

BIOSEMIOTICS AND SURVIVAL: LIFE AND DEATH, GENES AND SIGNALS

32nd Annual Meeting of the Semiotic Society of America

New Orleans, Louisiana, October 4 - 7, 2007

Conference theme: "Semiotics and Survival"

Eliseo Fernández

Linda Hall Library of Science and Technology

fernande@lindahall.org

ABSTRACT

Human survival, be it individual, social or cultural, is rooted in and dependent on the survival of life forms in general — on the survival of organisms, species and ecosystems.

The emerging discipline of biosemiotics is able to cast a new light on the meaning and nature of biological survival. In this paper I will attempt to show (in a brief and summary way) how a focus on the semiotic dimensions of living transactions can disclose new philosophical perspectives on well known phenomena, reveal new ways to organize those phenomena, and simultaneously suggest novel avenues of inquiry into their nature. I will take the notion of survival as an example and guiding thread, illustrating how the semiotic perspective yields such aforementioned benefits. In the process I will consider the role of the concept of survival in the evolution of living forms, from the "survival of the fittest" at the inception of current evolutionary theory, to present-day ideas on relative survival. Likewise, I will explore the subordination of individual survival to that of species or societies, and the semiotic aspects of apoptosis (i.e., programmed cell death).

Survival and biosemiotics

Human **survival**, be it individual, cultural or societal, obviously depends on, among other things, the survival of organisms in general. This is so not only because humans are one species of organism, but also because the fates of different organisms and their associations are inextricably linked in complex and often unpredictable ways. Here I would like to share some reflections on this topic as seen through the conceptual lens of **biosemiotics**.

Although it may seem superfluous at a meeting of semioticians, I think it may be useful to preface my reflections with a concise reminder of the nature and aims of

biosemiotics, a new discipline at the intersection of semiotics and biology. As we know, biosemiotics deals with the multifarious forms of communication and signification inherent in living systems. Overlying the study of this immense network of semiotic interactions, biosemiotics aims to integrate our knowledge of living forms through the application of insights from the general science of semiotics, as developed by Peirce, Sebeok, and others.¹

A historical parallel may help clarify the intended aims of biosemiotics. The introduction and application of the concepts of energy and entropy in mid-nineteenth century natural philosophy brought about a conceptual unification of mechanical, optical and electromagnetic processes. Moreover, that convergence made intelligible for the first time such basic biological phenomena as photosynthesis, metabolism, relative population abundances, etc. Biosemiotics attempts to bring about an analogous unification of ideas in biology through the application of semiotic concepts (e.g., semiosis, information, code, memory, recognition and error). Just as the notions of energy and entropy opened new ways of questioning and understanding physical phenomena, the semiotic perspective may reveal new vistas on the functioning of organisms and their evolution. To illustrate this possibility I propose to examine the concept of **survival** —the theme of our meeting— from the perspective of **biosemiotics**.

Individual and species survival

Since Darwin's appropriation of Spencer's phrase "survival of the fittest," this expression has become almost synonymous with natural selection in popular accounts of biological evolution. We will see that there is more to the notion of survival than first meets the eye. To begin with, survival is not merely one among the many things organisms do; **surviving is coextensive with living**. To survive — from its Latin roots *super* (above) + *vivere* (to live) — is to manage to stay afloat in the ocean of life. The entire functional orchestration of physical and chemical activities transpiring at every instant within every organism, from bacterium to semiotician, keeps busy repairing and rebuilding structures that are undergoing permanent and unrelenting decay. Otto Neurath's famous metaphor

for the life of science-- a boat that must be continuously rebuilt while remaining afloat -- is equally applicable to life in general.² The organism is ever at the brink of death, even when at perfect peace with its environment. *Vivere est supervivere*: every vital function or mechanism at work in an organism is almost always engaged in the service of **individual survival**, excepting functions directed at its reproduction.

Upon reflection it turns out that individual survival likewise concedes to a higher cause: **species (or “form”) survival**. For example, a rabbit who is very successful at securing clover and avoiding foxes would be lost at the screening gates of evolution were it not equally successful at making copies of itself. Survival of the fittest means survival of the successful reproducers. In our example the successful rabbit is the one that manages to pass the torch of rabbithood to the next generation. When forced to choose between the survival of the individual and that of the form, nature favors the form. Animal life histories abound with anecdotal illustrations of this fact: self-immolation of mothers for their progeny, suicidal mating by males, “altruistic” suicide of sterile members of insect societies to safeguard the reproducers, among other examples.

Survival and programmed cell death

In the case of the individual cells that are integrated into multicellular organisms (e.g., plants and animals), there is another, more subtle and complicated relationship between individual survival and species survival. Through a process called **programmed cell death**, individual cells self-destruct in order to facilitate the development and continued existence of the multicellular organism of which they are a part, so that it can carry on the task of species procreation. In recent years scientific research has shown that programmed cell death is a basic, omnipresent biological phenomenon which also plays a role in the lives of microbes, both prokaryotes (i.e., bacteria) and eukaryotes (e.g., yeasts or paramecia). The current pace of research in this field is extraordinary and concentrates on a ubiquitous form of programmed cell death called **apoptosis** (from the Greek *apoptein*, to fall off). Apoptosis plays a role of paramount importance in the evolution, embryonic development and everyday survival of all multicellular organisms.

Apoptosis is characterized by the self-destruction of individual cells through an internal process mediated by protein-dismantling enzymes called **caspases**. Under specific circumstances, a characteristic chain of intracellular events results in the fragmentation of the cell into many membrane-enclosed particles, known as apoptotic bodies. These particles, which contain fragments of the nucleus and other organelles, harmlessly disappear as they are engulfed by surrounding cells. In contrast, when cells die from accidental causes (e.g., trauma, infection, etc) their remains break down into toxic substances that lead to tissue inflammation and injury to neighboring cells (i.e., necrosis).

In a remarkable book, *La Sculpture du Vivant* (The Sculpture of Life) Jean-Claude Ameisen, a distinguished researcher in apoptosis, set out to explain the mechanisms of programmed cell death, their functions in embryonic development, their probable role in the evolutionary emergence of multicellular organisms, and their implications for the explanation and control of disease and aging.³ He eloquently develops these difficult themes in lucid, jargon-free language with the aid of illuminating, apt similes and metaphors. Notably, he compares the action of programmed cell death to that of a process that carves the shapes of life by the removal of cells. One can easily picture a sculptor who brings out the form of a marble statue by chiseling away superfluous parts of the original material. Here we would like to stretch the power of this metaphor by showing how this chisel operates as a **semiotic tool**.

From physical language to semiotic terminology

Throughout the 20th century biologists successfully explained key functions and processes essential to the functioning of living beings, in terms of physical and chemical mechanisms ultimately driven by thermodynamic laws. We can think of these laws as universal constraints on the behavior of everything existing in the natural world — restrictions enacted by the fact that in all natural processes energy is conserved as well as continuously degraded through the irreversible increase of entropy.

The concepts and experimental methods of biochemistry and molecular biology succeeded in disclosing, in particular, numerous pathways and complex chains of

chemical reactions involved in the metabolism and growth of individual cells and multicellular organisms. Many sequences have been mapped out in astonishing detail and are behind numerous advances of current medicine and pharmacology. The main protagonists in these complicated series of events are the **proteins**— molecules made up of long chains of relatively simple units called **amino acids**. From a fixed repertoire of 20 amino acids, cells can manufacture an unlimited variety of proteins with radically different shapes and properties.

Mid-twentieth century scientists made a discovery unparalleled in importance since the explanation of the evolution of species through natural selection: the unraveling of the **genetic code**. This breakthrough gave rise to a revolution throughout all branches of biology. Its main import was the discovery that **hereditary instructions** are transmitted from one generation to the next by means of a universal set of rules for constructing proteins. These instructions are **encoded** and transmitted by a long string of simple chemical structures, called nucleotides, which make up the DNA and RNA molecules. The need to expand the vocabulary of biology with expressions such as “**instructions**” and “**code**” heralds the necessity of new kinds of concepts and explanations in biology. Beyond the constraints of physical law, organisms are further determined by the reception, transmission and storage of “**information**,” an elusive influence tied up with the capacity of matter and energy to serve as vehicles for **signs**.⁴ In biological contexts, signs are typically referred to as “**signals**” so as to distinguish them from the signs of human language and to honor the tradition of communications technology, where for the first time information was made the object of rigorous scientific examination.⁵ When we find ourselves unable to articulate intelligible explanations without recourse to using these semiotic expressions, we should be aware that we have left the shores of traditional biology and have entered the as yet uncharted waters of biosemiotics.

Cell signaling in cell suicide

It is important to recognize that biosemiotic considerations are by no means limited to genetic code and hereditary instructions. On the contrary, it has become evident that biosemiotic transactions are pervasive and constitutive of all life processes. In

particular, the interaction of genetic information with intracellular and extracellular signals plays a decisive role in triggering, maintaining and inhibiting the action of most, if not all, biological mechanisms. The unfolding of the events leading to cell death or survival in apoptosis affords an excellent illustration of this kind of semiotic action. In **extracellular signaling** cells receive from the external medium targeted chemical signals, such as hormones and neurotransmitters. These molecules act by binding to special proteins called receptors, located on the cell membrane. Cells can also communicate with each other directly by contact, by means of membrane channels, called **gap junctions**, which allow the passage of electrical and chemical signals between them.

Through **intracellular signaling** cell suicide may be triggered by internal disruptions caused by stress or other factors, or by external stimulations of membrane receptors. A cascade of chemical reactions within the cell prompts the production of signals that are, in turn, capable of triggering the expression or silencing of genes, or of activating other essential intracellular mechanisms. The signals that orchestrate apoptosis in animals are part of a great variety of mechanisms, involving a multitude of substances and acting according to the different functions fulfilled by cell death in health and disease. Each of our cells is equipped with a genetically controlled mechanism of self-destruction. This machinery can be triggered either by the reception of apoptosis-activating death signals or by failure in receiving apoptosis-inhibiting survival signals. Cell survival continuously depends on the repression of a default suicide mechanism through the reception of the appropriate combination of chemical signals emitted by other cells. In most cases, the intracellular signaling activated by executioner molecules finds its way to a mitochondrion— an essential organelle in charge of supplying the energy needed to drive metabolic reactions in eukaryotic cells. The mitochondrial outer membrane becomes permeable and releases proteins which in turn activate **caspases**, the executioner enzymes that spark the cell's fragmentation and final disappearance.

Apoptosis and survival

In multicellular organisms apoptosis performs two main functions: the **sculpting of the developing embryo** (to use Ameisen's metaphor) xx and, both in the embryo and adult organisms, the **maintenance of physiological and tissue balance** (homeostasis) through the elimination of defective cells that menace the organism's survival.

Apoptosis' role in carving shape and function in embryonic tissues and organs is illustrated by well-known examples, such as the resorption of the tadpole tail during its metamorphosis into a toad, or the formation of the digits in fetal vertebrates by apoptotic elimination of the tissues that initially connect them. Ameisen notes that the proper connections (synapses) between the hundreds of billions of neurons in the mammalian brain cannot possibly be encoded in the few thousand genes of its genome. They are established through a quasi-Darwinian process, thanks to an extraordinary initial proliferation of neurons. Those which do not establish successful synapses receive signals to initiate self-destruction from those which do succeed. This is a remarkable process in which biological complexity is created through self-organization.

Apoptosis insures the survival of the adult organism through the continuous renewal and updating of its cells and tissues. In adult semioticians about a hundred thousand cells are produced every second, replacing as many other cells eliminated by apoptosis. In recent years programmed cell death has been shown to be centrally involved in the majority of human pathologies, usually through failures in its regulation. Both excess and deficit of apoptotic activity are at fault. Many degenerative diseases (e.g., Alzheimer's or Parkinson's) are characterized by cellular attrition of apoptotic origin. On the other hand the inactivation of apoptosis seems to underlie many, if not all, forms of cancer.⁶ Many articles in the journal *Apoptosis* concern the elucidation of apoptotic mechanisms that may lead to therapeutic or pharmacological developments for treatment of cancer and other diseases. It would seem that the scientific understanding and manipulation of apoptosis is of great importance for our personal survival. This understanding is beginning to change scientists' approach to fighting degenerative diseases: instead of seeking to physically destroy rebellious cells (as in surgery or some forms of radiotherapy), in most cases we are now trying to change their behavior, or bring about their self-elimination, through biochemical agents designed for switching and steering signaling pathways toward the desired outcomes.⁷

Concluding remarks

This brief incursion into the topic of survival suggests a need to more deeply examine important issues in the philosophy of biology, including the indispensability of biosemiotic concepts and explanations. Let us recapitulate some of the main points. Even in the most favorable conditions, life depends on an unremitting struggle for survival. The survival of an individual organism is subordinated to the survival of its species. This subordination takes a special, complex form in multicellular organisms, through the phenomenon of programmed cell death. Here the individual cells are equipped with an internal mechanism that leads them to suicide when they receive death signals or when they fail to suppress its automatic activation, upon failing to receive survival signals from other cells.

The development, renewal and survival of the organism are thus based on the unrelenting self-immolation of its individual cell components through a complex semiotic interplay of death and survival signals. In *La Sculpture du Vivant* Ameisen describes this dialectical interplay of life, death and community with eloquence:

These new ideas have begun to transform the very notion of life. In a troubling, counterintuitive, paradoxical way an event perceived until now as positive – life – seems to result from the negation of a negative event -- self-destruction. And an event perceived until now as individual, life, seems to require the continuous presence of others – and to be conceivable only as a collective adventure.⁸

Life is a collective adventure, I think, because it is a semiotic adventure. Communication is what makes a community. The fate of every organism, every cell, every organelle within each cell, is ruled by a hierarchy of communication links, which ultimately span the entire biosphere. Even an environmental event describable in purely physical terms – such as a sudden increase of temperature – may be read by an organism as a signal to activate dormant mechanisms, to de-activate others and to spontaneously communicate those changes to other organisms.

To be alive is to have been able to survive through the simultaneous survival of many and the ineluctable perishing of relatively fewer others. We survive as nodes in an all-

encompassing planetary net of physical, chemical and semiotic links. Our collective survival in the deepening environmental crises facing us, as an anthroposemiotic, language-organized community, depends on how well and how soon we are able to take this lesson to heart and start acting and signaling accordingly.

NOTES

¹Two detailed and scholarly accounts of the origins and development of biosemiotics have recently appeared: Kull 2005 and Favareau 2007. Favareau's contribution is the first chapter of Barbieri 2007. Both essays are supplemented by valuable and extensive bibliographies.

²In his contribution to Cartwright *et al.* 1996 Thomas Uebel traces the history and evolution of this wonderful metaphor for epistemological holism, from its birth in early 20th century Marxian polemics down to its epigraphic role in Quine's philosophy of science.

³This book earned two prestigious prizes: the *Prix Jean Rostand* and the *Prix Biguet* of the French Academy in the year 2000.

⁴"Information" is a contested concept in the philosophy of biology. See e.g. Maynard Smith, 2000, Roederer 2005, von Baeyer 2004, Seife 2006.

⁵The *locus classicus* of this analysis is in a seminal paper: Shannon 1948.

⁶According to Fesic 2005, p. 876, "... the evasion of programmed cell death has been recognized as one of the six essential alterations in cell physiology that dictate malignant growth and is a hallmark of most, and maybe all, types of cancer."

⁷A good review of the promises, problems and unknowns in the manipulation of apoptosis is found in Fadeel and Orrenius 2005.

⁸In Ameisen 2003, p.15 (my translation.)

REFERENCES

Ameisen, Jean-Claude (2002) On the origin, evolution, and nature of programmed cell death: a timeline of four billion years. *Cell Death and Differentiation*. **9**: 367-393.

_____ (2003) *La sculpture du vivant : Le suicide cellulaire ou la mort créatrice*. Paris : Éditions de Seuil.

_____ (2004) Looking for death at the core of life in the light of evolution. *Cell Death and Differentiation*. **11**: 4–10.

Barbieri, Marcello (Ed.)(2007)_*Introduction to Biosemiotics: The New Biological Synthesis*. Dordrecht: Springer.

Cartwright, N., Cat, J., Fleck, L. and Uebel.T (eds.)(1996) *Otto Neurath: philosophy between science and politics*. Cambridge, MA: Harvard University Press.

Fadeel, B., Orrenius, S. (2005) Apoptosis: a basic biological phenomenon with wide-ranging implications in human disease. *Journal of Internal Medicine*. **258** (6): 479–517.

Favareau, D.(2007) The Evolutionary History of Biosemiotics, in Barbieri 2007, 1-67.

Fesik, S. W. (2005) Promoting apoptosis as a strategy for cancer drug discovery. *Nature Reviews Cancer*. **5** (11): 876–885.

Hoffmeyer, J. and Emmeche, C. (2005) Code-duality and the Semiotics of Nature. *Journal of Biosemiotics* **1** (1): 27-64.

Kull, K. (2005) A brief History of Biosemiotics. *Journal of Biosemiotics* **1** (1): 1-25.

Lavrik, I. N., Golks, A., Krammer, P. H. (2005) Caspases: pharmacological manipulation of cell death. *Journal of Clinical Investigation*. **115**: 2665–2672.

Maynard Smith, J. (2000).The concept of information in biology, *Philosophy of Science* **67**(2): 177-194.

Roederer, J. G. (2005) *Information and its role in nature*. Heidelberg: Springer Verlag.

Seife, C.(2006) *Decoding the universe : how the new science of information is explaining everything in the cosmos, from our brains to black holes*. New York: Viking.

Shannon, C. E. (1948) A Mathematical Theory of Communication *Bell System Technical Journal* **27**: 379–423, 623–656.

von Baeyer, H. C. (2004) *Information: the new language of science*. Cambridge, MS: Harvard University Press.