

The Chicken and the Orphean Egg: On the Function of Meaning and the Meaning of Function

Claus Emmeche
Center for the Philosophy of Nature and Science Studies
Niels Bohr Institute
Blegdamsvej 17, DK-2100 Copenhagen, Denmark
E-mail: emmeche@nbi.dk

This article has been published and appears in *Sign Systems Studies* 30 (1): 15-32, 2002

©This paper is not for reproduction without permission of the author

ABSTRACT

A central aspect of the relation between biosemiotics and biology is investigated by asking: Is a biological concept of function intrinsically related to a biosemiotic concept of sign action, and vice versa? A biological notion of function (as some process or part that serves some purpose in the context of maintenance and reproduction of the whole organism) is discussed in the light of the attempt to provide an understanding of life processes as being of a semiotic nature, i.e., constituted by sign actions. Does signification and communication in biology (e.g., intracellular communication) always presuppose an organism with distinct semiotic or quasi-semiotic functions? And, symmetrically, is it the case that functional relations are simply not conceivable without living sign action? The present note is just an introduction to a project aiming at elucidating the relations between biofunction and biosemiosis.

Biology has celebrated some major triumphs in the period beginning with Darwin's publication of *Origin of Species* in 1859 all the way up to 2001, when newspaper headlines proclaimed that the human genome had now been charted. Now that biology has shown us what life is (from a scientific standpoint), what shall we do with biosemiotics?

The biosemiotic project involves looking from a completely different angle at natural biological processes of which, to be sure, we have already gained knowledge through the traditional science of biology and the research fields it includes (molecular biology, cellular biology, ethology, ecology, neo-Darwinian evolutionary theory, etc.). From these disciplines, we have now gained an enormous amount of knowledge of living organ-

isms. At the same time, however, there are gaping holes in this knowledge. It has a dual nature, i.e. on the one hand it comprises a large body of positive facts and theoretical generalizations, even coherent and well-confirmed theories (such as cellular theory and evolutionary theory), but on the other hand it takes the form of *non-knowledge*. The latter applies, in particular, to the knowledge we have gained of humans as a species by mapping the human genome. This non-knowledge exists at least at two levels.

First of all, there is non-knowledge in the form of holes or white blots on the previously existing theoretical map of biological fields that may be filled in, possibly in the near future. The hope is that more research funds and research hours will be able to fill these holes. For example, now that we have the complete human genome we would also like to map out the complete chimpanzee genome, since the chimpanzee is our nearest biological relative and we hope to gain a better understanding of that kinship. All we need to do is begin the task of DNA sequencing a chimpanzee—a major undertaking to be sure—but one that is fully feasible. In this way, we can continue doing the same with other species. Even today, we have detailed genetic maps of biologist's favourite model organisms (the fruit fly, a nematode worm, the coli bacteria, the yeast cell, and even, in part, the mouse).

Secondly, our biological non-knowledge exists at a level on which we are approaching the limits of what we can expect to know if we simply use existing methods without making theoretical fractures in the established paradigm, i.e. if we simply continue placing more small pieces into the existing puzzle. With regard to certain questions, if non-knowledge at this level were transformed into knowledge, we would probably need to look at them through different theoretical glasses or use a different paradigm, in the precise sense Thomas Kuhn uses this word. Here, a paradigm is not just another theory that may assign a slightly different meaning to the concepts that were previously used, but almost another world, at least for the researcher, i.e., a different set of theoretical tasks, some different values used to determine what constitutes good questions and even for which things a person, as a scientist, can research in the first place. It is on this latter level, in particular, that biosemiotics tackles the problem, using the following fundamental assertion: The traditional paradigm in biology which encompasses a number of experimental methods, normal scientific working procedures, neo-Darwinism and its mathematical population models, etc. alone is not and cannot be sufficient to answer the following key question: *How did meaning originate in biological systems? And what is it (if not meaning, i.e. the creation of signs, and semiotic processes in general) that makes biology something special, something that on certain points fundamentally differs from the types of systems studied, for example, by physicists and chemists?*

1 MEANING AND INFORMATION

Here we shall undertake a thorough examination of the idea of the biological creation of meaning as something central to all living things by taking a closer look at the way in which people normally answer the riddle of what it is about organisms that is special, i.e., we will look at the answer provided by 'mainstream' biologists or conventional anti-reductionist biologists such as Ernst Mayr (who did not like to see his field, evolutionary biology, reduced to chemistry as ap-

plied to biology) and compare it to the answer given by leading biosemioticians, in the tradition from Jakob and Thure von Uexkull and Thomas A. Sebeok up to biosemioticians such as Jesper Hoffmeyer and Kalevi Kull. Let us reveal right away that traditional biological understanding mentions two crucial characteristics of living systems that make them radically different and irreducible to physics and chemistry:

- (1) biosystems (organisms) contain genetic information;
- (2) biosystems (organisms) have functions.

The former, of course, is a cryptosemiotic concept, for even here biologists admit indirectly that it is necessary to use semiotic concepts to describe biological systems. It is just that biologists do not attribute any particular significance to this: after all, they typically say, ‘genetic information’ is just a metaphor for certain molecular processes that are organized in a certain way. Here the biosemiotician steps in and interprets the occurrence of such metaphors more realistically, namely as a sign that when one apparently cannot understand a key biological process without having to use informational metaphors, such as the hereditary transfer of traits between generations,, it is probably because the processes themselves—for which the metaphors are meaningfully used—actually have the nature of semiotic processes: sign production, sign transfer, and sign interpretation.

As we know, the second point—that organisms have functions—is particularly well known in biology. No biologist can get by without directly or indirectly referring to the (functional) role some part or another of the organism plays in the whole organism. On the other hand, many philosophers and some theoretical biologists, such as John Maynard Smith, have speculated that this all-pervasive interest in functions is what makes biology different from the science that deals with inorganic nature, such as those branches of basic physics that only study physical processes.

But do we not run into the concept of function here, too, one might ask? Certainly it is not complete nonsense to ask what function solar wind has for the earth’s atmosphere? The standard response here is that the question is understandable, to be sure, in so far as it can be reworded into a question of the causal role a phenomenon such as solar wind can conceivably have on earth’s atmosphere as a physical system, but to the extent that it can be answered as such—purely physically causal—there are nonetheless some significant differences between the limited role the concept of function can play in a subject such as geophysics or astrophysics and the key role it plays in biology. Of course, the difference is so great it is really just a matter of using the same term for two different concepts. In physics the assertion or question of function (such as the one

mentioned above) can be rewritten without loss of meaning to the purely causal question of direct cause-and-effect contexts in the traditional classical mechanical sense, in which a cause precedes an effect in time, but both cause and effect exist on the same ontological level, i.e., they are of the same nature, as in the example of the relationship between the sun and the earth's climate. This is a matter of material physical processes on the macroscale. As shown by the past 30 years of discussions on the concept of function in the philosophy of biology it is far more complex to state the connection between causality and functionality in biology.

Essentially, the reason for this difficulty is that in biological systems there is an inner connection between the informational (which, without hesitation, we will call here the semiotic aspect of a living system) and the functional aspect. This is a connection that has been largely overlooked in the past and we will examine it in greater detail now.

Traditional biologists know quite well, implicitly at least, that there is a connection between the functional and the informational aspect: No organism exists that does not consist of a *whole* of its *parts*, whereby the parts enter into *functional* relations with one another and with the whole. Even in the simplest conceivable organism, such as a simple, free-living cell, this is dependent on the cell's organizing its parts, not exclusively but in part with the help of a genetic memory (a semiotic code), which makes sure the (functionally) 'correct' parts are produced in the cell's autocatalytic network of processes. In this case, it is primarily protein synthesis, whereby without the genetic memory a mere jumble of 'dysfunctional' proteins that are useless to the cell would be produced.

As we know, from a chemical standpoint proteins are a rather normal kind of large molecule (polymers characterized by peptide bonds, which combine the individual building blocks, amino acids, into long chains). It is one thing, as a chemist, to use chemical theory and experimentation to identify a molecule as a protein, and not a sugar, a lipid, a nucleic acid, or something else. But it is something quite different, as a biologist, to characterize a particular protein as an enzyme, or a neuropeptide, or a hormone, or a histone (which is a class of proteins involved, among other things, in the packing of chromosomes). If it is found that a protein is a histone or an enzyme, for example, then this is also, in part, a functional description of the protein. It says something about the relationship between part (protein) and whole (the cell as an organism). This is rather banal, as far as it goes, and on the concrete level of molecular biology it is nothing new, but the semiotic and biotheoretical implications of this fact are far-reaching:

As we shall now show, this means that *function* and *sign*, both seen biosemiotically as phenomena that describe living organisms, are directly related to each other, even in the narrow sense, i.e. both ontologically and epistemologically, or in other words: both as (ontological) properties of nature and (epistemologically) as conditions for our knowledge of nature.

2 ENZYME FUNCTION AND CELL AS A SYSTEM OF INTERPRETANCE

Ontologically, sign and function are related like the chicken and the egg: it is a bit absurd to ask which came first, the sign in nature or functions in nature: biosemiotically, both arise simultaneously in the same lengthy historical process, with the creation of the first *organisms*, which of course have cellular structures, here on earth at least. Of course, a stolid biologist could choose to interpret the chicken/egg duality in the light of the biological difference between a single-celled and a multicelled organism. In this case, the question of the chicken and the egg is not quite so absurd: from the phylogenetic perspective, it is namely the egg that ‘came first,’ since we must assume that multicelled organisms (‘individuals’) are a (not uncomplicated) product of a long evolutionary process (cf. Buss 1987). But the evolutionary sequence of single-celled and multicelled organisms is not the point here at all. The point is, 1) that in our basic understanding of what living beings are, we must operate with a *concept of the organism* that presupposes that the organism is *both* a semiotic phenomenon—a system of sign processes—and a functional phenomenon, a whole made of parts, where the parts have functions relative to one another and relative to the maintenance of the whole, and 2) that these two aspects, the mereological and the semiotic, are closely linked.

With regard to the organism, understood not just as a concept, but as a real ontological entity, *the mutual functional relationships of the organism are semiotic*. For now, let us stick to single-celled organisms and look at a part of the cell, such as an enzyme. It has a function of catalyzing a chemical process, let us say, between two other molecules (there can be many other enzymatic functions, such as breaking down molecules into smaller parts, but that is secondary here). Of interest here is not the enzyme as chemistry (for example, its structural formula seen in isolation or its three-dimensional structure seen in isolation), but the circumstance that *when* the enzyme is found in a cell with such and such other molecules, *then* it ‘acts’ in such and such a way, i.e., it reacts with these molecules, thereby acquiring meaning to the cell (in this case: to reduce the activation energy required to establish a bond, for example, between two other molecules that are substrates for the active site on the enzyme, thereby increasing the rate of the proc-

ess). In other words, using the enzyme *cytochrome c* as an example, the function of this enzyme is the same as the cell's 'structural attribution of biological meaning' to the *cytochrome c* molecule.

What does this have to do with meaning, one might ask? After all, it is we who can see that it has meaning (functionality) to the cell. Certainly the cell itself cannot understand that? Correct, but we will avoid the nominalistic temptation of seeing signs only as something that can be of a mental nature (signs in human language or understanding). Although the cell does not realize, perceive, or understand anything, the cell is still a semiotic system in the sense that it is a system of meaning with its own autonomous self-catalysing, self-organising dynamic—a dynamic, as mentioned above, that is so complex as to presuppose genetic memory as a sign system. But the important thing here is not so much the latter digital and relatively stable DNA code found in the cell's nucleus in eukaryotic organisms, as it is the sign processes of a far more general kind: Saying that *cytochrome c* means something to the cell is the same as saying that it has a function. It is not just any molecule. We could very well synthesize small proteins and artificially introduce them into the cell. They would be without importance or they would be dysfunctional or, with certain fortuitous strokes of luck, they would actually fulfil some function in the cell.

To say that *cytochrome c* or any other molecule fulfils a function for the cell as an organism (or for multicellular organisms: an organ, or an organ part that fulfils a function) is the same as saying that the part operates appropriately in the whole (an idea entertained by Kant). It is the whole, with its special emergent structure, that establishes the framework for this appropriateness and even though the basic laws of nature are still in effect ('effective', or 'brute causation'), it is the cell as a complex system that manages or shapes the manner in which the natural laws operate on the individual parts: the whole operates as a constraint, as a limiting condition from the macro level down to the micro level, from the whole to the part.

The protein *cytochrome c* is specific and the biological specificity is precisely the difference *cytochrome c* makes to the cell. After all, if *cytochrome c* had not had precisely this particular form (at least in its active sites), it would not bring about the reaction between the components with which it interacts. It would be dysfunctional (as it can become if the gene for *cytochrome c* mutates, which can be fatal to the cell). *Cytochrome c* mediates precisely this reaction and not all kinds of other ones—therein lies its meaning. This 'meaning,' in the semiotic sense, of the individual enzyme is structural, understood in such a way that the cell's molecules form a system of dissimilarities (like the elements of language in Saussure), but these dissimilarities are

not of a mental or immaterial kind. The material elements of the system have a certain *agency* of their own, or a local semiotic capacity to act, if you will, and consequently the cell's molecular system of signs is self-organizing and self-interpreting, i.e., these signs are characterized better by the Peircean concept of sign as sign action than by the Saussurean concept of sign as an abstract system of differences. To a great extent, the cell is an interpretation system that is controlled by what Peirce called 'final causation,' the type of causation in nature that has to do with organization, habit formation, memory phenomena, information, appropriateness and purposefulness, evolution—all phenomena of the category of Thirdness (Santaella Braga 1999).

But epistemologically, too, there are close mutual conceptual conditional relations between sign and function, at least within the framework of a Peirce-inspired biosemiotics. The assertion here is that it is simply impossible to understand the concept of sign, without a concept of function (of some kind or another). And, as just indicated, the inverse is also true: it is not possible to understand the concept of function in biology in general without a good understanding of what an organism is and such an understanding presupposes a concept of information, whether it be in the slightly superficial molecular biology version as (DNA-) sequence information or in a more thoroughly thought-out Peircean version, where information *is* sign. As Bateson (1972) said, 'information is a difference that makes a difference' ('to an organism' implied) and this is 'straight Peirce,' even though Peirce probably would have stated it in a more complex, but more precise, form such as 'sign (representamen) is a difference that makes a difference (interpretant) by making the latter stand in relation to something else, namely that to which the sign refers (object).'

We might add: 'Function is the difference that the presence of a part of the organism makes with respect to other parts and to the whole.'

3 INTRINSIC SEMIOTICS OF CELL RELATIONSHIPS

The part refers to the whole and can be understood (functionally) only within this whole. That is an old mereological insight. When we recognize *cytochrome c* as a part of the organism, we are not just interested in a recognition of this protein as a part, similar to the recognition that a stone is part of a gravel heap or that $1/7$ is a part of the rational numbers. It is not the abstract part-whole relationship in itself or a physical version of such a relationship that is crucial here. The crux of the matter here is that the relationship between the parts of an organism and the whole organism is a mereological relationship of a particular specific nature: it is also an 'intrinsic semiotic relationship,' that is, it is in its very nature semiotic. And, it should be noted, its semiotic character is not merely something attributed to it, just as our consciousness is not just due

to the fact that other people attribute consciousness to me, but I am actually conscious and it is part of the concept's *sine qua non* that being conscious is not derived from anything else. Apart from this formal similarity, the intrinsic semiotics of the cell has nothing to do with consciousness in the human sense.

We now realize that there must be an internal relationship between sign and function, that is to say when the two concepts are used in conjunction with organisms and with what are essential features of organisms. We have also more than hinted at what is meant by internal relationship, but let us express it a bit more formally. In the philosophical usage of the term, if something, let us call it *S*, is *internally related* to something else, let us say *F*, then there is an essential property (a *sine qua non*) of *S* whereby *S* is actually linked to *F* by this relationship, symbolized here by *-R-*. Thus, *S* simply would not be *S*, if it were not related to *F* in this manner, i.e. if *S-R-F* were not valid. Specifically, it would mean that a sign would not be a sign (in the biosemiotic sense) if it were not a sign with a function, which normally means 'with a function for the organism.' The traditional biologist could accept this part of the argument, since it is hardly surprising that a process involving information, signals, or signs in an organism must serve the best interests of the organism, i.e. it must be functional for the organism.

At the same time, however, we would maintain that the relationship is symmetrical, i.e. if *S-R-F* is valid then so is *F-R-S*, or in plain language, if sign is internally related to function, then function is also internally related to sign. A thing would simply not be a function (for the organism) if it did not have the nature of a sign. Stated in this way, the assertion does not appear to be immediately obvious to the traditional biological viewpoint, since it is easy to imagine certain functional parts of an organism, without their obviously being signs and, as mentioned, biologists do not normally use semiotics as a conceptual tool. What does it mean, for example, to say that the liver of a vertebrate animal is a sign?—'Of what?' one might sceptically ask. And what have we gained by such an assertion?

Or, with an example from the single-celled level: the Golgi apparatus in eukaryotic cells, as seen under the electron microscope, looks like a stack of flat bladders (membranes) stacked one on top of the other. There are still some dark sides regarding the function of this structure, but a picture has developed of a membrane structure that is linked to the rest of the cell's transport system, a kind of halfway house between the endoplasmic reticulum, where proteins are synthesized, and the secretory vesicles, which (in the periphery of the cytoplasm, at the outer membrane of the cell) take proteins out of the cell by means of exocytosis (membrane fusion). In addition to being part of the transport system, the Golgi apparatus performs a biochemical modifi-

cation of the proteins that are on their way out into the surroundings (for example, ‘ripening’ of glycoproteins by removing certain oligosaccharides and adding others). Thus, the Golgi apparatus clearly has functions for the cell, but why would this make it a sign?

Here, the biosemiotician must either sacrifice the idea of the internal relationship, in its strong, symmetric form, which means that not all biofunctions are or can be interpreted by us as being real signs, or the biosemiotician can hold onto the symmetry; protest that we should not use an all-too narrow concept of sign, and instead interpret the relationship as follows: If a relationship is merely dyadic, or merely comprised of dyadic relationships, as indicated by the notation $F-R-S$ then, to be sure, the relationship need not have the nature of a sign. But if F and S do not stand for just anything, but for function and sign, and if, in conjunction with organisms, function is already a mereologic relationship, then $F-R-S$ will not formally be a dyadic, but rather a triadic quantity: Any biofunction is something (a process or a structure) that has meaning for the organism as an interpretant system (what theoretical biologist Stanley N. Salthe and others call a ‘system of interpretance’) and in this broad meaning of the statement $F-R-S$ any functional process or structure in a cell is ‘biologically meaningful,’ in that it makes a difference to the cell as a whole, as a system, that would be affected immediately (often in a rather fatal direction) if the process were blocked or the structure destroyed. Thus, the Golgi apparatus and everything at all we can understand in a biofunctional sense has the nature of a sign, where ‘sign’ need not be a communicative sign in the normal sense, but may instead be purposeful processes, with the special causal structure these processes have.

But even if biofunctions may be said to have the nature of signs, is it not crazy to claim that the Golgi apparatus is a sign that (according to the classical definition of sign) ‘stands for’ something else? Yes and no. This ‘stands for’ relationship is obviously not symbolic or conventional, but as we know there are also sign process forms other than the symbolic. As mentioned, the Golgi apparatus (if it is to be understood at all biologically and not just described physically and chemically) refers to other structures in the cell and here it is the assertion of biosemiotics that this reference relationship is triadic. The shape of the Golgi apparatus and the processes that occur in it are not of importance to the endoplasmic reticulum and the exocytotic vesicles alone. They are important to the cell as a whole. The mereological relationship is not just formal, but also causal, namely a case of what in some contexts is called ‘downward causation.’ It is the whole that ‘assigns’ meaning to the parts. Just as a protein is an enzyme only when it works within a meaningful whole, the same is true of the Golgi apparatus. Seen in itself, as a ‘pure’ spatial structure, it could just as well have been an accidental pattern in nature or a bizarre sculp-

ture on the nanoscale (nanoart!). But it is the organization of the cell as such that co-defines the boundary conditions under which the Golgi apparatus operates. It is part of the cell's quasi-cognitive scheme of protein synthesis and transport. It may have a diagrammatic character (which must be the subject of a more detailed semiotic analysis at a later time).

Such a biosemiotic understanding of the concept of function can also include cases in which the function is not yet known: The sequences of DNA (genes) that code for proteins or RNA molecules are easily seen as having the nature of signs, but what about the non-coding parts, such as the repetitive sequences (whose function is not known) or other parts of the so-called junk DNA which, as we know, forms the bulk of our genome? In this case, the function is not known and one might believe that the assertion concerning the internal relationship between function and sign applies only to those parts of the organism or cell where the function is known. However, the sequences mentioned above can be seen as instances, sinsigns, of the same type, legisign, i.e. they are sequences of the same pieces of non-coding DNA found in the previous generation. The way in which DNA is copied (template replication) assures the preservation of the sequence information and, thus, a simple sinsign/legisign relationship (just as a cookie cutter as a general type imparts its shape on each individual cookie instance). This is important to the relationship of general interest that organisms are internally related to one another through bonds of kinship. For example, I am related to my parents, since I would not be me if I did not have precisely those parents. A person who was apparently identical to me but had other parents would not really be me.

4 THE ORPHEAN EGG

But does everything in the cell have the nature of a sign? This may seem a bit hard to swallow for traditional thinking but to the extent that we can, first of all, stick to the biosemiotics of living organisms and not discuss the possibilities of sign processes in physical nature 'physi-cosemiosis' and, secondly, identify in organisms the triadic relationships and interpret them as instances of the abstract semiotic relationships and processes, which Peircean semiotics conceptualises, the answer must be 'yes.'

One clever person has said that the chicken is simply the egg's way of creating a new egg and there has been no shortage of sociobiological elucidations of this bit of wisdom. The egg as the active and acting, that which uses something else as a functional tool. Or the egg as the original, as in the elucidation of stolid evolutionary biology we saw earlier. But any child knows that

chickens and eggs belong together, in the same temporally continuing process, whose detailed embryological sign functions molecular biologists are still working to map out.

Life itself arises from the physical, but it cannot be fully explained by the physical from which it has arisen. The ancient Phoenicians, Egyptians, Hindus, Japanese, and others believed the world was egg-shaped and that the world as we know it was hatched from an egg laid by the creator. In some myths, including one attributed to Orpheus, a bird is seen as the one that lays the mundane egg in the primordial sea. If we assume that Orpheus actually existed, then as a poet he certainly refrained from asking whether that bird itself had hatched from some egg. Modern science, too, refrains from asking certain questions. But perhaps we cannot completely let go of the Orphean egg. When it comes to fundamental problems in modern biology and natural science as well as in general semiotics, there are always some things that simply have to be assumed and that refer to one another. Organisms are always pivotal. The Orphean egg is laid by a bird—it makes a splash, and slowly the dust begins to lift a bit.

REFERENCES

- Alberts, Bruce; Dennis Bray; Julian Lewis; Martin Raff; Keith Roberts; James D. Watson. 1994. *Molecular Biology of the Cell*. New York: Garland Publishing.
- Ayala, Francisco J. 1970. Teleological explanations in evolutionary biology. *Philosophy of Science* 37: 1-15. (Reprinted in: Colin Allen; Marc Bekoff; Georg Lauder, eds. 1998. *Nature's Purposes: Analysis of Function and Design in Biology*. pp.29-49. Cambridge: The MIT Press..)
- Bateson, Gregory. 1972. *Steps to an Ecology of Mind*. New York: Ballantine Books.
- Buss, Leo W. 1987. *The Evolution of Individuality*. Princeton: Princeton University Press.
- Chalmers, A. F. 1999. *What is this Thing Called Science*. 3rd ed. Buckingham: Open Univ.Press.
- Christiansen, Peder Voetmann 1988. Introduktion. in Charles S. Peirce, *Mursten og Mortel til en Metafysik. Fem artikler fra tidsskriftet i The Monist, 18 91-93*. (Tekst nr. 169 fra IMFUFA.) Roskilde: Roskilde Universitetscenter, 6-66.
- Collin, Finn. 1990. Videnskabsfilosofi: Enhed og mangfoldighed i videnskaberne. København: Museum Tusulanums Forlag.
- Deely, John. 1990. *Basics of Semiotics*. Bloomington: Indiana University Press.
- Emmeche, Claus. 1997. Den biosemiotiske tanke. in Keld Gall Jørgensen. ed., *Anvendt Semiotik*. pp. 62-94.. København: Gyldendal,
- . 1991. A semiotical reflection on biology, living signs and artificial life. *Biology and Philosophy* 6(3): 325-340.
- . 1990. Det biologiske Informationsbegreb. Århus: Kimære.
- . 1988. Den anden natur og naturens tegn [Second nature and the signs of nature]. in Jens Christensen, ed., *Natur og moral*. (Arbejdsrapporter fra NSU nr. 27.) Aalborg: Nordisk Sommeruniversitet, 67-91.
- Emmeche, Claus and Jesper Hoffmeyer. 1991. From language to nature—the semiotic metaphor in biology. *Semiotica* 84(1/2): 1-42.
- Emmeche, Claus; Simo Køppe; Frederik Stjernfelt. 2000. Levels, emergence, and three versions of downward causation. in Peter Bøgh Andersen; Claus Emmeche; Niels Ole Finnemann; Peder Voetmann Christiansen eds. *Downward Causation: Minds, Bodies and Matter*. Aarhus: Aarhus University Press, 13-34.
- Hoffmeyer, Jesper. 1996. *Signs of Meaning in the Universe*. Bloomington: Indiana University Press.

- Juarrero, Alicia. 1998. Causality as constraint. in Gertrudis Van de Vijver; Stanley N. Salthe; Manuela Delpos, eds. *Evolutionary Systems: Biological and Epistemological Perspectives on Selection and Self-organization*. Dordrecht: Kluwer, 233-242.
- Kull, Kalevi. 1999. Biosemiotics in the twentieth century: A view from biology. *Semiotica* 127(1/4): 385-414.
- Kuppers, Bernd-Olaf. 1992. Understanding complexity. in Ansgar Beckermann; Hans Flohr; Jaegwon Kim eds. *Emergence or Reduction? Essays on the Prospects of Nonreductive Physicalism*. Berlin: Walter de Gruyter, 241-256.
- Kuhn, Thomas S. 1970 [1962]. *The Structure of Scientific Revolutions*. 2nd. ed.. Chicago: The University of Chicago Press.
- Maynard Smith, John. 1999a. The idea of information in biology. *Quarterly Review of Biology* 74(4): 395-400.
- . 1999b. The concept of information in biology. *Philosophy of Science* 67: 177-194 [with commentaries from Kim Sterelny, pp. 195-201, Peter Godfrey-Smith, pp. 202-.207, Sahotra Sarkar pp. 208-213, and a reply from Maynard Smith pp. 214-218].
- . 1986. *The Problems of Biology*. Oxford: Oxford University Press.
- Nöth, Winfried .2000a. Umberto Eco's semiotic threshold. *Sign Systems Studies* 28: 49-61.
- . 2000b. *Handbuch der Semiotik*. (2te Auflage.) Stuttgart: Verlag J. B. Metzler.
- Polanyi, Michael. 1968. Life's irreducible structure. *Science* 160: 1308-1312.
- Salthe, Stanley N. 1998. Naturalizing semiotics. *Semiotica* 120(3/4): 381-394.
- Santaella Braga, Lucia. 1999. A new causality for understanding the living. *Semiotica* 127(1/4): 497-519.
- Schaffner, Kenneth F. 1993: *Discovery and Explanation in Biology and Medicine*. Chicago: University of Chicago Press.
- Stjernfelt, Frederik. 2000. Mereology and semiotics. *Sign Systems Studies* 28: 72-98.
- Wagner, Steven J. 1999. Relation. in Robert Audi, ed. *The Cambridge Dictionary of Philosophy*. pp.788-789. Cambridge: Cambridge University Press.