SIGNS, INSTRUMENTS AND SELF-REFERENCE IN BIOSEMIOTICS

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ABSTRACT

We propose to explore some problems and deficiencies in current approaches to biosemiotics and offer some tentative solutions or improvements. For these purposes we approach our field not so much as a separate discipline but rather as a program for a radical re-conceptualization and generalization of theoretical biology in light of the essential role played by semiotic and instrumental notions in biological modeling. We consider a triple approach to this task.

First: we examine the historical origins and development of the traditional exclusion or lack of integration of semiotic considerations in the life sciences. In particular, we examine these issues in connection with some historical parallels in the conceptual development of physics.

Second: we sketch an attempt to integrate under a single perspective three elusive conceptions which appear ubiquitously, under diverse guises, in the work of several important biosemiotic theorists. These are the notions of **triadicity**, **self-reference** and **final causation**.

Third: we carry out an analysis of the manifold meanings of the concept of **instrument** (*organon*): its role in scientific modeling, its special status in living systems, and its connection to the three conceptions mentioned above.

Finally, we show how the conclusions reached through these three approaches converge into a perspective that suggests new ways of relating **signs** to **instruments**. This in turn suggests the possibility of expanding Peircean semiotics to include the relations of the triadic action of signs (semiosis) to the action of various dyadic **mediators** (i.e., different types of instruments).

INTRODUCTION

Biosemiotics--this new discipline that we are trying to foster, nurture and develop in meetings such as this--is part of a much wider intellectual movement aimed at radically re-conceptualizing basic approaches to our understanding of the world and our place in it. Biosemiotics is based on the appropriation of key insights from the general science of semiotics (as conceived and developed to a great extent by Charles Sanders Peirce and his later followers) for the task of unifying and restructuring basic biological conceptions.

At this early stage of our endeavors we are still groping with some ill-defined notions and an assortment of mutually supporting but partially conflicting ideas. For this reason our discussions are apt to mix specialized technical reports of empirical research with deep-probing questionings of basic philosophical issues. In disagreement with some critics, I think this reveals a healthy situation because it bears a telling resemblance to the physics community's successful response to some disconcerting empirical discoveries in the earlier decades of the twentieth century. At that time protracted discussions of experimental facts in combination with bold philosophical pondering ushered in the introduction of the new quantum conceptions. Subsequently, the new facts were accommodated into a wider and deeper framework, and this was followed by the concomitant reformulation of the classical ideas. Something similar may be happening in our discipline.

The impact on biology that the discovery of the organic codes had in the second half of the last century may lead to far-reaching epistemological consequences. Indeed, it may be comparable to the introduction of the quantum of action in physics in earlier decades. If this parallel holds, one basic task of biosemiotics shall be the reformulation of basic biological concepts to make room for the essential role of semiosis, by means of experimental research guided by new philosophical insights. In this paper I would like to suggest that an examination of the role of instruments in scientific explanation, along with a broad consideration of the historical evolution of this role may help in re-organizing and integrating basic ideas of biology in this new light.

In the transition from classical to quantum physics, one of the philosophical clarifications that enabled the reformulation and generalization of classical concepts was an unprecedented examination of the **epistemic role of scientific instruments** both in disclosing and recording the phenomena, as well as in testing theoretical predictions about the future occurrence of similar phenomena. This analysis led to the realization that the construction of scientific instruments embodies, in a certain way, the very concepts they serve to define and the very theories they serve to test.[1] In the functioning of scientific instruments we seem thus to encounter a form of non-vicious circularity. Analogous instances of self-referential closure have frequently been remarked in biosemiotic investigations. I believe that these may be special cases of a general phenomenon of self-reference which is inherent to semiosis.

A reconsideration of the notion of instrument in biology may similarly help to clarify some philosophical issues in biosemiotics. To this end I will briefly discuss the relational structure of instruments and its role in the functioning of organisms. I will also trace the traditional exclusion of semiotic ideas in biology to the historically motivated proscription of notions involving goal-directed action from scientific explanations. I will relate this proscription's origin to the successful role played by some basic idealizations at the inception of modern science. Finally, I would like to indicate briefly how these considerations may help us in the reformulation of basic biological conceptions in terms of the intrinsically semiotic nature of biological transactions.

EXPLANATION IN ARISTOTELIAN AND NEWTONIAN SCIENCE

Currently the terms "science" and "scientific," when applied without further qualification, refer to a powerful enterprise for understanding and controlling the world of nature which originated in Europe through 17th century natural philosophers and which, through a complicated process, became consolidated and institutionalized some 200 years ago.

In classical physics, **explanations** are linked to **predictions** by means of a causal scheme that in a sketchy and oversimplified manner can be described as

follows. Changes in the course of events are explained by showing how they can be mathematically predicted from a particular and contingent constellation of circumstances at a given instant. These initial conditions are described by quantities, obtained and recorded by means of measuring instruments. They are used to describe the instantaneous state of a system of objects which has been prepared so as to remain causally isolated from its surroundings.

The outcomes of these measurements are used as inputs for the generation of predictions by means of special algorithms known as “laws of nature.” Newtonian physics succeeded in deriving, from high-level laws of great generality and universality, some lower-level laws (previously discovered by Galileo, Kepler and others) describing particular kinds of celestial and terrestrial motions,. This accomplishment set the basis and model for all subsequent progress in explaining and making scientifically intelligible the course of natural phenomena.

The high-level laws of Newtonian mechanics describe the behavior of objects in motion when they are causally isolated (i.e., inertial motion) and the alteration of this behavior (i.e., acceleration) under the influences of other objects, through impact or gravitational attraction. These influences were understood as a special kind of efficient cause, “forces,” acting from outside on corpuscles or other bodies similarly idealized. Such bodies were considered, for the purposes of explanation, as devoid of internal structure. The “mechanical philosophy” developed in the 17th and 18th centuries unfolded a program for the systematic reduction of our understanding of natural phenomena to the explanation of such general mechanical interactions.

This classical explanatory program, based on a novel cooperation between mathematical idealization and instrumental manipulation of natural phenomena, was born and developed in self-conscious reaction against a formerly established model of scientific explanation. The old scheme had been fashioned by the scholastic thinkers on the basis of Aristotelian ideas about the nature of reality and the intellectual methods required for a rational account of it.

For our purposes the most important development was the rejection of final causation in its Aristotelian form of "**immanent teleology.**" This expression refers to a system of explanations in which the behavior of entities of a given "natural class" is accounted for by investigating their intrinsic tendencies to perform certain kinds of actions. These actions are directed toward reaching characteristic types of final states and are brought about by well-defined sets of external circumstances that would trigger their enactment. The inspiration for this form of explanation obviously stems from considering natural classes of living organisms, in contrast to the idealized, inert corpuscles that inspired both ancient atomism and modern science.

To avoid frequent philosophical confusions and historical misrepresentations, it is important to draw a sharp contrast between this **immanent teleology** and the **transcendent**, theologically inspired teleology embraced by many of the founders of modern science (Johnson 2005, Steigerwald 2006). This extra-scientific notion has been lately revived by religious fundamentalists under the label of "intelligent design." Here finality is the product of conscious design by an external supernatural agency whose extraordinary powers are conceived in strict analogy to human intentionality. The modern rejection of final causality, a gradual process that can be traced to the Nominalist scholastics of the 14th century, refers exclusively to the natural, immanent causality of Aristotelian science (Johnson 2005).

SIGNS, PURPOSES, AND SELF-REFERENCE

Several of the founders of biosemiotics, some of whom I have had the honor to meet at this gathering, have pondered on the presence of self-referential or recursive loops in biological organization. In English biosemiotic literature, this phenomenon is frequently indicated by the prefixes **auto-** (from the Greek **autos**, same) and **self-** (akin to the Latin possessive pronoun **sui**, of its own). One can list at random some terms associated with self-reference in biosemiotic texts: autocatalysis, autopoiesis, autonomy, autoimmune, automaton, self-organization, self-similarity, self-generation, self-perpetuation, self-replication, and also, of

course, self-reference itself. Traditionally self-reference has seldom been the focus of discussion unless associated with its negative effects: the paradoxes of set theory, impredicative definitions, or limitations of mathematical provability and computability (as in Gödel's theorems).

I would like to consider a positive role for self-reference at the very core of semiotics, within the Peircean definition of a **sign**, the paradigmatic instance of a genuine triadic relation. This definition is itself self-referential--since it is, of course, a sign, as is any other concatenation of signs. It is a special self-referential kind of sign about signs in general.

As we know, in Peircean semiotics the sign is defined as a representamen in terms of its capacity to determine another sign, its interpretant, to represent an object. In Peirce's mature semiotic theory he emphasized that the interpretant, besides representing the object, must at the same time represent the **very relation of representation which the sign has to that object**. As André De Tienne has recently remarked (De Tienne 2006),

> There are thus two overlapping triadic relations within semiosis, one that is first-intentional, and the other second-intentional. Within the first-intentional relation the interpretant collaborates to represent the object, while within the second-intentional relation it is busy representing the representation itself. The interpretant is both an agent and a meta-agent.

Since the sign relation is the prototype of all genuine triadic relations, it is reasonable to assume that self-reference is always inherent in triadicity and is thus expected to appear in all semiotic transactions.

Together with triadicity and self-reference there is a third term that is everywhere present in semiotic and biological discourse: **purpose**. We apprehend this notion immediately as originally revealed in the intentionality of our actions, but have no difficulty in applying it to the behavior of animals or living beings in general. The idea of purpose seems to presuppose the existence of agents capable of performing actions, selected from a virtual range of possibilities with some degree of freedom, and aimed at reaching some general anticipated outcome or result. As Kant observed, purposive behavior is characteristic of life and we

employ this notion implicitly in the empirical recognition of life forms. He considered that explanations based on the idea of purpose are necessary and unavoidable, but merely heuristic devices that serve to guide us in searching for genuine—namely, mechanical--explanations (Steigerwald, 2006, Walsh 2006).

At present, after learning the limitations of mechanical explanations in physical theory, we are inclined to regard purposive behavior as an emergent phenomenon somehow coordinated with the emergence of self-referential and semiotic (triadic) dynamic structures and cycles in organisms. I hope to cast some light on this coordination by inquiring into the nature of instruments.

WHAT IS AN INSTRUMENT?

Both the acquisition of information and the attainment of purposes require the existence of physical mechanisms capable of acting as **mediators** between the internal states of an agent and the changes transpiring in its environment. The relations of means to ends that characterize these devices cannot be found by analyzing them as isolated physical structures. Only in connection with an actual or potential user is an instrument an instrument.

When instruments are external natural parts of an organism they are traditionally called **external organs** (or organelles in the case of single cells). Examples are the eyes or claws of an animal or the chemical receptors or flagellum of a bacterium. We contrast them with **internal organs** or organelles, such as the heart of a mammal or the mitochondrion of a eukaryotic cell. For our purposes the most important external organs fall within two classes: sensory organs and motor organs. To simplify I will leave aside other efferent pathways, like those responsible for the secretion of hormones or pheromones, and concentrate on examples involving work performance.

When instruments are external artifacts--like the tools used by humans and other animals--they cannot function as such unless physically coupled to a natural external organ. This coupling may be continuous, as in the case of using a microscope, or just momentary, as in pressing a button to call an elevator.

Sensory and motor organs function in opposite directions. Sensory organs bring in information to selectively alter the internal state of organisms. We can say they **in-form** the organism. Motor organs, on the other hand, may be said to **con-form** the environment to forms determined by the purposes of the organism. This is achieved by altering the organism's location with respect to different components of its environment (e.g., running, flying) or more generally by performing mechanical work on them (e.g., clawing, digging), and by signaling information to other organisms. The actions of external organs seem to be purely deterministic.[2] Their behavior's purposive nature springs from internal organismal sources of semiotic action that somehow channel the future-oriented drive of signs toward their interpretation, through the physical mediation of instruments.

Instruments and signs are similar in their mediatory role, but quite different as relational structures. They differ, among other things, **in the way they are embodied in the world**. I propose to consider both instruments and signs as relational structures embodied or realized in material artifacts or energetic processes. After reaching a minimum threshold of quantity of matter or rates of energy, signs act independently of the properties of their physical embodiment. A large token of the letter A made of wood, for instance, achieves the same semiotic results as a small token made of ink. Instrumental relationality, on the contrary, is essentially dependent on the properties and quantities of its embodiments. This is most evident in the case of artifactual instruments, where the availability of materials with new properties makes possible new kinds of tools (e.g., the advent of the Bronze Age). But the most fundamental difference (and probably the main reason for the others) is their **type of relationality**. Signs essentially involve triadic relations, while instruments are intrinsically the embodiment of systems of dyadic relations. Their modes of action thus exemplify the contrast between semiotic and causal modes of determination. This contrast offers a key for understanding the way in which Peircean semiotics may help to reconcile Aristotelian and Newtonian models of explanation, as we will see further on.

INSTRUMENTS AND PURPOSES

The words “organ,” “organic” and “organism” have their common root in the Greek term ***organon*** which originally meant instrument or tool. This term looms large in Aristotle’s understanding of living beings, based as it was on artifactual analogies.[3] I would like to take it as a point of departure for revisiting some Aristotelian conceptions relevant to semiotics in general and biosemiotics in particular. In book 3 of *De Anima* Aristotle says:

> It follows that the soul is analogous to the hand; for as the hand is a tool of tools, so the mind is the form of forms and sense the form of sensible things. (De Anima III, viii, 432a)

From a perspective informed by contemporary semiotics this sentence can be given a new, if somewhat anachronistic, interpretation. If we consider the human hand as a meta-tool, as the condition for the possibility of human tools in general, we are led by analogy to consider the mind as a species of meta-form--a supra-formal self-referential structure that receives sensible forms from the senses, combines and trans-forms them into new forms, and finally impresses them onto the world through instrumental action. This purposeful action has two main objectives: to make the environment conform to forms anticipated by the mind and to communicate such forms to other organisms. The term “mind” refers here, of course, to its Peircean use in biosemiotic contexts, and not to the special self-referential characteristics of the human mind.

But, what are these **forms** communicated in semiosis and instrumental action? In “Aristotle-totle-totle,” a half-philosophical and half-humorous piece, Max Delbrück, a student of Niels Bohr and one of the founders of molecular biology, gave somewhat extravagant praises to Aristotle (Delbrück 1971). He referred to his many biological insights and his alleged discovery of the “principle implied in DNA.” Delbrück characterizes the Aristotelian form as an agency that:

> "…contributes nothing to the material body of the embryo but only communicates its program of development."

Delbrück is here assimilating the Aristotelian form into the conception, dominant until quite recently, that an organism's development is in principle reducible to the mechanical execution of an algorithm representing genetically coded instructions. The current synthesis of evolutionary and developmental biology (*evo-devo*) has led many practitioners to reject this reductionist view. Information encoded in DNA must be combined with complex information from the surrounding cellular structures and the external environment at different stages of ontogenesis. In eukaryotes most of the genetic information is encoded in genes that do not contain instructions for making proteins. Among these non-coding genes there are "meta-genes," whose second-order function is to regulate the expression of coding genes in response to information originating in the concerted activity and timing of entire gene networks. But even at the level of protein synthesis we face non-mechanical, circular forms of causation: proteins are produced by transcription of DNA sequences, but transcription in turn is regulated by proteins that trigger the initiation or suppression of gene expression.

In spite of these reservations we may retain Delbrück's interpretation of the Aristotelian form by taking the word "program" in an epigenetic rather than an algorithmic sense. The program unfolds as chains of physical and chemical transformations. Taken in isolation from their circular causal loops, each segment of these sequences is an instance of mechanical causation. The entire process, on the other hand, cannot be explained by invoking efficient causation alone. Had he known what we now know Delbrück might have seen this interpretation of development as the achievement of a goal that initiated his turn to biological research and animated many of his efforts: to establish Bohr's thesis of the complementarity of mechanical and teleological explanations in biology (McKaughan 2005).

CAUSATION, SEMIOSIS AND ARTIFACTS

The relation between efficient and final causation has been a point of contention in philosophy since before Aristotle's time. Here we can consider only a few highlights.

Aristotle thought that both mechanical and teleological explanations are necessary, but favored final causation. The founders of modern science were unanimous in rejecting teleology in its immanent form. Kant, on the other hand, considered that genuine explanations are mechanical, but thought that teleological explanations are necessary because of the limitations of human cognitive powers.[4]

In his seminal article "Life and Light" Bohr proposed to consider mechanical and teleological explanations as complementary, in analogy with the relation between conjugate quantities in quantum mechanics (Bohr 1933). The instrumental setups required for observing either the behavior of the parts or that of the whole organism are mutually exclusive but jointly necessary (Folse 1990).

Peirce, through a conception of causality informed by his semiotics, aimed at a different synthesis of the mechanical and teleological models of explanation. Characteristically, he did not see a dichotomy of separate "either … or" explanations, but a **triadic complementarity** at work, within each individual explanation, in the interplay of mechanical causation, final causation and chance. He was led to these ideas by considering the relationships between physical causation and semiotic determination. This topic is too complicated and unsettled to be developed here, but a few remarks may prove helpful for understanding the relations between semiotic and instrumental mediation. Further examination of Peirce's views on causation can be found in Hulswit 2002. In a manuscript dated 1905[5] Peirce remarked:

> That which is communicated from the Object through the Sign to the Interpretant is a Form; that is to say, it is nothing like an existent, but is a power, is the fact

> that something would happen under certain conditions. This Form is really embodied in the object, meaning that the conditional relation that constitutes the form is *true* of the form, just as it is in the Object. In the Sign **it is embodied only in a *representative* sense**, meaning that whether by virtue of some real modification of the Sign, or otherwise, the Sign becomes endowed with the power of communicating it to an interpretant. [MS **793**:1-3, 1905, my emphasis])

Mechanical action in the functioning of instruments may also be thought of as a dynamical transmission of physical forms (i.e., patterns of energy or momentum transfer) which in turn may serve as a substratum to embody, **in a representative sense**, superimposed semiotic forms. There is nothing especially mysterious in this transmission of immaterial forms. As I talk and you listen, some patterns in the firing of my neurons bring about corresponding patterns of contractions and relaxations through the instrumental mediation of my vocal cords, which in turn manage to embody similar patterns into compressions and expansions of the surrounding air. These travel as sound waves to your ears, where they bring analogous patterns of vibrations …and so forth. No pattern exists in disembodied form, but the same pattern may become successively embodied in different vehicles of form communication. From this perspective, Aristotelian forms can be regarded as precursors of the formal, dynamic patterns that contemporary media technology embodies into sequences of electrical impulses and electromagnetic waves.

In order to develop further Peirce's incipient attempt at reconciling the mechanical and teleological models of explanation, it might be helpful to inquire into their instrumentally inspired root metaphors: clockwork action and craftsman action. In his conception of life as "artifact-making" Marcello Barbieri achieves a new and original application of the craftsman metaphor by changing it into a literal formulation, generalizing it away from its anthroposemiotic origins.

In this new context *artifactual* means "put together" by external agents of any kind according to a set of external instructions. Genes and proteins first arose as molecular artifacts fabricated by molecular machines, ***copymakers*** and

codemakers. Unfortunately for our purposes, Barbieri articulates his valuable ideas--including his proposal of a triadic relationship of genotype, phenotype and ribotype--within a Nominalistic ontology of objective "entities" (i.e., quantities and nominable entities) and subjective ones (i.e., qualities). This ontology seems inhospitable to the real potentialities and relational structures essential to Peircean semiotics.

Our examination of the role of instruments may lead to a reconciliation of Barbieri's ideas with standard semiotics. Most, if not all, artifacts are instruments, themselves fabricated by the convergence of many concerted instrumental actions. Whatever else they are, Barbieri's codemakers and copymakers are certainly internal instruments of cells. As such their function may be thought of, in agreement with Peircean semiotics, as the performance of meaningful **actions** rather than the production of meanings as substantial objects.

CONCLUSIONS

My conclusions are mostly programmatic. This discussion has aimed at bringing to your attention the functions of natural instruments (organs), in particular those of external instruments, as indispensable mediators between organisms and their environment in their physical and semiotic transactions. The instrumental scheme of afferent and efferent pathways seems essential to the structure of all organisms and to be preserved throughout their most varied Baupläne, from bacterium to rabbit.

Another reason I advanced for considering the nature of instruments is that its elucidation was instrumental (no pun intended) in the resolution of epistemological problems and the generation of new research strategies in the transition from classical to quantum physics. The discovery of the organic codes through molecular biology may have an effect analogous to that of the introduction of Planck's quantum into physics. If that be so, we anticipate that a similar inquiry into the function of instruments in organisms could help in the transition from classical to semiotic biology.

In unfolding these considerations I have tried to relate them to the historical roots of present-day conceptual problems. I think their resolution may demand the recovery of some basic Aristotelian intuitions that were swept out by the modeling schemes adopted by modern physics. Such recovery would entail the articulation of old ideas within the framework of contemporary science and philosophy. I think Peircean semiotics, being in part a synthesis of Aristotelian and Kantian ideas, may prove to be a most valuable instrument in this task.

NOTES

[1] Abner Shimony calls this self-referential phenomenon an "epistemic circle" in analogy with the "hermeneutic circle" of phenomenology. See, for instance, Shimony, 1993.

[2] Here I view these external organs as mechanisms in the traditional sense, as structures that transmit efficient causation unidirectionally (Machamer *et al*. 2000). Some authors extend this notion to include causal loops: See Bechtel 2007.

[3] This tradition has recent echoes in the self-reproducing automata of John von Neumann (1966), the work of Robert Rosen (1991), the autopoiesis of Humberto Maturana and Francisco Varela (1980) and the autocatalytic networks of Stuart Kauffman (1993).

[4] Kant thought of organisms as self-organizing wholes made of **natural instruments** that generate each other reciprocally: "…In such a product of nature each part is conceived as if it exists only through all the others, thus as if existing for the sake of the others and on account of the whole, i.e., as an instrument (organ), which is, however, not sufficient (for it could also be an instrument of art, and thus represented as possible at all only as an end); rather it must be thought of as an organ that produces the other parts (consequently each produces the others reciprocally), which cannot be the case in any instrument of art, but only of nature, which provides all the matter for instruments (even those of art): only then and on that account can such a product, as an organized and self-organizing being, be called a natural end "(Kant 2000, §65, 245)

[5] Another version of this characterization, from a letter to Lady Welby, is found in Peirce 1998, 477.

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