Biotranslation

Biotranslation: Translation between *Umwelten*

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The concept of translation is redefined in a way that allows us to apply it to sign processes in non-humans. An approach to biology that makes organisms understandable via translation technology which is able to transmit the life of a sign system, the meaning of a biotext, without destroying it, is an aim for any biologist. Biotranslation, as distinct from eutranslation, occurs as a general process in message transfer between the *Umwelten* of organisms, including both intraspecific and in some cases also interspecific translation. Defining translation as transmission between *Umwelten* generalizes the notion of translation as transmission between languages. Since biological texts differ from human texts particularly at the level of syntactic elements, present to a lesser extent in the former, the concept of prosyntax is introduced for biological situations.

> Dank der Übernahme fremder Motive gestaltet sich der Körper eines jeden Subjektes zu einem Bedeutungsempfänger jener Bedeutungsträger, deren Bildungsmelodien als Motive in seinem Körper Gestalt gewonnen haben.
>
> (J. v. Uexküll 1940: 54)

Conversation with nature has a direct, non-metaphoric meaning, if (a) there exist signs besides the human signs, (b) it is possible to understand these signs, and (c) it is possible to restore these signs. The biosemiotic view that there exist signs, *per se,* in animal communication, or in any other communication among living systems, poses the question about the translatability of these signs, both by humans and by other organisms.

Since *talking with nature* has been so often used in an anti-scientific way, a serious attempt to approach this topic may cause a feeling of fear, as expressed by Umberto Eco (1988: 15). However, we may consider a trivial situation with a man and his cat, and ask whether the man can understand what his cat is staring at when it miaows at the door. If he can (and this is possible), then is this the same as what the cat itself means? Probably not exactly the same. And when the cat sees the man approaching the door, it is seemingly expecting him to open it. This might be quite the same as what the man has in mind, but certainly not his whole thought. Thus, it seems to be quite natural to believe that living organisms of different species are able

to mutually access some signs, without using a word. Accordingly, we may ask directly, whether an animal message can be translated into a human one?[1]. Can a human message be translated into an animal one? And can animals themselves do any translation?

As we have seen from the example above, a cat might be able to construct a denotatum which overlaps to a certain extent with the one of the man, whereas a door (or any other non-living object) evidently cannot do so.

The notions *dead*, *living*, and *self-conscious* (as well as *signifying*) – clearly very obvious and natural characteristics – are not liked by natural scientists when defining terms or building models. Biology, chemistry, and physics, when developing their theories, have been trying more and more to escape these notions, at the same time being led by a wish to explain them. Accordingly, in the history of natural science one can follow a clear trend towards replacing these terms with thermodynamic, molecular, and cybernetic ones, leaving *death*, *life, consciousness* and *signification* more and more with only a metaphoric status. The ring dance with these notions has taken these features from inside to outside of the circle of operational scientific terms.

Indeed, it has been very difficult to define these terms via their mechanisms. On the other hand, these are simple categories. It is not easy to be mistaken when applying them, particularly considering that these are all living, self-conscious and signifying scientists who are using them in creating scientific texts. Thus, if the semiotic paradigm change will take place in biology, these simple categories may be moved back into use as operational terms. Furthermore, much of the terminology of semiotic discourse can be used in life science.

One of the reasons for developing biosemiotics is an attempt to find simpler explanations for complex phenomena with the help and application of a semiotic approach and its concepts. To discover an entrance to the organic sign systems, assumes that we understand how signs are created and translated in nature itself.

Translating, as people do from one language into another, is usually a self-conscious process. Accordingly, most of literary translation theory stands within this framework. If applying the notion to unconscious processes, i.e., considering that there exists an unconscious translation, it becomes reasonable to distinguish between two main types of translation: *protranslation* and *eutranslation*, or we may call them also *biotranslation* and *logotranslation*. There is no translating in the non-living. Eutranslating is conscious translating, as opposed to unconscious translating, the latter still being always a process of the living. Every conscious translation assumes an unconscious component, i.e. every eutranslation assumes biotranslation.

On one hand, eutranslation is a directed activity, which frames the interpretation level and determines the dominant (which may be the original,

the translation, or the readers). On this basis, the translation method is formed as a set of technical procedures. On the other hand, reading and translating the text originates from the feeling of comfort, i.e., one recognises rhythm, proportions, etc. The convenience of reading depends on the activation of senses – the more visual, the more correspondent, both spatially and temporally, is the translation, and the easier it is to read it (cf. Schulte 1980; Caws 1986). For instance, a noticeable oversight of novice translators concerns the usage of tenses, which may destroy the continuity of text. However, among translators there are some who use intuition, who perceive the specifics of the original via the rhythm and intonation without recognising the technical problems (Wilss 1988). Some texts may open sufficiently on such a basis. For linguistic texts, it may even be stated that in the community of discrete and continuous aspects, the latter is more important. Mistakes in words can be replaced, whereas mistakes in perception may require a new translation. "A theory of how sign tokens are exchanged and connected must be supplemented with a notion of how signs together form an interrelated system" (Mertz 1985: 16).

Quite generally, if we take a *living* system which exists within a larger living system, and transfer it into another large living system where it will stay living, then this whole process seems to be very much homologous with translation. Similarly, the transmission of texts from one environment to another reflects the ecology of translation.

Since the difference between eu- and biotranslation comes largely from the difference in the *translator* (i.e., whether the translator is a conscious or unconscious organism), and since a large part of translation theory is quite independent from the notion of *translator*, we do not see any real restriction which may not permit the application of translation concepts to the situations and phenomena of biotranslation.

The quest for translation theory in biology is also connected with the search for an adequate methodology for biology. Since the modern age, nature mastered by technology has become the instrument of science. For living systems, it is very much a destructive technology. An approach to biology that makes organisms understandable via translation technology which is able to transmit (and make understandable) the life of a sign system, the meaning of a biotext, both in its details and in its wholeness, without destroying it, would be an aim for any biologist. The individuality (in the sense of uniqueness) of the original, which a translator can transmit, has always created problems for natural sciences. Thus, *translation can be seen as a method for use in biology*.

Thus, our intention is to analyse the biological examples from the viewpoint of the applicability of the concept of translation. To do this, we need to specify that which we call translation, in terms which might have biological counterparts.

The Concept of Translation, for Biology

Translation, quite generally, means that some signs in one *language* are put into a correspondence with some signs in another language (cf. Barnstone 1994). An additional requirement, but quite hidden and more difficult to define, is that which states that the worlds of the two users of these languages, between whom the translation occurs, should be functionally similar – otherwise the meanings cannot be transmitted. If this is the same person who uses both languages (i.e., when the translator is translating for him/herself), then the situation is trivial. But if these are persons belonging to different cultures and living in very different environments, then this assumption becomes conspicuous.

We assume, following Jakob v. Uexküll (1982), Thomas Sebeok (1989), Jesper Hoffmeyer (1996) and others, that *Umwelten* of organisms are composed of signs. *Umwelt* can be seen as the sphere of the organism's personal language, its own, quite closed, language sphere. Or, more generally, if considering also simple *Umwelten – Umwelt* is the world as it exists in an organism's sign system, i.e., it is the semiotic world of an organism. Or, more specifically, if distinguishing between *langue* and *parole*, then the former is *plan* and the latter is *Umwelt*. It should be admitted that the understanding of *Umwelt* as the acting of the individual sign system does not contradict the understanding of *Umwelt* as a *model* of the world (Sebeok 2001), since any natural and working sign system can be seen as a certain model of the world.

Accordingly, we can generalise our definition and say that translation also means that some signs in one *Umwelt* are put into a correspondence with some signs in another *Umwelt*. In addition, these *Umwelten* have to possess some similar functional cycles.

Let there be two organisms (with their *Umwelten*), *A* and *B*. Let *A* include a sign *a*, and *B* include a sign *b*. Let both these signs have certain behaviourally recognisable representations. That means, *A*, when recognising *a*, represents a behaviour *a'*, and *B*, when recognising *b*, represents a behaviour *b'*.

For it to be possible for translation to occur, there must be a certain connection, or overlapping, between the *Umwelten*. This is usually called a message, or text, that is transmitted and should be made understandable. In our case, for instance, let *a'* be the message to be recognisable in the *Umwelt* of *B*.

If *B* will categorise *b* and *a'* into one, i.e. into the same category, then we can say that *a* is *translated* into *b*. In addition, it is required that *A* and *B* include a similar functional cycle, into which *a* and *b* belong.

For us as observers, this situation can be observable if *a* and *b* have sign vehicles (certain objects) which are distinguishable for us as a_v and b_v. Then, operationally, we can observe this as both a_v and b_v resulting in the behaviour *b'*.

We may consider the following example with a cat, and two birds of different species - *Parus cristatus* and *Parus montanus*. Belonging to different species, they have their own species-specific *Umwelt* and sign systems. Either one of these birds, if it sees the cat coming too near, flies away. We consider now the situation where these two birds are feeding quite close to each other near the corner of a house. When the cat arrives, *P. cristatus* can see it, whereas *P. montanus* is around the corner and cannot see the cat. *P. cristatus* gives an alarm call and flies away, and, hearing the call, *P. montanus* also flies away.

Considering the definition given above, we may say that *P. montanus* has made a translation, something like translating the alarm call of *P. cristatus* into a possible danger for itself.

If such a translation is symmetrical, i.e. possible in both directions, then it can be called an *interindividual sign system*. In our example, considering that the alarm calls are mutually recognised by both *P. cristatus* and *P. montanus*, this is also an *interspecific* sign system.

For a sign system to be a *language*, we assume an additional feature – syntax, defined as the existence of a special type of signs (defined as syntactic signs) which do not refer to anything else except to a certain type of relationship between signs. Considering (together with Bickerton 1990; cf. also Jablonka, Rechav 1996) that animal communication systems generally do not have syntax, we should say that animal sign systems, except the human ones, are not languages. However, we still think that translation can also be possible for syntax-free sign systems.

It should be admitted that there exists a broader understanding of syntax, which interprets any relationship between categories of the same sign system as syntax, even if there is no differentiation into functional types (like verb and noun) between these categories. Indeed, the categorisation process always presumes a relationship between categories – two things cannot be distinguished without any relationship of one to the other. This broad meaning of syntax can be called *prosyntax* and should be distinguished from *syntax* as it is usually understood when speaking about human languages, and also used by Derek Bickerton (1990) and, here, by us.

In the case of translations between languages, the condition that these are used by humans is so evident that the similarity of the general functional structure of human bodies, as a necessary condition for translatability, can easily remain unnoticed[2]. In the case of translation between different species, though, this requirement becomes important. Particularly, it appears as a significant problem if we ask whether the translation is adequate or not[3] which may be a difficult problem for syntax-free (i.e., prosyntactic) sign systems. A possible criterion for the existence of translation is the survival (staying alive) of the transmitted signs and the feedback of their recognition.

Willard v. O. Quine (1959) points out that it is possible to translate into and from a *jungle language*, and that, in this case, a translation can be successful not on the level of single signs, but on the level of a whole text. Or, as Noam Chomsky (1975) has stated, semantic may precede syntactic, and translatability can be achieved due to the existence of deep structures (cf. Torop 1995).

Translation is a transmission of meaning from one sign system to another. Consequently, the application of the term translation requires the existence of two distinguishable sign systems. In the case of languages, this is usually possible and does not create big problems. Simple sign systems, which consist of only a few signs, and particularly if some of the signs are shared with another sign system, may often be much more difficult to distinguish. For instance, if the alarm call of other species is indistinguishable from the alarm call of one's own species, then these can be seen to belong to the same sign system and, accordingly, there is no translation needed to transmit the meaning. However, if the alarm call performed by an organism is distinguishable, for that organism, from the alarm call of another organism, then there exist different *Umwelten* and, accordingly, a translation between them. If even this is indistinguishable, then we have one and the same *Umwelt*, which may physically behave, of course, as a swarm.

Defining translation as transmission between umwelten generalises the notion of translation as transmission between languages. This, we hope, does not only make it possible to apply some results of translation theory to biology, but, in turn, also emphasises some fundamental aspects in cultural translation theory which have not been given enough attention, e.g., translation as directed to (and by) an individual person.

The Concept of Sign, for Biology

Since our formulation of biological translation uses the term *sign*, we need to specify this notion in relation to our context.

Despite the application of the sign concept, in biosemiotic works of the recent decade, to many biological examples, including some intracellular processes, the assumptions required for something to be a sign in biological situations have not been defined clearly enough. Thus, before going further with analysis of translation in the biological realm, we need to specify the notion of sign, attempting to make it a bit more operational for biology.

When does a factor *X* appear as a sign for an organism? This question is crucial, since there are evidently many factors which influence the organism without being signs. For instance, a decrease of temperature from 20 degrees to 17 degrees C has a measurable influence on the rate of many processes in

Paramecium, without this seemingly being recognised by the organism as a sign. On the other hand, the same *Paramecium* can recognise the bacteria which it can eat, as distinct from anything else it touches (the example described by Uexküll 1992: 342-343).

A factor, X, is a sign for the organism, A, if it results in behaviour via a historically developed code, and this behaviour is recognised (via another code) by the organism, A, as belonging to the same category as the influence of the factor, X.

Referring to J. v. Uexküll's terms, sign is a unity of *Merkmal* and *Wirkmal*. That means, something is a sign for an organism only if 'how it is perceived' and 'how it is reacted to' are categorised into the same category by the organism (cf. T. v. Uexküll 1987: 169).

Categorisation (both perceptual and motor) is based on an analogue code, whereas recognition is seen as digital. Here, we can therefore directly apply the concept of code duality (Hoffmeyer, Emmeche 1991) as a condition for something to be a sign.

Thus, expressing J. v. Uexküll's approach in the more classical semiotic terms of sign, denotatum and interpretant, we may notice the correspondence between them: sign is *Merkzeichen*, denotatum is *Wirkzeichen*, and interpretant is *Funktionskreis*. This also corresponds well to Roland Posner's formulation of these terms in his writing about Charles W. Morris and George H. Mead (Posner 1987: 28): "The role of a *sign* is played primarily by a stimulus which occurs in the orientation phase of an action [...]. The *denotatum* of a sign is primarily an impulse-satisfying object which, as such, occurs in the consummation phase of the action. [...] An *interpretant* is primarily the disposition of the actor to eliminate the impulse to act through consummation of the denotatum". Or, as Thure v. Uexküll (1987: 169) has put it, "in the simple formula of *sign = meaning-carrier + meaning* and *meaning = reference to the meaning-utilizer*, 'meaning' has the central function of bracketing heterogeneous elements into a whole (the sign). [...] Thus meaning turns out to be a 'drama', which deals with meaning-utilization. [...] In this way, signs suddenly come alive".

A particular example of sign transmission is *imitation*. Cecilia M. Heyes (1993: 1000) defines imitation as a phenomenon where "individuals acquire, as a result of observing a conspecific's behaviour, *X*, the capacity to execute a behaviour that is topographically similar to *X*". Adam Miklósi (1999: 349) points out that "for 'true' imitation to occur the observer needs both to recognize the goal of the demonstrator and to realize that reaching this goal is only possible by copying the act(s) of the other animal. Copying which does not involve recognition of goal has been termed 'mimicking' or 'response facilitation' ". Thus, there is a clear difference between copying and translating signs (cf. Kull 1999b).

Inheritance as Translation

We shall move now, after these necessary preliminary considerations, to some biological examples as candidates for biotranslation.

An interesting example of eutranslation is the educating and nurturing of a child by its parents, in which the personalities of the mother and the father are translated into the personality of the child. Simultaneously, at least genetic, epigenetic, behavioural, and linguistic components can be distinguished as participating in this process. These are also the different types of inheritance, or different inheritance systems (Jablonka et al. 1998).

Given that inheritance systems work in the framework of the general conditions necessary for the process of translation, we have a situation which may allow us to apply the principles of translation theory to biological inheritance systems. In other words, what we shall do in the following is to provide a sketch of a semiotic analysis of inheritance, using the concepts of an extended translation theory.

First, we need to specify the range of applicability of the term *inheritance*. With this we mean that there exists a sequence of patterns which are produced, one on the basis of the other, and that this production requires codes. In addition to this, we assume that each of these patterns can participate, at least potentially, in a process of communication other than translation. We also assume that the production of these patterns is carried out by a living system.

The phenomenon of parents and offspring being alike can be explained by the fact that (1) DNA in parents is copied and transmitted to offspring, and (2) the organism is built up in most of its details using the patterns of DNA. This is the core of the genetic paradigm, as used by neo-Darwinian biology.

DNA-copying being the case, either fully, as in the case of vegetative reproduction, or hybridically, as for sexual reproduction, this still does not mean that the same DNA shared by parent and offspring on a structural level is also the same on a functional level.

What works for the production of a new organism is not the structural genome, but the functional one. The functional genome is the part of the DNA which is read by an organism, i.e., which is used by it in one way or another to build up enzymes and RNAs.

Eva Jablonka et al. (1998) distinguish between four *inheritance systems*: epigenetic (EIS), genetic (GIS), behavioral (BIS), and linguistic (LIS). The means of information transmission include, correspondingly, regeneration of cell structures and metabolic circuits (EIS), DNA replication (GIS), and social learning (BIS, LIS), the latter based on symbols. These inheritance systems transmit variations from generation to generation, the variations including cellular morphology (EIS), DNA base sequences (GIS), patterns of behaviour

(BIS), and language structures (LIS). For instance, on the chromatine there are some molecular (methylene) marks, which have a certain relationship to gene expression, and these marks can be, as Eva Jablonka and others have shown, transferred to the daughter cells. This is an example of epigenetic inheritance, which can transfer a message from one generation to another (along the mother line, by the way), without any change in DNA. These marks, indeed, are reversible; however, they can stand where they are for quite a number of generations.

In addition to this, it is important to acknowledge the role of *environment*. For instance, a behaviour pattern in organisms can vary according to the environment in which these organisms live, which means that particular behavioural forms are connected (or limited) to a particular environment. Thus, for instance, what can be inherited via BIS may only be the behaviour used in limited conditions, in the case that this environment remains within its limits. Therefore, the stability of environmental conditions is a necessary part of the inheritance systems, being itself a carrier of a part of the information from generation to generation.

As opposed to a genocentric view of biological evolution, the distinction between several independent inheritance systems makes it clear that GIS cannot explain all that goes on in evolution. Also, we should consider that the change or stability of the environment (i.e., environmental information) is itself an obligatory component of inheritance. Changes in any of these inheritance systems may have evolutionary importance (cf. Kull 1998b, 1999a).

Now, to view inheritance systems as those which effect translations from the umwelt of parent to the umwelt of child, we need to find out whether there is anything like DNA in the organism's umwelt. Since this is seemingly not so on the level of behavioural functional cycles in multicellular animals, we need to move to the intracellular level – to the sphere of microsemiosis, as Thure v. Uexküll et al. (1993) have termed it [4].

On the level of the cell, indeed, DNA is a constituent of functional cycles. A zygote growing into an adult organism is interpreting its DNA, very much like a reader (or translator) interpreting a text which is not created by her/himself, but whose author may already be dead. As regards this example, Hoffmeyer (1996: 19-20) has established a correspondence between DNA and sign vehicle, ontogenetic trajectory and object, fertilised egg and interpretant. "The fertilised egg understands the DNA message. That is to say, it interprets it as an instruction to construct the organism and thus implement the ontogenetic trajectory" (Hoffmeyer 1996: 20). However, this example seemingly requires more elaboration.

Namely, the functional cycle under consideration here is that of gene expression. This is a complex system, which can recognise some patterns in DNA, build up polypeptide and other products as a result of this recognition,

and, as a result of such behaviour, either continue reading the DNA or turn its attention away from it.

The main problem, here, with the application of the concept of translation would seem to concern the existence of categorisation. On one hand, there exists the genetic code, which is a result of historical processes and not deducible from physico-chemical laws. On the other hand, it is not yet clear to what extent the gene expression system may be just a result of purely accidental matching (cf. Kauffman 1993).

In the case of perceptual categorisation, the discrete categories are formed due to amplification of meaningful, and non-amplification of meaningless, as discovered in the communication process. Could there be something analogous to this in the case for 'genes as units'? While leaving the final answer open, we may note that different patterns of DNA, as well as different sites of the genome, can be selectively used or suppressed by the gene expression system of the cell, and there exists a possibility to see it as analogous to categorisation.

If gene expression is not just determined by the genes themselves, but is an interpretation process carried out by a cell, with a possibility to do this in several different ways, then we may have a chance to see, in this, a kind of semiotic process. And if, in addition to this, the way of interpretation of its genome by one cell can be transmitted into the way of interpretation in some other cell, we have reason to speak here about this process as a kind of translation.

Interpretation of the genome by a parent organism can be transmitted to interpretation of the genome by its child. Biologically, this happens due to the work of both genetic and epigenetic inheritance systems jointly. This can be called translation, as far as it seems to correspond to the definition of translation given above.

It is important to notice that the transmission of the genome alone is usually not sufficient to be interpreted adequately by the recipient cell; in addition, much of the epigenetic information is required. Therefore, we think that these systems (EIS and GIS) have to be taken together, as forming the same inheritance system. However, if the epigenetic systems happen to be quite similar in themselves, then it is sometimes possible that in the experiments where the genome of the cell is replaced, the cell may still be able to interpret much of it. This can be seen as analogous to the situation where a text from another culture, about which we have not the slightest knowledge, still may happen to be partly readable for us, due to some general similarities between that culture and our own (cf. Stanosz 1990).

Behavioural patterns, as well as linguistic patterns, can also be transmitted via behavioural (BIS) and linguistic (LIS) inheritance systems. Accordingly, behavioural and linguistic signs can be translated. BIS and LIS are, correspondingly, the different forms of translation.

In molecular biology of recent decades, the term *translation* is among the most commonly used. It is defined as "the step in protein synthesis at which the genetic information encoded in mRNA is used to synthesize a polypeptide chain" (Kendrew and Lawrence 1994: 1094). As generally assumed and often noted, the word *translation* is used in molecular biology as a metaphor (e.g., Emmeche 1994). Indeed, as applied to one particular step in protein synthesis, it is and should stay as a metaphor. However, this same process certainly is a constituent part of a biotranslation process, in which a daughter cell interprets the genome inherited from its mother cell, but the whole process is much richer than the one named as *translation* in molecular biology.

Lessons from the Semiotics of Translation: Further Problems

In the case of translations between human languages, it is generally assumed that the translator knows both languages – from which and into which s/he is translating. In any biological example, we can hardly find this. Accordingly, this is an assumption which we do not use when speaking about biotranslation.

However, this difference between eu- and biotranslation may not be as strict as it appears at first glance. First, translation is certainly possible even with a very poor knowledge of the original language. Second, the boundary between translation and non-translation may be very difficult to draw (cf. Torop 1998). And third, as in the example above with the two species of *Parus*, understanding the other species' alarm call (the alarm calls of these species differ) can be interpreted as partial knowledge of the other species' sign system.

The second questionable point is that the language of the original and the language of the translation have to be different – without that border there would be no translation, but only a repeated reading, just the repetition. The counter-argument, here, will be that the *Umwelten* (including the *Umwelten* of the individuals of the same species) *are* different. Otherwise, if the *Umwelten* were identical, then (as Yuri Lotman 1978 has emphasised) there would be nothing to communicate about. Consequently, every communication perceived as making a message originating from another *Umwelt* understandable in one's own *Umwelt*, assumes translation (cf. Holz-Mänttäri 1988).

The next question concerns the possibility of translating without any syntax in the message whatsoever. While agreeing that the profound difference in richness between communication systems in humans and in other animals owes very much to the lack of syntax in the latter, this may not mean the inability to translate. Syntax organises complex messages and is very helpful for translation indeed. However, the correct identification of meaning may also be based on the recognition of context, or deep structure, since, as observed by R. de Beaugrande (1980), equivalence in translating must be obtained not

between words or grammatical constructions, but, rather, between the functions of texts in communicative situations.

The absence of syntactic signs in animal communication may also be questioned in the case of visual communication, in which animals (when moving together in pairs or flocks, or fighting with each other, etc., including communication between specimens of different species, e.g., a predator and a prey) can coordinate their movements with a high level of precision. An animal's analysis of visual signs, which are represented by the other party's movements, may, in principle, include syntactic elements in addition to prosyntactic ones.

In the place of syntactic signs, an analogous function may be performed, e.g., by the differences in social status between communicating animals, or by a hierarchy of behavioural acts. This can be compared to the translation of an innovative text which has no analogues, and which can be marked by a sign (e.g., title, motto, introduction, or design) as guiding its perception.

Notes

[1] As stated by Louis Hjelmslev (1973: 115): "Language [...] is a sign system into which all the other sign systems can be translated".

[2] In the case of handicaps, still, the same problem arises. Similar problems have also been discussed in some contemporary feminist studies.

[3] This is important, since wrong translation may be indistinguishable from non-translation, particularly in the case of the non-human situations which we want to analyse.

[4] On a semiotic analysis of intra-organism processes, cf. also Hoffmeyer 1997, Kull 1998a, Vehkavaara 1998.

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