that slows the heart; sympathetic nerves release norepinephrine which speeds heart rate and increases the strength of contraction. In response to physical or emotional stress the adrenal glands release epinephrine and norepinephrine, which speed up the heart rate. Psychological states interact through the hypothalamus with sympathetic nerves and - more indirectly - with parasympathetic nerves.

historical in the sense that its continuation depends on an ability to learn: Strategies that have proved effective in overcoming past challenges must be "remembered" so that descendent organisms will be able to cope with those same challenges; and - just as important - those strategies that did not work well must be "forgotten". The effect of these two processes is *learning*, and since natural selection is precisely a mechanism for remembering the fit and forgetting the unfit natural selection is a kind of learning process. Now, learning processes are different from normal mechanical processes in that they depend on the formation of some form of a coded *representation* (the functional response must be incorporated in the system in some way or other, for instance as here in the form of the genetic setup). But the moment a representation becomes a constituent of a mechanism "misunderstandings" will necessarily lurk in the background.³ An unpredictable source of change is thereby introduced into the system and change in systems with a capacity for learning is therefore historical in nature, not mechanical.

Learning is of course a semiotic process, an interpretative agency must be a part of the process, and in natural selection this interpretative agency resides in the lineage, i.e., the population as an evolving unit.⁴ *Populations* are coterminous with the concrete individuals living here and now, while the *lineage* is a *historical* and *transgenerational subject* that possess a *collective agency* as such, since its destiny as a temporal integrative structure is formed through the accumulated interactions of its single units (individuals) with their environments—much in the same way that multicellular organisms are integrative structures interacting with their surroundings via the activity of individual cells (Hoffmeyer 2008, 116). The lineage is the subject that may eventually learn to cope with changes in the ecological niche conditions or, otherwise, go extinct. According to present fashion in biology this learning process can be measured simply as changes in gene frequencies down through the generations. Each generation in this simplified optic constitutes a cohort of genotypes expressing themselves as phenotypes that enter into the competitive acts of survival and reproduction. The resulting cohort of genotypes in the next generation will thus

³ Numerous diseases are known to interfere with normal heart function and some of them are caused by a "misreading" of important genes due to genetic deficiencies or to disturbances in normal embryonic development.

⁴ The word *lineage* here is used in the conventional sense of a succession of ancestors and descendents, parents and offspring.

reflect the failures and successes of the preceding cohort⁵ (i.e., what was "remembered" and what was "forgotten").

DARWIN'S STRIVING

Since biological function is ultimately anchored in the evolutionary learning process which itself is the outcome of semiotically controlled interactions between millions and millions of individual organisms, it is not very surprising that biological functions always look "as if" they are teleologic in nature, for that is exactly what they are. It is therefore also no wonder that teleological language is popping up everywhere in biological literature even in scholarly work. When confronted with this embarrassing but broadly accepted use of language biologists or philosophers of biology usually respond by claiming that these ways of expression should be understood as only metaphorical, and that in due time, they can be and will be reduced into the chemical and physical interactions that produce the effects or functions so labeled. Thus at a Wikipedia website on "function (biology)" we find the following typical response: "teleological terminology is often used by biologists as a sort of 'short hand' way of describing function, even though they know it is technically incorrect. *Laypersons may not understand this distinction, however*" (my italics).

The irony here is that Charles Darwin didn't understand this subtle distinction either. In chapter 3 of the "origin of species," where Darwin describes the Malthusian character of the struggle for existence, he explicitly writes that: "In looking at Nature, it is most necessary ... never to forget that every single organic being may be said to be striving to the utmost to increase in numbers" (Darwin 1971 [1859], 71). This was certainly not meant as a 'short hand' way of expression. Darwin's masterpiece was concerned with the origin of species, not with the origin of life, and he remained agnostic when it came to the question of the origin of life. That all the creatures of this world were incessantly "striving" to find food, escape predators, find mating partners etc. was so obvious to Darwin that he simply took this fact as a point of departure for his whole analysis. And in the very last two sentences of "Origin of species" he even expresses the view that God has created the first life forms: "Thus, from the war of nature, from famine and death, the most exalted object which we are capable of

⁵ While this simple pattern may indeed catch the biological learning process quite well as long as we are dealing with early states of evolution or with semiotically unsophisticated species, it is the opinion of this author that it gravely underestimates the importance of individual semiotic activity in later stages of evolution particularly when brained animals are involved (cf. Hoffmeyer 2008).

conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved." (Darwin 1971 [1859], 463). Among the "several powers", breathed into the first organisms by the Creator, Darwin of course counted "striving" or what we today would call *agency*.

Whether or not Darwin also in private believed in the Creator is not essential in this context. What is essential is, that he had no trouble in accepting the idea that living beings possess agency and that his conception of the human situation, vis-à-vis nature, was in fact not very far from the biosemiotic one.

In the neo-Darwinist reinterpretation of Darwin's work which took place during the first half of the 20th Century the allusion to the Creator had to be abolished and with it disappeared Darwin's conception of "life, with its several powers". The task at hand was here to make a synthesis between the different branches of evolutionary biology inside a modern probabilistic understanding. Changes in a population now became seen as a movement through an "adaptive landscape" toward a state of equilibrium, where gene frequencies were stabilized. The individual organism lost its role as the leading evolutionary agent and became a slave to internal and external events and forces: the selective pressures from without and the mutational processes inside germ cells.

With the fusion of Darwin's theory with molecular genetics, a further burden was placed upon the shoulders of *natural selection*, a burden that slowly annihilated the original vision of Darwin. For now even thoughts and feelings had to be understood as genetically-based components in the behavior of an animal— involuntary reflexes not much different from the mechanical movements of a compass needle. Gone was the possibility of visualizing animals as *agents* in their own life.

So, while Darwin had placed the human being safely and understandably within the masterpiece of nature, the neo-Darwinist threw us out again—telling us that our *genes* may well belong to the reality of nature, but our *thoughts* and *feelings* are well outside of the reach of science. Consequently, those previously least deniable aspects of our own biological experience—because they could not be reduced to a molecular explanation—came to be viewed with increasing suspicion, as if they were

Fata Morganas, or epiphenomena without proper autonomous ontological reality (Hoffmeyer 2008).

Genes are segments of molecules, namely those long threads of nucleic acid bases coiled into a double helix structure which we call DNA. And to claim that molecules or segments of molecules possess agency is absurd. So, on the surface of it, the neo-Darwinian synthesis has indeed managed to get rid of the teleological aspect of life or to redefine it as survival strategies to be explained through game theoretical analysis. Properties of "winner-genes" would prevail and "loser genes" would be lost.

THE HOMUNCULUS TRAP

That a majority of scientists seems satisfied with this hiding away of life's agential aspect behind a statistical curtain of competing "gene strategies" never stops surprising me: How can a segment of a molecule possibly have a strategy?! The majority is so overwhelming in fact that the most obvious conclusion would seem to be that I must be wrong⁶. While I will leave the judgment of this possibility with the reader, I must dare to continue my argument comforting myself, at least, with the fact that giants like Darwin himself and the English philosopher Bertrand Russel were on my side. Russel stated the matter very clearly when in 1960 he said that "every living thing is a sort of imperialist, seeking to transform as much as possible of its environment into itself and its seed... We may regard the whole of evolution as flowing from this "chemical imperialism" of living matter" (Russel 1960). Theoretical ecologist Robert Ulanowicz, from whom I have taken this quote, make the further comment that "Russel, unfortunately, did not offer to explain the etiology of such "imperialism", but it was obvious in the way Russell phrased his comment that he was *not* referring to the disembodied, external action of "natural selection". (Ulanowicz Forthcoming).

The chemical imperialism Russel talks about here is the same property that I have chosen to call agency, the capacity of a unit system to generate end-directed behaviors. The central point is that agency cannot be explained away by natural selection. This is because natural selection could not - as Darwin saw - work in the

⁶ One of the few modern biologists to take note of this "homunculus gap", as John Deely pointed out in some detail in his 1969 discussion of species (Part i, pp. 105–115; Part ii, p. 293 and *passim*), was c. H. Waddington (e.g., 1960, 1961), with his insistence that the epigenetic system (i.e., the individual development and agency of the organism), and not only natural selection, acts as an anti-chance factor in evolution.

absence of "striving" or agency. Non-human organisms do not ever try to survive (for the simple reason, that they do not know that they shall die), but all of them do exhibit agency: they ceaselessly strive to find nourishment, find shelter, escape predators, find mating partners or whatever it is necessary for them to do in their life. Without this agency fertility and competition would be pointless, and since the core of natural selection is the so-called "surplus-production" of individuals, i.e., the production of more individuals than can possibly survive under the given ecological conditions, natural selection would never get to do its work if the individual organisms did not exhibit agency.

The claim that the neo-Darwinian scheme explains function therefore rests upon a tacit smuggling in of a "homunculus", i.e., some unspoken of agency hidden in the deep structure of the theory. Homunculus means "little man" and the concept was originally used to refer to attempts by alchemists to produce human beings in the laboratory through obscure experimental procedures, but the term came to fame when the first microscopists discovered small "animalcules" in the semen of humans and other animals. The idea then appeared that a little man, a homunculus, lay preformed inside the head of the sperm cell, and that this would explain human ontogeny: Upon fusion with the egg cell the little homunculus just had to grow to adulthood.

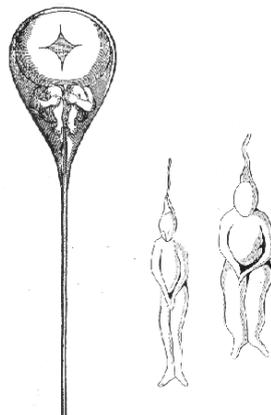


Figure 1: Homunculus in sperm as drawn by N. Hartsoecker in 1695.

Homunculus-theories are surprisingly widespread and were for instance common in early cognitive science where people were led to search for a "central processor" in the brain that was then somehow supposed to be responsible for human thinking. I remember to have learned at school that due to refraction a newborn baby would see

the world upside down - until she learned to turn it around. This of course presupposes that vision depends on somebody, a homunculus, sitting inside the brain looking at a screen showing the projected image.

The general problem with homunculi as theoretical entities is that they themselves need to be explained. The homunculi inside a sperm head would die childless unless its miniscule testicles would contain preformed sperm cells containing even smaller homunculi inside them leading us to an infinite regress. The same goes for the homunculus in baby's brain that in order to look at the inverted picture on the little brain-screen will have to have yet another small homunculus inside its own brain executing the same surprising activity.

GENES AND SEMIOTIC SCAFFOLDING

We can see then that whenever biology uses semiotic terms such as information, adaptation, signal, messenger, fidelity, cross-talk, cue etc. it tacitly presupposes some homunculus-like principle to substitute for Darwin's "striving" (Kull, et al. forthcoming). Essentially this is because biological function and semiosis are intertwined or even perhaps co-extensive. The evolutionary roots of agency, function and semiosis are buried in the now extinct prebiotic systems which app. 4 billion years ago gave rise to the first life forms. Realistic modeling of such systems may give us indications of the concrete steps such a process may have taken, but for the moment being we simply prefer to push back the origin question to a "threshold zone" below which we do not find semiosis, function or agency and above which these properties are indeed exhibited by the system. Important work is presently done in this area by several groups (Kauffman and Clayton 2005, Deacon 2006)

Here we shall elaborate a little further on how semiosis and genetic fixation are intertwined in the learning process called natural selection (as if nature could select). I shall claim that this process becomes fully understandable only when the semiotics of the process is integrated into the analysis. The evolution of the hemoglobin family of proteins will illustrate this point.

In addition to the operational genes that most people equate with the very concept *genes*, the genome contains huge stores of hidden, never sought-after "menu items"—what scientists call *pseudogenes*—that potentially may be brought into circulation, and thus may come to play a role in evolutionary changes. Pseudogenes are areas of the genome that are *nonfunctional* in the sense that they are not available

to the transcription process—but which nevertheless exhibit remarkable similarity to known *functional* genes in their base sequences.

Before the mid-1970s, DNA was considered a very static molecule. But it has become very clear since then that there exist quite a number of mechanisms whereby sequences on the DNA molecule may be duplicated and even change positions on the chromosome. Such mechanisms is supposed to have led to the formation of *gene families*—i.e., families of narrowly related functional genes, as well as *pseudogenes*.

Pseudogenes are of evolutionary interest because, unlike functional genes, they are not expressed and, therefore, are not subject to natural selection. Since they do not in any way contribute to the success or failure of their carrier organisms, they are free to undergo mutation without incurring the selectional consequences that normal genes do. (Normal genes mutate just as frequently, but those mutants that express functional deficiencies are accordingly sorted out.) Pseudogenes therefore represent a tacit *resource base* of latent proteins with unexplored properties—from which natural selection may eventually pick up new functional genes.

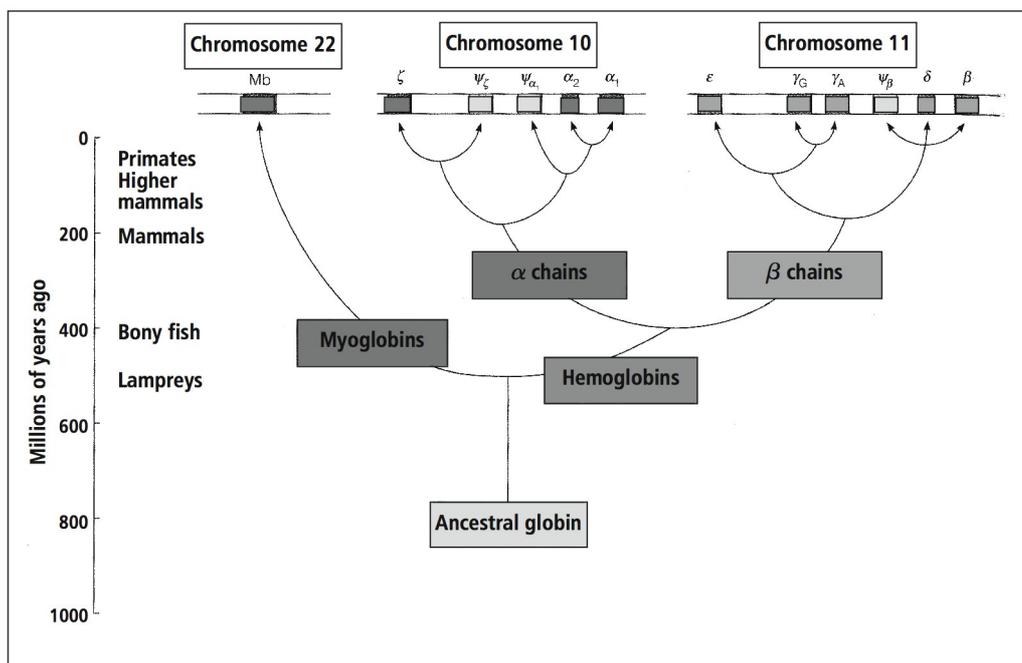


Figure 2: An evolutionary tree for human hemoglobin. Above is shown the arrangement of human hemoglobin genes over three different chromosomes. Sequences that are still transcribed are shown in dark gray. The very light areas are no longer transcribed in humans, but are now pseudogenes. Below is shown a time axis (in millions of years) indicating approximately when in evolution different

hemoglobin genes appeared (modified from Mathews, van Holde and Ahern 1999, 234).

Human hemoglobin is in reality a complex (a *tetramer*) of four subunits each of which is a protein chain of just under 150 amino acids. All four subunits are derived from the same ancestral protein chain but pair wise they are now slightly different and are called *alpha* and *beta chains* respectively.

Significantly, the early embryo doesn't form any of these two subunits, but instead forms *ksi* and *epsilon chains* that deviate somewhat from the alpha and beta chains of the adult hemoglobin. Towards the end of embryonic development, a fifth chain is made called the *gamma chain*—this is because the oxygen supply for the embryo comes through the placenta, and it therefore needs a special hemoglobin tuned to this temporary—but life-sustaining for that time period—condition. And for a short period around birth, the newborn baby even produces a sixth chain of proteins called the *delta chain*.

Such variety in the kinds of hemoglobin chain formation found through the embryogenesis of one individual is a relatively recent phenomenon, in terms of evolution—as is disclosed by comparing hemoglobin chains from a number of different species, as in figure 3. This figure shows that the original oxygen-carrying protein was a monomer not very different from the protein, *myoglobin*—a protein that nowadays is used for storing oxygen in muscle cells. Approximately five hundred million years ago, the gene involved in the protein synthesis of *myoglobin* underwent a duplication, where one of the gene copies became the ancestor of the *myoglobin* genes found in all higher organisms today, while the other gene copy, in time, developed (probably as a *pseudogene*) to become a proper oxygen transporter—and *this* gene thus became the progenitor of all the world's hemoglobin genes today. Thus, all later species in this lineage have separate genes for myoglobin and hemoglobin.

In retrospect, it is easy to see this evolutionary development as a reflection of a new "size strategy" in evolution. In the small animals of early evolutionary time (e.g., the protozoans and flatworms), there was not much need for an oxygen transporter, since the distance to the surface of the animal would always be insignificant. But as animals began to increase in size some 500 million years ago, and as a result began to feed on smaller animals for their nourishment, oxygen transportation became a major challenge. Four hundred million years ago, a second gene duplication occurred

through which the ancestral forms of *alpha* and *beta chains* were established. Since then, all organisms in the lineage have both *alpha* and *beta chains* in their hemoglobin. In natural history, this corresponds with the divergence into sharks and bony fishes, and the evolutionary line of the latter that led to the reptiles and eventually to the mammals.

Similarly, the gene duplications behind the divergence of the *specialized fetal hemoglobin chains* occurred some two hundred million years ago, which roughly corresponds with the appearance of placental mammals—where the particular oxygen-binding properties of these chains would be needed for the special tasks of ensuring an adequate supply of oxygen to the embryo. And thus the numbering of the chromosomes in the upper part of figure 3 refers to the positions of the different hemoglobin genes on the human chromosome as they are today. Like the musical motifs of a classical symphony that are interwoven in a variety of ways to form the experience of a unified whole, so we see how evolution little by little has managed to weave the hemoglobin themes into one another to form a functionally optimal unity. But contrary to the product that is the symphony, here there is no composer behind this evolution, and its dynamics must be explained by means of natural processes.

Summarizing this case we can say that the decisive cause of the birth of a new functional gene would be a lucky conjunction of two events: 1) an already existing nonfunctional gene might acquire a new meaning through integration into a functional (transcribed) part of the genome, and 2) the gene product (e.g. a protein species) would hit an unfilled gap in the semiotic needs of the cell or the embryo. In this way, a new gene becomes a scaffolding mechanism, supporting a new kind of interaction imbuing some kind of semiotic advantage upon its bearer. It would thus be proper to refer to this phenomenon as *semiogenic scaffolding* (Hoffmeyer 2008). For by entering the realm of digitality, the gene's new semiotic functionality becomes available not only to the cells of the organism carrying it, but also to future generations—and, if we allow for horizontal gene transfer, even to unrelated organisms. Digitality in the life sphere assures the sharing (objectifying) of functions (and, in the human case, ideas), and thereby also their conservation through time.

But this very function is itself dependent on the relative *inertness* of the genetic material and its very indirect and highly sophisticated way of interfering with the worldliness of cellular life. Genes, like human words, do not directly influence the world around them (which is why we do not believe in the power of spells), but have

whatever causal efficacy that they have *only* when—and for so long as—some living system *interprets* them. And just as inert, intrinsically meaningless words serve to *support* human activity and communication, so do inert, intrinsically meaningless genes *support* cellular activity and communication.

BIOSEMIOTICS AND THE THEORY OF EVOLUTION

Biosemiotics implies a major change in our conception of the role of the genetic material, the genome. Whereas the traditional view sees the developmental process and thus the phenotype as specified by the genetic setup of the organism, the genotype, biosemiotics makes us consider the over-all process as one of interpretation rather than one of specification. The so-called genomic "instructions" are buried deeply inside the nuclei of individual cells that cannot for good reasons "know" which destiny or function in the adult organism they are "meant" to occupy (a liver cell, a nerve cell, a lymphocyte etc), and the cellular apparatus is therefore utterly dependent on external "instructions" to tell it which genetic "instructions" to execute at each moment. External cues derived from neighboring cells or tissues, or from body glands, or "traveling cells" such as the cells of the immune system (lymphocytes) must be picked up by specific receptors located on or in the cell membrane and translated to intracellular processes (signal transduction) that interact with the protein complexes involved in transcription and translation of DNA as well as with the targeting of virgin proteins either to their final positions in the landscape of the cell or to excretion into extracellular space. At each step in this complex chain of linked processes contextual factors may interact significantly with the outcome. Obviously the gene does not therefore in any ordinary sense of the word *determine* its own "reading", and neither is it justified to talk about this process as a *specification*. The process is best described as an interpretation with the implication that epigenetic and environmental factors must be seen as autonomous resources for ontogeny and phenotypic activity.

The fact that ontogeny is nevertheless very rigidly controlled has been taken as evidence for a dominating conservative mechanism linking the genetic setup to the functional phenotype through well-buffered chains of causal processes. In biosemiotics this explanation is supplemented or replaced by the notion of *semiotic scaffolding*: Processes at all levels of organismic function are controlled by semiotic interactions between components that incessantly adjust biochemical or physiological

activity to changing situations. This network of semiotic controls establishes an enormously complex semiotic scaffolding for living systems. Semiotic scaffolding safeguards the optimal performance of organisms through semiotic interaction with cue elements which are characteristically present in dynamic situations. And as we saw, at the cellular level, semiotic scaffolding assures the proper integration of the digital coding system (the genome) into the myriad of analogical coding systems operative across the membranes of cells and cell organelles. The big advantage of this mechanism is that contrary to physically based interactions, semiotic interactions do not depend on any direct causal connection between the sign vehicle and the effect. Instead the two events are connected through the intervention of an interpretative response. The point is that in semiotic interactions the causal machinery of the receptive system is itself in charge of producing the behavior, and it thus only needs to acquire a sensitivity towards the sign as an inducing factor. The biochemical machinery underlying the response is not, therefore, restricted by any bonds deriving from the chemistry of the releasing sign⁷. When functionality first arises at a holistic level (e.g. the level of the tissue rather than the individual cells making up the tissue), any mechanism that will stabilize such functionality will be favored by selection, and in this context semiotic interaction patterns provides fast and versatile mechanisms for adaptations, mechanisms that depend on communication and "learning"⁸ rather than on genetic preformation.

The emergence of this sophisticated kind of stabilizing agency poses important challenges to our conceptions of evolution. In many cases semiotic scaffolding might work as a possible forerunner for natural selection: due to its stabilizing capacity semiotic scaffolding implies that natural selection may take routes that has been semiotically prepared for it rather than being directed by the haphazard events of fortunate chance mutations. Thus, biosemiotics holds that while genetic fixation may ultimately be the most secure mechanism for the stabilization of new traits or behaviors, such traits and behaviors were probably often initially stabilized through semiotic loops and thus kept functional for an indefinite period of generations

⁷ Thus any volatile compound, pheromone, may be taken up and used by the evolutionary process as a vehicle for the sign process whereby a certain behavior is released in an given insect no matter what the exact chemistry of that pheromone is. This absence of a direct involvement of the sign in the biochemistry and physiology of behavior of the receptive organism removes the hard limitations on causal mechanisms that would otherwise have to be obeyed.

⁸ By learning at this level we refer to cells' acquisition of internal structural markers that reflect past events and influence future activity.

allowing the time needed for the much slower mechanism of supportive genetic change to take place. Especially in the later states of evolution such semiotic preparation (a kind of *vis a prospecto*) is likely to have had an important influence on the actual outcome of selective solutions.

The introduction of a semiotic understanding has significant implications for ethology. Rather than reducing organismic behavior to inherited holistic lumps of reflexes, so-called instincts, biosemiotics suggests new subtle kinds of learning *in situ* associated with the establishment of semiotic scaffolding. The eventual appearance in big-brained animals such as birds and mammals of an experiential world would also be less of a mystery in the biosemiotic perspective than it is normally seen to be (and certainly not the meaningless epiphenomenon that it is claimed to be by some philosophers). Since the sign itself is a pure relation (and cannot be identified with any of the three entities it brings together), biosemiotics necessarily accepts the reality of a causality that is directed (but not effectuated) by the influence of pure relations, which suggests the possibility that the experiential worlds might be analyzed as a realm of pure relations connecting environmental cues and sensomotoric brain modules to contextual patterns dependent on memory and intentions.

At the ecological level biosemiotics requires us to extend our concept of an ecological niche to embrace the *semiotic niche*, i.e., the totality of cues around the organism (or species) which the organism (or species) must necessarily be capable of interpreting wisely in order to survive and reproduce. One important aspect of the semiotic niche concerns the semiotic interactions between individuals from different species. Most notably among these, of course, stands predator-prey relations but just as significant perhaps is the range of interactive behaviors connected to symbiotic relations. When symbiosis is seen as a semiotically controlled kind of interspecific interaction it becomes evident that symbioses encompasses a lot of subtle interaction forms that are not normally seen as belonging in this category. An illustrative case is so-called *plant signaling*. Undamaged fava beans (*Vicia fabea*), for instance, immediately started to attract aphid parasites (*Aphidus ervi*) after having been grown in a sterilized nutrient medium in which aphid-infected fava beans had previously grown. The damaged beans thus had managed to signal their predicament through the medium to the undamaged beans, which then immediately started to attract aphid parasites, although no aphids were, of course, available for parasites to find.

The difference between this kind of *semiotic mutualism*, involving a delicate balance of interactions between many species, and symbiosis proper is one of degree rather than one of kind, and biosemiotics takes semiotic mutualism to be not only widespread in nature but nearly ubiquitous. This implies that the relative *fitness* of changed morphological or behavioral traits become dependent on the whole system of existing semiotic relations that the species finds itself a part of and, accordingly, the firm organism-versus-environment borderline will be dissolved, and a new integrative level intermediate between the species and the ecosystem would have to be considered—i.e., the level of the *ecosemiotic interaction structure* (Hoffmeyer 2008).

Clearly, this possibility becomes most interesting in cases where individual experience and learning enters the interaction pattern, as will often be the case in mammals and birds. Such learning might on occasion even subsume the evolutionary process, as is the case in human culture. Conversely, one might wonder if a relatively autonomous ecosemiotic interaction structure is precisely what is needed for learning to evolve in the first place. In this way, eventual increases in semiotic freedom, i.e. the capacity of a system to derive useful information from complex signs, will be prone to feed back into the evolutionary process by strengthening the advantages of possessing semiotic freedom. It follows that the evolutionary dynamics would possess an in-built tendency to invent and establish species exhibiting more and more *semiotic freedom* in the sense that their behavior would be increasingly underdetermined by the constraints of natural lawfulness and increasingly dependent on the *in situ* interpretative capacity of individual organisms.

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It is indeed possible to explain non-human living systems as if they were deprived of semiosis, agency and true interests. This is exactly what biology has been doing for more than a century and often in ingenious ways. In the course of the last few decades, however, it has become clear that the reductionist assumptions that lead scientist to pursue such an awkward approach are no longer supported by scientific evidence. A new understanding of the thermodynamics of irreversible systems and of the dynamics of complex systems has given us a picture of a non-deterministic world in which bottom-up processes are interacting with top-down processes in intricate ways (Laughlin 2005, Kauffman 2008). This is - or ought to be - a great relief to biology because it implies that not everything can be predicted and that complex

systems like life systems may evolve to create higher-order structures with properties that may have causal influence on lower-level entities. In other words, it implies a view of nature as creative.

The order of things was not predictable from the outset but has to be explained by theories of a true emergence. We have argued in this paper that the emergence of life systems implied the simultaneous emergence of agency and semiosis as integral parts of the dynamics of such systems. A biology that wants to explain evolution cannot therefore fulfill its goal unless it integrates semiosis into its theoretical repertoire. In the absence of this explanatory tool biology will never get rid of the hidden homunculi that unavoidably pop up underneath its mechanistic surface structure. Biosemiotics is necessary in order to make explicit those manifold assumptions imported into biology by such unanalyzed teleological concepts as function, adaptation, information, code, signal, cue, etc. and to provide a theoretical grounding for these concepts.

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