

Semiotic modelling of biological processes: semiotic systems

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General abstract: Here we introduce biosemiotics as a field of research that develops models of life processes focusing on their informational aspects. Peirce's general concept of semiosis can be used to analyze such processes, and provide a powerful basis for understanding the emergence of meaning in living systems, by contributing to the construction of a theory of biological information. Peirce's theory of sign action is introduced, and the relation between 'information processing' and sign processes is discussed, in fact, a semiotic definition of information is introduced. Three biosemiotic models of informational processes, at the behavioral and molecular levels, are developed, first, a model of genetic information processing in protein synthesis; second, a model of signal transduction in Bcell activation in the immune system; and, finally, a model of symbolic non-human primate communication. We also address some perspectives for the development of applied semiotic research in fields such as Artificial life, cognitive ethology, cognitive robotics, theoretical biology, and education.

The self-corrective behavior exhibited by semiotic systems depends on the capability of using signs of different kinds as media for the communication of forms from objects to interpretants so as to constrain their own behavior.

For James Fetzer, who has defined cognition as semiosis, cognitive systems develop three radically distinct modalities of semiotic behavior, corresponding to the capacity to be causally affected by signs of qualities, events and laws, respectively iconic, indexical and symbolic semiotic systems -- "What makes a system 'semiotic' thus becomes that the behavior of the system is causally affected by the presence of signals because it stands for something else iconically, indexically, or symbolically, for that system" (Fetzer 1997, p.358; also 1988). In this lecture we introduce Fetzer's notion of semiotic system and explore some biological examples of his conception.

Semiotic systems and the most fundamental division of signs

Systems that produce, communicate, receive, compute, and interpret signs of different kinds can be classified as semiotic systems. As Fetzer writes: "What makes a system 'semiotic' thus becomes that the behavior of the system is causally affected by the presence of a sign because that sign stands for something else iconically, indexically, or symbolically, for that system" (Fetzer 1997, p.358). By interpreting signs, semiotic systems can show self-corrective behavior (Ransdell 1977, p.162). Semiosis can be defined as a self-corrective process involving cooperative interaction between its three components. Such a self-corrective behavior depends on the capability of semiotic systems of using signs as media for the communication of forms from objects to interpretants so as to constrain their own behavior.

Peirce suggested that semiotic systems could be treated as the embodiment of semiotic processes (CP 5.314). Surely, this blurs a distinction between entities and processes which characterized Western thinking for most of its history. Peirce was, however, a process thinker, i.e., a representative of a philosophical tendency of treating processes as being more fundamental than entities as ontological categories (Rescher, 1996). A process philosophy can address entities, as Peirce does, as relatively stable bunches of processes. A semiotic system can be understood in these terms as a relatively stable (both spatially and temporally) cluster of semiotic processes.

If we wish to understand how semiotic systems instantiate sign processes, we have to refine our understanding of the types of signs involved in particular semiotic processes. Particularly, we should explore in a more technical way the fundamental differences between iconic, indexical, and symbolic processes, and the Peircean framework is a proper place to pursue such an understanding (Fetzer 1988, 1997).

In his “most fundamental division of signs” (CP 2.275), Peirce characterized icons, indexes, and symbols as matching, respectively, relations of similarity, contiguity, and law between S and O (sign-object relation) in the triad S-O-I.

Iconic semiotic systems

Icons are signs which stand for their objects through similarity or resemblance (CP 2.276), irrespective of any spatio-temporal physical correlation that S may have with an existent O (CP 2.299). If a determinative relation of the sign (S) by the object (O) is a relation of analogy, that is, if S is a sign of O in virtue of a certain quality that S and O share, then S is an icon of O. If S is an icon, then S communicates to I a quality of O:

“An Icon is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not” (CP 2.247).

Among the examples of icons mentioned by Peirce, we find images, diagrams, metaphors, pictures, maps, ideographs, hieroglyphics. In terms of cognitive processes, icons are associated with sensory tasks. They are present in the sensorial recognition of external stimuli of any modality, and in the cognitive relation of analogy. According to Sebeok (1989, p.121), “iconic signs are found throughout the phylogenetic series, in all modalities as circumscribed by the sense organs by which members of a given species are able to inform themselves about their environment. Signal forgery, viz., the phenomenon of mimicry, in fact, all deceptive maneuvering by plants and animals, as well as humans, often crucially depends on iconicity”. Figure 3 shows an example of an iconic sign, a structure in a thorn bug which mimics a real thorn.



Figure 3: Mimicry offers an example of iconicity. In the picture, a thorn bug (Membracid). (Photo from Chip Clark, Smithsonian Institution, Copyright 1993. Reproduced under permission).

Figure 4 shows a semiotic interpretation of this case of mimicry. The interpretant is the effect of the thorn on a potential predator of the bug, namely, that the latter will not try to eat the bug. In this iconic sign process, the form which is communicated from the object to the interpretant through the sign is a general similarity between the thorn in the bug and the thorn in the plant. Generally speaking, an iconic sign communicates a habit embodied in an object to the interpretant, so as to constrain the interpreter's behavior, as a result of a certain quality that the sign and the object share.

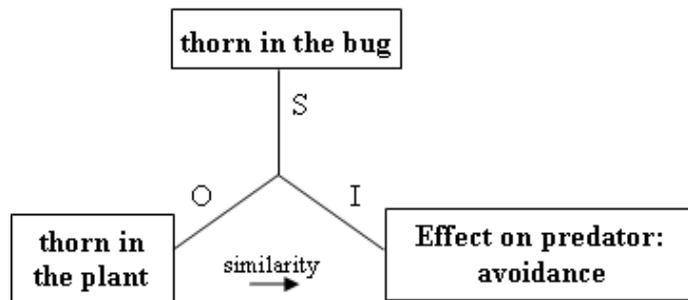


Figure 4: a semiotic interpretation of mimicry in the thorn bug

Indexical semiotic systems

In contrast, if S is a sign of O by reason of “a direct physical connection” between them (CP 1.372), then S is said to be an index of O. In that case, S is really determined by O, and both must exist as events: “An Index is a sign which refers to the Object that it denotes by virtue of being really affected by that Object” (CP 2.248). The notion of spatio-temporal co-variation is the most characteristic property of indexical processes. The examples range from a pronoun demonstrative or relative, which “forces the attention to the

particular object intended without describing it” (CP 1.369), to physical symptoms of diseases, photographs, weathercocks, thermometers.

In a Peircean analysis, small red spots in a child’s skin, for instance, can be treated as a sign (S) which stands for a disease, say, measles, its object (O), so as to constrain its interpretant, the effect the red spots have on an interpreter, say, a doctor performing a diagnosis. The sign processes involved are indexical. The small red spots operate as signs because they are physically correlated with the disease, which is the primary constraining factor in the process, the form of which will end up producing an effect on the interpreter (Figure 5).

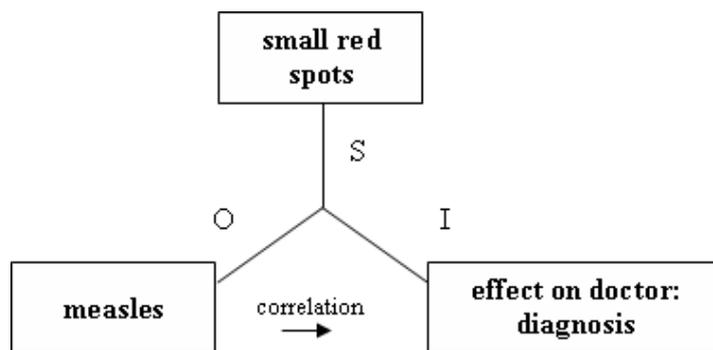


Figure 5: a semiotic interpretation of the diagnosis of measles.

In this indexical sign process, the form which is communicated from the object to the interpretant through the sign is a general physical correlation between measles and the small red spots in the skin. Generally speaking, an indexical sign communicates a habit embodied in an object to the interpretant as a result of a direct physical connection between sign and object.

Symbolic semiotic systems

Finally, in a symbolic relation, the interpretant stands for ‘the object through the sign’ by a determinative relation of law, rule or convention (CP 2.276). According to Peirce (CP 2.307), a symbol is “a Sign (q.v.) which is constituted a sign merely or mainly by the fact that it is used and understood as such, whether the habit is natural or conventional, and without regard to the motives which originally governed its selection.”

We have claimed elsewhere that the alarm-call system used by African vervet monkeys (*Cercopithecus aethiops*), a well-known case of vocal communication in non-human primates, logically satisfies the Peircean definition of symbol (Queiroz 2004, 2003; Queiroz & Ribeiro 2002). These primates possess a sophisticated repertoire of vocal signs used for intra-specific alarm purposes regarding imminent predation on the group (Seyfarth et al., 1980). Field studies have revealed three main kinds of alarm-calls, used to warn about the presence of (a) terrestrial stalking predators such as leopards, (b) aerial raptors such as eagles, and (c) ground predators such as snakes (Figure 6). Adult vervets produce these calls only in reference to the

presence of specific predators. Such calls motivate whole-group escape reactions that are specific to predator type (Figure 6). For instance, when a ‘terrestrial predator’ call is uttered, vervets escape to the top of nearby trees; ‘aerial predator’ calls cause vervets to hide under trees; and ‘ground predator’ calls elicit rearing on the hind paws and careful scrutiny of the surrounding terrain. These are the interpretants of the calls, as signs.

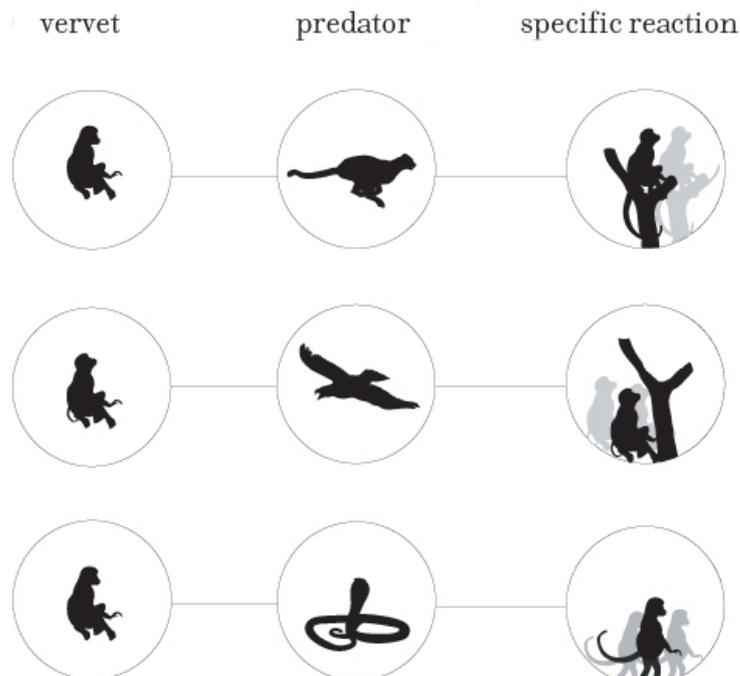


Figure 6: Vervet monkeys’ alarm-calls, their referents, and their effects on the monkeys as interpreters (interpretants).

While adults share a code for predator reference, infant vervet monkeys babble these calls in response to a variety of animals (predators and non-predators), as well as to inanimate objects. Thus, adults pay little attention to infant calls (Cheney and Seyfarth 1990). The progressive specificity of alarm-call production as vervets grow older indicates that they should learn how to use the calls in the proper context. Field experiments in which predator-specific alarm-calls were played from loudspeakers to groups of wild vervet monkeys showed that adult individuals first responded to playbacks of alarm-calls by looking around in search of a referent (predator). Remarkably, even though this referent was always absent, adult animals consistently fled away to nearby refuges according to the specific type of alarm-call played. Infant monkeys, in turn, responded poorly to playbacks, and teenagers displayed intermediate behaviors.

According to the Peircean classification of signs, if the alarm-call operates in a specific way even in the absence of the external referent, it must be interpreted as a symbol of a predator class. The transition from a sensory scan behavior after the alarm auditory perception to an escape reaction motivated solely by the alarm-call corresponds to the transition from indexical semiosis (interpretation by spatio-temporal coincidence) to symbolic semiosis (interpretation mediated by law or convention) (Figure 7). The object of the sign, in the latter case, is not an object-token but rather a class of objects,

i.e., an object-type, and therefore does not need to exist as a singular event. To say that an alarm-call is a symbol of a type of predator is equivalent to say that this call evokes a brain representation (of any modality) that stands for the class of predators represented in a law-like and specific way.

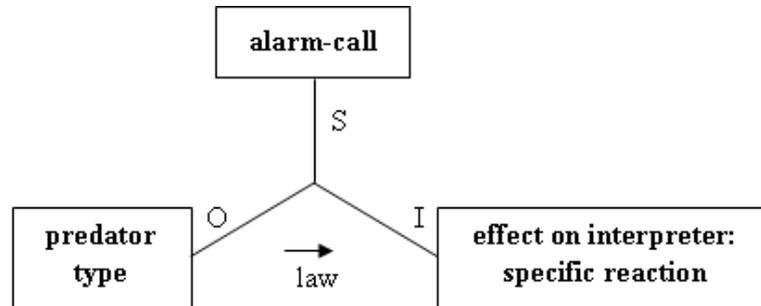


Figure 7: a semiotic interpretation of communication in vervet monkeys.

In this symbolic sign process, the form which is communicated from the object to the interpretant through the sign is a lawful relationship between a given kind of alarm-call and a given type of predator. Generally speaking, a symbolic sign communicates a habit embodied in an object to the interpretant as a result of a regularity in the relationship between sign and object.

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Next lecture (Genetic information system) > In the next lecture we will employ semiotic concepts to propose a semantic and pragmatic account of biological information. In particular, we propose a model of genetic information system as semiosis, grounded in Peirce's theory of signs.

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