Signs, Models, and Interpretation - Modern Aspects of Semiotics in Biology

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Abstract

In the beginning, a short survey of general semiotics is given in modern terminology. The broad spectra of signs and of descriptive semiotics are reviewed with special emphasis on biological applications. It is shown that a tool for description and analysis in modern mathematical biology must offer a chance to handle structures and patterns in an adequate and comfortable manner; hence fundamental „pattern-related operations" are characterized. A discussion of the role of information in biology leads to the concept of pragmatic information, which is also studied in its relations with other perspective notions, like meaning, interpretation, and complexity. Finally, arguments are given for the position that biology cannot be completely grounded upon or reduced to physics; at the same time, cues for a future research are presented which may lead to a unified description of biological and other processes.

Keywords: Semiotics, theoretical biology, biological information, pragmatic information, meaning and interpretation

1 The Theory of Signs from Pierce to Morris

Starting mainly from some specific parts in the extensive work of Charles S. Pierce (1839 - 1924), the American philosopher Charles William Morris (1901 -1979) was the first to formulate *semiotics*, the theory of signs, as an explicit and elaborated concept (Morris 1938). In modern terms, semiotics can be defined as the scientific theory of the *characterization, utilization, and efficiency of signs*. The broad spectra both of „signs" and of semiotic subdisciplines will be outlined in the next section.

Morris gave the following subdivision, which has become influential since the early days of analytical philosophy. Semiotics consists of

- *syntactics:* the theory of the relations between the signs,
- *semantics*: the theory of the relations between the signs and the objects symbolized by them (designata),

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- *pragmatics*: the theory of the relations between the signs and their users.

Furthermore, Morris made a distinction between *general* (or *pure*) semiotics as a neutral and fundamental theory, and *descriptive* semiotics - the latter term denotes the utilization of the theory to „concrete instances of signs", or, in other words, to a specific field of applications.

2 The Diversity of Signs and Sign Functions

2.1 Various Kinds of Signs and the Spectrum of Descriptive Semiotics

In semiotics the term „sign" is used in a by far more extensive way than in everyday language. Following Peirce, a sign is „standing for something to someone in some respect". Not only characters of a scripture, traffic signs, and pictograms are included; rather, the complete spectrum of visual, acoustical, and olfactory signs is comprehended, as well as any kind of non-verbal communication and concrete units of information transmitted by texts, drawings, photographs, films, tape or video recordings, or the specific shape of a work of art or architecture. Signs may have an extension in time, as exemplified by speeches, or by scenes of a stage-play or a motion picture. Umberto Eco even admits formalized languages, unknown alphabets, and cryptographic codes (Eco, 1968; Eschbach and Rader, 1976).

Accordingly, descriptive semiotics covers a great variety of fields like linguistic semiotics, medical semiotics, architectural, musical, theatre and film semiotics (Eschbach and Rader, 1976), and, of particular interest here, zoosemiotics, the study of signs in the communication between animals (Sebeok, 1972), and phytosemiotics as its counterpart related to plants (Krampen, 1981).

Signs can represent something else as a *symbol*, or act upon a receiver of information as a *signal*, or serve as a *symptom* when conclusions about the interior of a system are derived from some external features.

2.2 Signs in Biology

The complexity of biological systems can be understood only if it is interpreted as being completely controlled by informational processes (Küppers, 1996). Küppers even maintains that the diversity of the biosphere can be reduced to a universal concept of information, which has its foundation on the molecular level (Küppers, 1990). Since informational processes are always processes of generation, transfer, and interpretation of signs, too, the informational processes in biology can also be studied in terms of semiotics.

As mentioned before, the exchange of signs between animals forms the topic of zoosemiotics. As far as a single organism is considered, we find plenty of processes that can be adequately described as processes of sign generation and sign recognition; such processes can take place on a molecular, cellular, or neural level. Recognition of self and non-self (self/non-self discrimination) plays a role in immunology and transplantation. Processes of ordering and organization (with special emphasis on self-organization) require an underlying sign recognition; morphogenesis and cell differentiation are primarily processes of pattern generation, which can be placed in the context of sign generation (see Section 3.1).

2.3 Image Models, a Special Kind of Signs

Image models are generated when a section of our world is mapped onto or represented by an image.[1)] Such models can take on a concrete shape, like a sculpture or a wind-tunnel model, or an abstract, symbolic shape, like texts, diagrams, formulas, digital files, computer programs, or systems of equations. The act of mapping can use an analog technique, as in photography or video recording, or proceed to a symbolic representation. For practical purposes also models of „imagined realities", like plans, designs, and scenarios, are included.

Image models form „concrete instances of signs", and hence they belong to descriptive semiotics (see Section 2.1). There are some reasons to deal with image models as a special kind of signs separately. It may sound strange, e.g., to call a system of equations and inequalities a „sign". Furthermore, some discourses can be formulated more conveniently and concisely in terms of image models, and concepts already developed within the theory of image models (Stachowiak, 1973) can be adopted more easily.

3 Which Kind of Information Concept is Required in Biology?

3.1 The Necessity to Cope with Structures and Patterns

When real or potential models of biological systems are to be analysed, no matter whether these are ecosystems, populations, organisms, or parts or functions of an organism, then the crucial question relates to the predominant descriptive tool underlying the models. It was exactly in this context that Robert Rosen (1993) summarized his criticism in the headline „Good mathematics, bad models".

In the late 1920s, a pioneer of mathematical biology, Nicholas Rashevsky, set up mathematical models of specific biological processes, such as nerve excitation, cytokinesis, cardiovascular dynamics, central nervous functions, and many others. This

[1] Image models are distinguished from interpretation models. The latter occur in mathematics and formal logic, and are generated by assigning concrete instances to the terms in a formal system (e.g. Rubik's cube is a model for noncommutative groups).

was done with the mathematics of that time, and nowadays his techniques of modelling have been generally accepted (Rosen, 1984).

Later on, however, Rashevsky himself was more and more worried by doubts about the reach of his models, and looked for „a successful mathematical theory which would treat the integrated activities of the organism as a whole“ (Rosen, 1984, p. 423). His endeavours led to what he called *relational biology*, as distinct from quantitative or metric biology. What really counts is no longer one or another variable, accessible to physical measurement, like blood pressure or electric potential at a certain spot, but the overall structure, which can be expressed, e.g., by a set of organs and the set of all relations between the organs (see e.g. Rashevsky, 1967).

In modern terms, the necessary properties of a tool for description and analysis can be epitomized as follows: such a tool must offer a chance to handle *structures and patterns* in an adequate and comfortable manner. The term „pattern“ can be considered quasi-synonymous to „structure“, or it can be understood as a collection of traits, events, or other observable features that are sufficient to characterize a configuration and to distinguish it from other configurations (also temporal patterns, like bird songs, are included). Molecular biology, developmental biology, and other fields require *fundamental pattern-related operations*: pattern generation, pattern transfer, pattern recognition, pattern interpretation, and pattern application (Gernert, 1994). Intrinsic complications with the very concept of pattern and with some of these fundamental operations, altogether entangled with context-dependence and interpreatation, will be discussed in later sections.

3.2 Context-Dependence of any Biological Information

„DNA acts as a biologically informational molecule when surrounded by a host of other biological molecules at 37°C, but not at 370°C nor at 37°C and surrounded by chloroform.“ (Rohlfing, 1984, p. 33) A hormone acts on part of the organs, and pheromones or acoustic signals only influence animals of the right species.

Any biological information is context-dependent (Küppers, 1996); the information contents of a message is determined not only by the message itself, but also by the momentary state of the receiving system and by a lot of side conditions.

3.3 Information as an Impact upon a Receiver: the Concept of Pragmatic Information

Information begins when the channel has ended; information exists as soon as the structure and/or the behaviour of a receiving system has been altered.

Already in the early origins of information theory it was realized that a high „information contents“ can be ascribed to a sequence of signals, when it is valuated according to classical information theory, even if that sequence consists of randomly chosen, totally scrambled signs without any meaning to any interpretant. In modern terms, we are used to express this dilemma by distinguishing *syntactic information* and *pragmatic information*. Hence, soon after the publication of the classical information theory, various endeavours were started to develop this theory in different directions, particularly to account for the semantic and pragmatic aspects of information.

Nevertheless, there were exaggerations and false expectations tied with the classical information theory, together with inevitable disappointment. In 1956, Shannon himself felt urged to publish a leading article in a renowned journal, arguing against an over-estimation of his own theory (Shannon, 1956).

Evidently, „information" can exist only if a sequence of signals also has a *meaning*. This meaning carried by signals gave rise to the concept of semantic information. At a closer look, we will find that a meaning can be defined only by reference to a - present or future - „interpretant", that is, in the general case, a receiving system which interprets the signals. For *instance, the Latin letter* „P" will be interpreted as the letter „R" by all who only know the Cyrillic scripture.

With respect to hormones, pheromones, or zoosemiotics the „interpretants" can be identified. In these cases, and generally in all cases in which a certain category of receivers has been fixed (at least for a certain discourse), it is no more necessary to address a class of receivers explicitly; therefore, the concept of semantic information is included in the concept of pragmatic information as a special case. Many modern publications which use the term „semantic information" are in full harmony with the concept of pragmatic information; minor differences in terminology are unimportant here.

Since the 1960s, the concept of *pragmatic information* has evolved as a continuous research programme (see Gernert, 1996). From the very beginning, pragmatic information has been characterized by „the property to change the receiving system" (Kornwachs and von Lucadou, 1982), or, more formally, by the *property to alter structure and or behaviour of the receiving system*.

Also very soon it was considered essential to develop a formal theory and to enable a measurement of pragmatic information. The mathematics applicable here is beyond the scope of this paper; but some principal aspects must be discussed, which are decisive for the present topic.

Two constituents of pragmatic information are termed *novelty* and *confirmation*. A message only repeating well-known stuff contains no novelty and hence no pragmatic information (here again, a comparison with syntactic information is worthwile). On the other hand, a message in an unknown foreign language can bring about no impact upon a receiver - it carries no „confirmation", that is no relation to the receiver's state of knowledge, predisposition, or information requirement. Pragmatic information requires both novelty and a concrete relation to the receiver's predisposition; the amount of pragmatic information will rise as novelty and/or confirmation increase.

The mathematical procedure for a measurement of pragmatic information follows this line:

- In order to measure the *novelty* of a message M we must quantify the *similarity* between M and the receiver's prior knowledge.
- In order to measure the *confirmation* contained in a message M we must quantify the *similarity* between M and the receiver's predisposition.

The mathematical details must be skipped here, but the following facts of general interest should be noted. First of all, the *similarity between two complex structures* must be quantified, and this is possible indeed (Gernert, 1996, with further references). The mathematical procedure includes an intrinsic ambiguity: given a certain set of complex structures for which a measure of similarity must be found, this measure is not uniquely defined - rather, the human author must contribute a specific mathematical object. This ambiguity mirrors the fundamental principle that „similarity" is a *perspective notion*: similarity can be defined only with respect to a context, which includes the situation, the underlying question, and the purpose pursued with the individual mathematical analysis. There are very important relationships to other perspective notions (see Section 4.1).

The concept of pragmatic information is neither a competitor nor a substitute to classical information theory. Rather, the classical theory is contained in the more comprehensive modern concept as a *special case*. Classical information theory is obtained as the special case in which the valuation is that of telecommunication engineers. Syntactic information is the alteration produced by incoming signals in the heads of telecommunication engineers who are waiting at the end of the channel and valuate the finished transmission under the aspects of their profession, e.g. channel capacity, efficiency, or reliability.

Since any information is pragmatic information, the adjective „pragmatic" is tautological, strictly speaking. But it seems to be indispensable as long as the concept of pragmatic information is not yet generally accepted. Indeed, some scholars, drowsy with classical information theory and its extensions and ramifications, and ignoring Shannon's famous warning, seem to have a problem here, hesitating and shrinking back as if they were facing a paradigm change. Probably a main obstacle to reception lies in the fact that in the modern concept there is no longer one formula, nor a small bundle of formulas, into which some problem parameters could be simply inserted; but this is inevitable since in non-trivial cases the context-dependence must be accounted for.

In biology situations can occur in which the decisive point is the transfer of information; then, consequently, classical information theory is relevant and sufficient.

But in the general case, information must be regarded as an impact upon the receiving system, together with its context-dependence and related issues to be discussed next.

4. Meaning and Interpretation as Keywords for Future Research

4.1 Meaning and Interpretation in the Context of Other Central Notions

The statement that information is defined by an impact upon a receiving system can be expressed in a mirror-symmetric form: information is generated when a system finds out the *meaning* of an incoming message or, equivalently, when it is able to perform an *interpretation* of that message. Both „meaning" and „interpretation" are *perspective notions*, and hence they are in a line with two other perspective notions treated above: „information" and „similarity". Overall we find four central notions (or pairs of notions), which are perspective notions altogether; their mutual relations can be illustrated as in Figure 1.

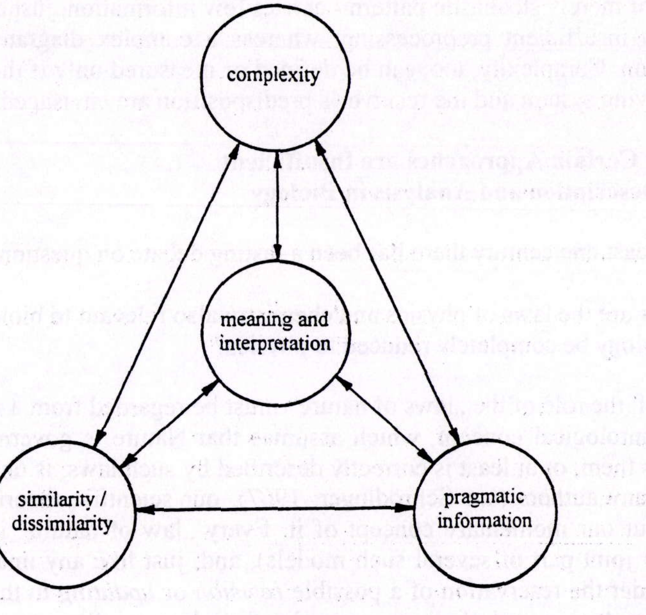

Figure 1: Some central perspective notions and the relationships between them, as discussed in the text

It may be unusual to speak about „meaning" and „interpretation" in the context of any kind of receiving system; but such an embarassement would only be due to a cultural tradition. The use of these terms aims at a unified description (not at tacit assumptions about consciousness); positive arguments in favour of these terms will be advanced in Section 4.3.

The notion of similarity (or dissimilarity) becomes indispensable as a technical tool when a strict definition - or even a measurement procedure - for one of the three other entries of Figure1 is requested. Although the details must be omitted here, it must be emphasized that the definition of similarity itself mirrors the character of the *perspective* notions to be formalized; indeed, it is possible - but also inevitable - to account for the context within the process of formalization (see Gernert, 1996). The dissimilarity of two structures increases as their similarity diminishes, and vice versa (the mathematical transformation is trivial). In some cases it is more practical or illustrative to speak about dissimilarity - this term is equivalent to *distance* or *metric*, two terms more familiar in some fields.

Also the *complexity* of a structure or pattern is coupled with its meaning or information contents. „Complexity" is a perspective notion, too: what seems to be clear or trivial to an expert may appear very complex to less informed people. A dull pattern - e.g. a periodic or merely stochastic pattern - carries few information, just as a chaotic mass of data with insufficient preprocessing, whereas a complex diagram may contain rich information. Complexity, too, can be defined or measured only if the meaning of a sign to a receiving system and the receiver's predisposition are envisaged.

4.2 Why Certain Approaches are Insufficient for Description and Analysis in Biology

Since at least one century there has been a lasting debate on questions like:

- How far are the laws of physics and chemistry also relevant to biology?
- Can biology be completely reduced to physics?

First of all, the role of the „laws of nature" must be regarded from a modern stance. The realistic-ontological concept, which assumes that Nature is governed by certain laws and obeys them, or at least is correctly described by such laws, is untenable. As pointed out by many authors (see Schrödinger, 1967), our scientific theories do not describe Nature, but our momentary concept of it. Every „law of nature" is part of an image model (or joint part of several such models), and, just like any image model, must be placed under the reservation of a possible *revision* or *updating* in the light of advanced knowledge. And indeed, there are examples from history of science showing that a law of nature had to be dropped or significantly modified.

Another important insight from the theory of image models states that such models can never be considered „true" or „false", but only more or less appropriate for a given situation. Here is the context-dependence again - a model broadly accepted formerly may turn out to be insufficient for a new, more sophisticated problem.

The idea of reducing biology to physics can be questioned by historical and philosophical arguments. Other fields of science, like psychology and economics, to some extent took physics as a standard for their own internal structure and their world-view, and in this way they were given a wrong drive and cramped by unjustified restrictions. Why should such a risk not exist for biology? Already in 1874, the French philosopher Émile Boutroux showed that in every transition from a less complex realm of reality to the next, more complex one - from physics to chemistry, from there to biology, etc. - principally new phenomena will emerge, which are „contingent“ (in modern terms: emergent) with respect to the preceding lower level; hence the higher level can never be theoretically founded upon the lower level.

The relations between physics and biology can also be discussed by scrutinizing some fundamental assumptions and modelling techniques of physics itself. To a large extent, physics is based upon *variables* (or *observables*) as a central descriptive tool (exceptions and modern trends are discussed later). Measurement assigns numerical values to variables, and the relations between variables are described by equations. Variables can be defined by a measurement prescription, but, vice versa, the variables already known and accepted may determine the physicists' new experiments. Even if variables come in bundles (vectors, matrices, etc.), they are a poor substitute where a description by patterns and pattern operations would fit by far better.

Another basic assumption is that all boundary conditions (Matsuno, 1993) are *known* and *invariable*. In physical experiments the known boundary conditions are kept constant by the experimental setting (constant temperature or pressure, shielding of perturbations like radiation or vibrations, etc.); all this is no more realistic outside the laboratory. Also in theory assumptions about boundary conditions must be made.

Quite differently, living organisms modify and alter their boundary conditions, as shown by ant-heaps, fox-earths, beaver-dams, or migrations to another biotope. A similar statement holds for single organs: in order to support their functioning, temperature, blood pressure, chemical concentrations, etc. can be adapted. In biological evolution, finally, new species emerge, and hence the boundary conditions for older species are changed.

The rise of a new species is best suited to demonstrate the necessity of patterns and pattern operations as a descriptive tool: the „object of discourse“ itself changes, and the transition to a new species can never be described in a practicable manner by assigning different numerical values to a huge lot of variables; the same holds for ontogenesis. Pattern transformations can be formalized, but this is beyond the scope of this paper (Gernert, 1997). Physical models based on variables and equations between them are valid in biology if they supply „local descriptions“: e.g. for the flow in a vessel, the current in a nerve, or the diffusion through a cell membrane. It remains dubious whether this can be extended without trouble to the study of interactions between a small number of heterogeneous organs. The dilemma of an adequate modelling tool is highlighted by the discontinuous transition which Rashevsky made from his earlier to his later work (see Section 3.1).

As it was remarked before, modern physics does not exclusively work with variables and equations between them. There is a variety of analytical and descriptive tools, from Feynman diagrams to group theory and further, less known branches of algebra. Research on pattern formation or structure formation is done from different starting points, e.g. under the aspects of chaotic dynamical systems, cellular automata, or neural networks[2)]. It seems that modern physics from time to time steps into the realm of structures just like an explorer sets his feet on unexplored territory. In a similar manner as modern concepts of information, meaning, and interpretation (see the next Section), also patterns and structures have not yet obtained full civil rights. In any case, the work in progress deserves fair and open-minded attention, and useful applications to biology can be expected.

4.3 Interpretation as a Key for a Unified Description of Biological and Other Processes

Every living organism must separate the *meaningful* from the floods of stimuli arriving through the sense organs; any sign, be it from outside or from an internal source, triggers an act of *interpretation*. Both terms, *meaning* and *interpretation*, turn out to be important in physics, too. The arriving of a rolling billard-ball has a meaning for another, hitherto motionless ball, and the latter can perform an interpretation by starting in a certain direction and at the right speed.

In this sense, the term „interpretation" forms a link between different fields of science and disparate views, and opens a pathway towards a unified description. Interaction in physics can be described in terms of interpretation, too, but not all processes describable as acts of interpretation can be expressed in terms of variables and equations.

Of course, interpretation is not meant as a substitute for a treatment by equations with its quantitative results - but both stances are compatible. Already some years ago, physicists spoke about „emergence of meaning" and „self-creation of meaning" (Amit, 1987; Haken, 1988), mainly in the context of self-organization, where apparently this aspect cannot be circumvented. Wheeler (1984/1989) even coined the term *„meaning physics"*, which he distinguished from earlier physics that could do without this notion.

It is impossible here to report about the existing constructive applications to physics (see Gernert, 1994), but a rather frequent argument should be discussed. Sometimes, there is a sentiment of uneasiness about the use of terms like „meaning", which is

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² See the proceedings volumes edited by Atmanspacher et al. (1991) and by Güttinger et al. (1987).

evidently due to effects from the sociology and history of science, particularly to a traditional borderline between „natural sciences“ and „hermeneutical sciences“. As a consequence it is argued that the terms in question are unnecessary, and that everything

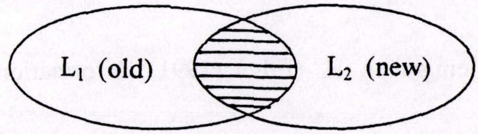

Figure 2: Domains of two languages L_1 and L_2 with their overlap

can be expressed in an older, more customary language, e.g. in the language of quantum mechanics. The main point can be illustrated by Figure 2. The reach of an older language L_1 and a more recent language L_2 partially overlap; hence the statements in the overlap region „can also be expressed in L_1“. But this argument ignores that the new language possibly opens a pathway to a novel territory of knowledge: there may be statements expressible in L_2, but not in L_1 - the history of science has always been a history of language extensions, too.

5 Concluding Remarks and Outlook

It can be taken from this discussion that semiotics as a fundamental tool, and particularly such central notions as signs, meaning, and interpretation, offer a quite specific support in the analysis of problems underlying biology. Finally, an uncostumary answer shall be tried to a question partly handled above: Can biology be founded on physics - or rather the other way around? (Matsuno, 1993)

„Complexity“ as a perspective notion (Section 4.1) can take on different contents in the course of time. At Boutroux's time it was possible to define a linear order between several scientific disciplines, such that one of them could be called more complex than the preceding one. Hence it made sense to ask whether the „more complex“ field of science could be founded on the „less complex“. But now, physics is moving farther and farther away from human intuition, whilst biologists still will have to do with concrete cells, organisms, or ecosystems. In the long run, the question whether physics or biololgy is „the more complex one“ may become „incongruent“. A possible answer can be that biology and physics will become independent, but co-operating disciplines.

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