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Semiosis, Logic, and Language

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Three fundamental forms of semiotic process (reference, addressing, and intentionality) are presented and their relations to language explained. After that, the fundamental inference forms (formal deduction, induction, and abduction) are presented and their connections with semiosis shown. Finally, we show some important differences between semiosis and inference, and propose to see information processing as a dynamical attractor of inference.

1. *Introduction*

Semiotics is a particularly interesting subject insofar that it covers an area that goes far beyond the sphere of human communication. For this reason it has attracted a lot of interest in the later years (Sebeok [2001]). However, it still presents many open areas and it is fundamental that this science will acquire a more stable and rigorous structure as soon as possible. I hope that the present contribution will help in this direction.

The main thesis of the present paper is that semiotics may provide an interesting connection between language and logical operations. This theme has acquired a rising interest in recent linguistic researches (Pinker [1995], 136; Larson [1995]). Furthermore, semiotics may prove an important link between information theory and language. The latter point is only touched upon here and deserves a separate work.

Unfortunately, many authors tend to see semiotic processes in sharp contrast to informational processes (Hoffmeyer [1996]; [1997]). This should not, and must not be the case, since information theory is a solid construction that represents a general framework for any process involving information. The problem of dealing with this perceived antagonism between these two processes is a worthy topic of further research.

In this paper, I will first discuss the main forms of semiosis. Then I will examine the main forms inference. After that, a comparative examination of the relationships between the structures of semiotic and logic aspects will be developed. Finally, I will offer some concluding remarks to synthesize the extent to which the relationship between logic and semiotics may be taken.

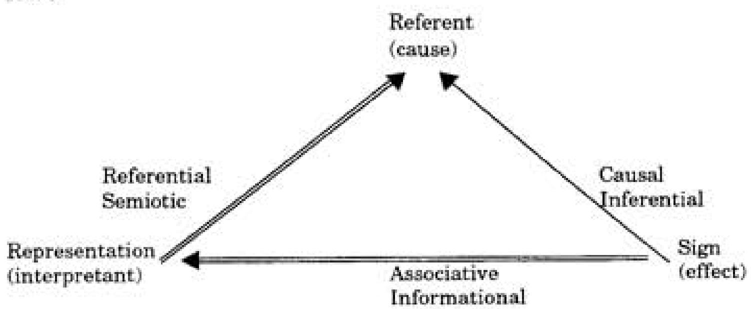
2. *Semiosis, Language, and Information*

We may distinguish between different types of semiosis. Since, in the first instance, semiosis covers the biological domain (Hoffmeyer [1997]), it is interesting to see what eminent specialists in animal behaviour and signaling have to say on the subject. It seems to me that Peter Marler has given fundamental contributions in this area. I will partly modify and develop a scheme that can be found in a paper by Marler and Green [1979]. I believe that all semiotic processes can be assigned to the following categories: (1) Reference (Marler and Green's *indexical reference* that is not an active production of a sign), which is common to all semiosis; (2) Addressing (*deictic semiosis* in Marler and Green's language that also covers other contextual forms of communication), which is basic to all form of communication; and (3) Intentionality, which is the active transmission of a sign as sign of something to a partner who can understand it as a sign of this something. The first aspect is the basic one, possibly found in all living forms, and the other two may be derived from the first.

The first type of semiosis can be synthesized as follows: An agent interprets something as a sign of a referent. For instance, an animal sees a specific mark on the ground and interprets this as a trace of some prey.

This first type has three important features: It shows (1) that the relationship to the referent is, in general, indirect and that therefore the referent is intended (it is not physically present generally), (2) that in this passive and elemental form of semiosis there must be some dependency of the sign on the referent, even if this may be not the case for more advanced forms of semiosis—I wish to stress, however, that generally, this dependence is only inferred and not actually experienced—, and (3) that in this elementary form of semiosis the referent can be seen as a past source of information (again in more advanced forms this may no longer be the case).

Cherry [1957], following Peirce (CP 2.228 and 1.540; [1894]) and Morris [1938], proposes a semiotic triangle, which I could reformulate as follows



The triangle goes from the sign to the representation, from the representation to the referent (*qua* referent), and from the sign to the referent (not as referent but rather as an inferred cause of the sign).

It is interesting to note that the relationship between the sign and the representation is, on the one hand, a free association, but, on the other hand, also an informational (in the classical sense) relation to the extent in which there must be some informational flow from the sign (through the senses or other forms of receiving signals) to the living organism that produces the representation.

The relationship between the referent and the sign is inferred from the perspective of a given representation (for this reason is shown with a single line). In other words, the representation here plays the role of an interpretant, i.e. it assigns the sign to the referent by referentially associating a given representation to the latter. For instance, I see a trace and I have a representation of a rabbit that could have left it. In this case, I refer myself to a possible cause of the trace that I represent as a rabbit. Moreover, the inference, properly speaking, goes from the sign as an effect to the referent as a possible cause.

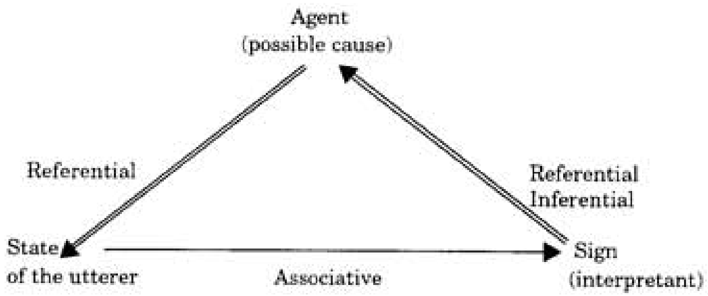
It is important that the term "representation" here does not necessarily has to do with psychology. Even a bacterium is capable of orienting itself (by moving) in a nutritional gradient (Hoffmeyer [1997]). The amount of nutrient molecules hitting the receptors of the outer cell membrane changes as the bacterium moves, and this change is registered by the cell, thus allowing the cell to select the direction to move toward. In this case the bacterium is able to "interpret" the impinging molecules as a sign of the concentration of nutritional matter. Exactly how this is possible is a question that goes beyond the scope of the present article. I will limit myself to report it as a fact.

I wish also to stress that the "representation" need not be analogous to the referent. In principle, it is a free production of the agent that is only associated to the referent because it was phylogenetically or ontogenetically successful (see Auletta [2002]).

As regards the connection between the first mode of semiosis and information, I observe that we may infer a given referent through an interpretation of a sign. If we make a successful interpretation, it generally means that we have understood the causal relationship that has allowed the referent to produce such a sign. This causal process may legitimately be seen as an informational flow: the referent, the intended end-point of the semiotic process, is the informational source. The sign is the signal and is strictly connected with a channel between the source and the receiver (the mark on the ground is an optical signal (Hailman [1977]) and, in order for it to be received, the subject of semiosis must be provided with suitable organs). Finally, the interpretant is the receiver (I have already spoken of the informational flow from the sign to the interpretant).

The first semiotic process thus covers what may be seen as an informational process. However, as we shall see in the concluding remarks, there are important differences between the first mode of semiosis and classical information processing. In fact, while a semiotic process requires an active agent, nothing of this type is required by an informational process itself. It is for this reason that the arrow in this semiotic process goes from the effect to the cause and not vice versa, as would be the case in a pure informational process. However, it is because the relationship between referent and sign may be understood in terms of a relationship between a source and a signal that the first mode of semiosis denotes the interface between information and semiosis.

The other two forms of semiosis are both active, in the sense that in both cases the sign is actively produced as a sign. As regards the second form—addressing—the relationships may be cast in this way:

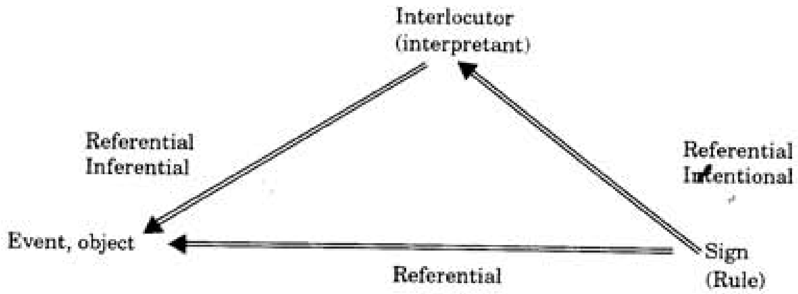


In this case, the semiotic process is contextual. The sign, as an interpretation of a given utterer's state, is (not necessarily intentionally) communicated to another agent in order that the agent understands the state of which the sign is a sign. For instance, I threaten (sign) a possible enemy (agent) in order that it (the agent is not necessarily human) understands that I am angry and ready to fight (state). In other words, I want the agent to infer that my threat is a sign of the fact that I am angry so that it promptly reacts to my expressive sign. In this case, I wish that the agent infers a given attitude that I hold relative to it through reference to the state I am in, and therefore by interpreting my sign as a sign of this state. It is for this reason that the arrow that goes from the state to the sign is not doubled. The process is contextual because there must be some immediate relationship between the state and the sign in order that the agent may infer the former.

This second form of semiotic process may be found in multicellular organisms—definitely in vertebrates and social insects. It is also the basis of two fundamental functions of human language. We use language in order to provoke a certain action in a partner (perlocutionary speech acts) and to express emotions. Obviously, in the case of the imperative form there is no longer a direct reference to a state. However, one will obey to an imperative only if one thinks that the utterer has the force and the will (the state) to harm or punish one if one fails to comply. This schema thus throws light on the implicit assumptions that are present in perlocutionary acts. As regards the expression of emotions, Baldwin [1894] already took them as a consequence of expression, rather than as a direct manifestation of an emotional state. In this sense, one may distinguish between feeling and emotion, taking the latter as more active and symbolically mediated than the former (Elster [1999a-b]).

What Mead [1934] instead calls *symptom* must be understood as the first mode of semiotic process. For example, a physician interprets a given temperature as a sign of influenza. For this reason, I have said that the first mode is the interface between information and semiosis. Otherwise, there must always be some referential attitude to communicate, even implicitly, a given state. One could draw a distinction between purely somatic signs (symptoms) and active signs. The former may only be object of a further semiotic process but they are not signs in themselves: they only represent information. On the contrary, in the second—and third—mode a sign is actively produced in order to obtain some consequence.

The third semiotic mode is the intentional one, which may be represented as



In this mode all relations are referential. The process is no longer necessarily contextual. In this case, a sign is given to an interlocutor in order that one understands (refers to) a given event to which the sign is referred. For instance, a rhesus monkey communicates to its group members that there is a leopard nearby (see Cheney/Seyfarth [1990]). In such a case we expect that the interlocutor will understand that our sign is referred to the event, that is, we wish that one interprets our sign as a sign of a given event and therefore infer the event itself. In other words, the relationship between our interlocutor and the event is only an intended one and not necessarily real. There can be misunderstanding between my interlocutor and myself such that she or he may not understand to what the sign refers. To the best of my knowledge, other than in human language, this form of semiotic process is found only in monkeys and apes. In human language it corresponds to the third function of language, namely that of communicating information.

Let us recall that the first mode is *monadic*, a single agent may perform this inference without considering any other agent, and therefore do not include either communication or linguistic media. Consequently, there is only a single referential relationship.

The second mode is *dyadic* in that the presence of the other agent is fundamental, and therefore there are two referential relations. The third mode is *triadic*, in that there are three referential relations.

A further evidence of this increase in referential relationships may be found in the fact that any referential relation somehow presupposes an arbitrary relationship between its two terms. In the first mode, the relationship between the agent and the state is arbitrary and could be in fact false, in the sense that the agent may misunderstand the state of which my sign is an expression. Also the relationship between sign and state can be arbitrary because I can express, for instance, an emotional state, through a different sign, as well as the other agent may misunderstand this relation. Many deception tactics (Byrne/Whiten [1985]; [1988]) are based on the possibility to falsify the relationship between state and sign, and between the other agent and the expressed state. This is an important difference between the first form of semiosis, which does not depend on interpretation by another agent, and the second mode, which includes, at least, one other subject. My thesis is that deception requires at least two referential relations, whereas in the first mode, where we have only one referential relation, only errors are possible. A typical example of deception might be that I give an agent a sign that I am attacking when my actual intention is rather to provoke panic.

There are far more possibilities for deception in the *third semiotic mode*, which are in fact used by monkeys, and especially by apes (Byrne [1995]). In fact, in the third mode all relations are arbitrary and can all be false or deceptive. In this third mode, the sign is a convention (rule) between my interlocutor and me. For this reason, the possibility of error arises. Moreover, I may have addressed myself to other interlocutors without changing, on the whole, anything essential. For instance, a rhesus monkey may alert several group members, who, to a certain extent, may be taken as equivalent. Finally, my interlocutor's referential act may be mistaken. She or he may simply not understand to what thing or event I am referring. An example of deception tactic in the third mode might be that I give my interlocutor the false information that a third person will attack her or him because I fear a possible alliance between my speech partner and the other person.

3. *Inferences*

An important point of the preceding examination is that all modes of semiosis have to do with some form of inference. For this reason, a short examination of the problem of inference may be very useful. My starting point here is again Peirce's intuitions on the matter ([1865]; [1866]; [1878]). Peirce has shown that there is a certain relationship between Aristotle's three figures of syllogism and three forms of reasoning, formal deduction, induction, and abduction.

Any reasoning must have at least three elements: a rule, a case (sample), and a result. A multiplication of rules or of cases will add nothing to the conceptual features that we are considering, and therefore we may limit ourselves to these three elements without loss of generality. Let us now consider why they are necessary conditions of any reasoning. Without a *rule* (or law, norm, convention, habit, and the like), there would only be a juxtaposition of unrelated terms, with the consequence that the result would be unrelated to the premises of the inference and therefore completely arbitrary. This could not be called reasoning. Reasoning must always have a *case*, a sample, to which the rule may be applied. This case may be ideal, hypothetical, or real. Without such evidence that may represent an application of the rule it is difficult to arrive to any result that is not merely the repetition of the rule in different terms. Finally, any reasoning points to a *result*. Nobody will consider a sequence of words as reasoning unless it arrives at a conclusion that is perceived as following in some way from the premises.

Obviously, when the rules of logic are respected, all forms of formal deduction are possible. These formal inferences, however, are not reasoning proper but are, at most, schemes of reasoning.

In its most general and primitive form, reasoning is simply application of a rule to a case in order to derive a result. An example could be

RULE	All living beings have DNA.
CASE	All those structures found on Mars are living beings.
RESULT	Therefore, all those structures must have DNA.

Clearly, someone could object that a judgement is not a proposition of general form, and so a syllogism constituted of three judgements is not sufficiently general. For this reason, Peirce [1895] preferred to speak of *index* or the set of indices instead of *subject*, of *icon* instead of *predicate*, and of *symbol* or proposition itself instead of *judgement*. My argument, however, loses nothing of its generality if we consider judgements. For this reason, I will consider this form in particular because it is simpler and more intuitive.

Now, how many types of deduction are there? In any case, we can assert or deny something of some elements of a given set or of the entire set. As was already known to Aristotle, by combining these possibilities, we obtain four propositions

Universal assertion	$(\forall x)(Sx \rightarrow Px)$
Universal denial	$(\forall x)(Sx \rightarrow \neg Px)$
Particular assertion	$(\exists x)(Sx \wedge Px)$
Particular denial	$(\exists x)(Sx \wedge \neg Px)$

where S stands for an arbitrary subject and P for an arbitrary predicate. In the Middle Ages, the four propositions were symbolized as A, E, I, and O, respectively.

The abstract combination possibilities of these propositions as rule, case, and result, are numerous. They are significantly reduced, however, if we apply following syllogistic rules. (1) Nothing can be concluded from two particular propositions. (2) Nothing can be concluded from two denials. (3) A particular proposition cannot be inferred from two universal propositions (this is a modern rule). This means that we must discard all premises (rule and case) that have the forms: II, OO, EE, EO. In other words, we are left with only AA, AI, AE, AO, and EI as premises. For instance, from the form

$$(\forall x)(Bx \rightarrow Cx)$$
$$(\exists x)(Ax \wedge \neg Bx)$$

nothing can be derived for three arbitrary terms A, B, C. Moreover, according to the third syllogistic rule, we must exclude all inferences of a particular conclusion (I or O) from AA and EE. Then, we obtain AAA, AAE, EAE, EAA, AOO, AII, and EIO. By means of logical calculation, we reject AAE, EAA, and, for a deduction of the form of the above example, also AOO, and arrive to AAA, AII, EAE, and EIO. Therefore, these four form are all possible abstract structures of deduction. There can be no others.

Now, I ask: What are other forms of reasoning? First, let us start from the elementary consideration of what would follow if someone would argue against our reasoning. How could one do that? By denying the result of our deduction. (Not the premises, otherwise no possible discussion or examination could follow.) Then, from this one might try to infer the negation either of the rule or of the case. Considering the example above, if we try to deny the case, we obtain something like this:

RULE	All living beings have DNA.
NEG. RESULT	It is not true that all those structures found on Mars have DNA.
NEG. CASE	Therefore, it is not true that all those structures found on Mars are living beings.

Suppose, instead, that we wish to infer the negation of the rule. In this case we have:

NEG. RESULT	It is not true that all those structures found on Mars have DNA.
CASE	Those structures found on Mars are living beings.
NEG. RULE	Therefore, not all living beings have DNA.

In this way, we may derive all the first three figures of syllogisms:

I	II	III
Rule +	Rule +	Result –
Case +	Result –	Case +
Result +	Case –	Rule –

Here the sign '+' means assertion of the relative proposition, while the sign '–' means its denial.

Again, applying the logical rules and adopting a simplified symbolic form, we may write all valid syllogisms as follows (the names are traditional expressions of the syllogisms given in the Middle Ages):

I	II	III
Barbara	*Baroco*	*Bocardo*
$B \rightarrow C$	$B \rightarrow C$	$A \wedge \neg C$
$A \rightarrow B$	$A \wedge \neg C$	$A \rightarrow B$
$A \rightarrow C$	$A \wedge \neg B$	$B \wedge \neg C$
Celarent	*Festino*	*Disamis*
$B \rightarrow \neg C$	$B \rightarrow \neg C$	$A \wedge C$
$A \rightarrow B$	$A \wedge C$	$A \rightarrow B$
$A \rightarrow \neg C$	$A \wedge \neg B$	$B \wedge C$
Darii	*Camestres*	*Fresison*
$B \rightarrow C$	$B \rightarrow C$	$A \rightarrow \neg C$
$A \wedge B$	$A \rightarrow \neg C$	$A \wedge B$
$A \wedge C$	$A \rightarrow \neg B$	$B \wedge \neg C$
Ferio	*Cesare*	*Datisi*
$B \rightarrow \neg C$	$B \rightarrow \neg C$	$A \rightarrow C$
$A \wedge B$	$A \rightarrow C$	$A \wedge B$
$A \wedge \neg C$	$A \rightarrow \neg B$	$B \wedge C$

The syllogisms of the second and third figure are derived along the same horizontal line from the corresponding one of the first figure by assuming either the rule or the case together with the denial of the result of the corresponding syllogism of the first figure.

Peirce did not consider the fourth figure a logical inference. In fact, it is exactly the same as the first figure, but with exchanged premises, which has no logical meaning, however. For example, it can be seen that the syllogism *Calemes* of the fourth figure

$$A \rightarrow B$$
$$B \rightarrow \neg C$$
$$A \rightarrow \neg C$$

has the same structure as the syllogism *Celarent* of the first figure.

All the figures represent deductions. Moreover, the syllogisms along the same lines in the scheme above represent the same inference in different forms. The syllogisms of the second and third figure can be considered as *ad absurdum* proofs of the syllogisms of the first figure. In fact, to affirm that

All living beings have DNA.
All those structures found on Mars are living beings.

Therefore, all those structures must have DNA.

implicitly means to affirm that, if, in an absurd situation, not all those structures had DNA, yet we wish to maintain the rule, then it must follow that not all those structures are living forms. If, on the other hand, we wish to maintain the truth of the case, then we must be able to admit that the rule is not general, i.e. that it may be contradicted. The other two figures, therefore, although valuable forms of deduction, may be taken as mere variations of the first.

Take yet another example:

All pellets in this box are white.
All the pellets of this sample come from this box.
Therefore, all the pellets of this sample are white.

If we wish to deny the case, we may write

All pellets in this box are white.
Not all the pellets of this sample are white.
Therefore, not all the pellets of this sample come from this box.

Let us consider this conclusion. If we take it literally, it adds nothing new to what we already know, because it says that at least some of these pellets are not from this box. This could also be stated in other words so that the conclusion is rewritten as:

Therefore, some of the pellets of this sample must come from somewhere else.

From somewhere else is a simple negation of *from this box*—properly speaking, it is the set of all things that are not in this box. But suppose that the conclusion had been stated as:

Therefore, some of the pellets of this sample must come from another box.

In this case we would have gone beyond the information contained in the premises (*another box* is not simply the negation of *to be in this box*, but adds some additional information). This is not a formal deduction, i.e. a logical inference, but is it an inference? In most cases we would answer positively and in some cases it may also lead us to a new experience, for instance to find a new box. It is an inference, then. In particular, it is an *abduction* or, in other words, a hypothesis. We never have absolute certainty about the truth of a hypothesis (and in this sense it is not a result of a deduction from true premises), but sometimes an inference of this type is far more valuable than deduction precisely in that it allows new experiences. In the case above, we are authorized to infer the conclusion if, for instance, we think that there are some reasons to think that pellets mainly come from boxes.

Suppose, however, that we wish to deny the rule. Then, we would write:

Not all the pellets of this sample are white.
All the pellets of this sample come from this box.
Therefore, not all the pellets in this box are white.

Again, the question is how we understand this conclusion. If we understand it literally, it refers to the same collection of pellets presented in the premises. This becomes clearer if we state the number explicitly:

Fifty pellets of this sample are not white.
All the pellets of this sample come from this box.
Therefore, at least fifty pellets in this box are not white.

In this case it is a deduction, and the conclusion has added nothing new to the information already contained in the premises. Suppose, however, that we say:

Most of the pellets of this sample are not white.
All the pellets of this sample come from this box.
Most of the pellets in this box are not white.

In this case we are generalizing from the number of not-white pellets of this sample to the number of not-white pellets from the box, which is necessarily supposed to be larger. Then, we have an *induction*, which is also an inference, although not a logical inference. It is a valuable inference, however, where, due to the large number of elements of a given set, it is necessary to have recourse to statistical means.

Let us briefly consider the relationship between abduction and induction. Neither abduction, nor induction is a logical inference; nevertheless, they are very different. Abduction is the inference of a *new property* (to be in another box) of the same set (sample) of elements. The case of induction, rather, is a generalization from a statistical sample *to other elements* having the same property (numerical generalization).

The problem by all forms of inferences is finding the correct connection between a general element—a rule or a law—and a particular element—a statement about specific facts. The problem was already discussed by Kant ([1787], 95), though with a different terminology and in the limited framework determined by the Aristotelian logic. Kant spoke of individual judgements as a synthesis of general and particular judgements. Returning to the problem of the three forms of inference, in deductive inference the stress is on the law. Although one tries to deduce a specific result, the result is an immediate consequence of the application of the rule. In this sense the rule dominates deduction. In induction, on the contrary, the stress is on particular facts, i.e. on the case. One tries to infer a law, but the law remains statistical regularity extrapolated from particular facts. In abduction, whose result is a new property with the aim of connecting facts and the law in a novel way, there is a true mediation between the law and the facts, and the stress is here on the result.

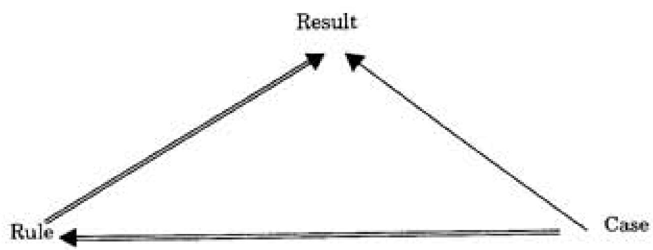
I have said that abduction and induction are not logical inferences. However, we may understand deduction as the limiting case of abduction, i.e. as in the generally impossible case in which we know all possible hypotheses (properties that, in given circumstances, may be assigned to the elements we refer to) and are therefore permitted to infer just one of them with absolute certainty. For example, if we know that all pellets under consideration come from a box of a given set and we also know the distribution of white pellets in any box, we may determine with high accuracy where this sample comes from. Similarly, we may understand deduction as a limiting case of induction, i.e. when the sample grows so large as to finally coincide with all the pellets in the box. This continuity of induction and abduction with deduction, justifies their being considered as inferences. On the other hand, this also shows that pure deductions are very rare and their scope is very narrow, because, in almost all circumstances of life and of scientific enterprise, we only know a small part of the possible properties or of the possible elements. On the other hand, deduction is more valuable regarding the certainty of its results. For this reason, generally speaking, true knowledge can be obtained if one succeeds in an optimal combining of the three forms of inference (see Peirce [1901], 96–97).

There are no other possible forms of inference. Any inference may be cast in one of these forms and reduced by analogy to a "syllogism" of the above schema. In other words, we have three inferential types of reasoning, each one expressed in four forms.

4. *Semiotic and Inference*

There is an interesting relationship between the semiotic processes first presented and the three forms of inference above.

I will approach this relationship starting with the first semiotic mode. In this mode, I have a case (a sign), and having a rule—for instance, the psychological association between a given trace and a representation of a given prey—I infer a result—that that particular prey has run along this path. If I am right, in this case the result retrospectively provides a reason for the case (the sign). This is clearly a form of deduction.

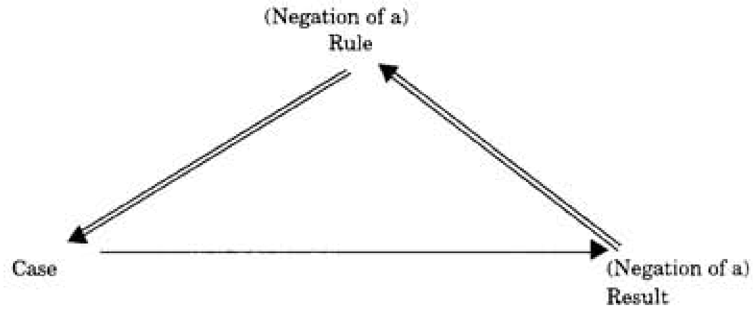


The second mode of semiotic process is just as clearly induction, because here, having a case (an emotional state, for instance) and a result (a certain sign), I wish that another agent infers a particular representation,

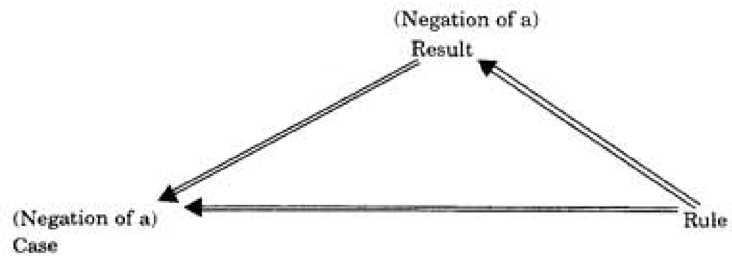
i.e. the rule that allows the inference of the case and therefore the connection between the case and the result (sign). I would point out that, as we wish to attract the attention of the agent to the case, I ask for a rule that is able to explain it. In other words, I tacitly suppose that the case is an anomaly, i. e. *not* an ordinary case, and therefore I demand a new rule, i.e. something that is *not* an old rule.

For instance, if I am angry and I wish to inspire fear in a certain agent, I cannot effectively do so through signs that are subjected to already known rules, because the agent might not take my state seriously. I want the agent to consider my state as exceptional and therefore infer a rule like "When this persons makes this—new—sign, I must be afraid because he is truly angry". In another example, if I give a command, I wish to be taken seriously and obeyed, but, if the agent has received this sign many times before, the sign will not be very effective.

This explains why, with cases such as imperatives, it is necessary to continually change the strategy (the signs used) in order to keep obtaining an effect. Too much regularity transforms the relationship between state and sign into a ritualized form, a habit that is no longer efficacious in the long run. Such a scheme can be represented as



The third type of semiotic process is abduction: a rule is represented by a sign, which is conventionally acknowledged by both my partner and myself, as happens with words. When, however, I wish to attract my interlocutor's attention to a case that I consider surprising or irregular (see Peirce [1903c], 287)—a case that is *not* ordinary—I want them to arrive at a new result by means of which they could retrospectively refer to the case. In this case, the scheme would look like:



In this case, an already existent rule is used to stimulate a new result in order to understand a new case. For instance, I use expected words to signal a new danger to my interlocutor.

5. *Conclusions*

An interesting result of this reasoning is the conclusion that language is based on addressing (imperatives and expressive forms) and intentional forms (communication of information to partners) of semiosis. Obviously, the relationship between semiotics and logic also has some degree of freedom. Though induction and abduction are connected with dialogical forms of semiosis, this does not mean that "solitary" induction and abduction is not possible. In fact, they occur any time that deduction does not suffice.

For instance, many actions are almost automatic, such as driving a car along a well-known path, and in this sense they are examples of deduction, i.e. of application of a law to a well-known case in order to obtain automatic output. However, when unexpected danger forces us to focus our attention and emerge from such an automatic state, we are generally forced to make an abduction. For this reason, Peirce spoke of "shadowing" the abduction into perceptual judgement ([1903b], 227) and sometime also into perception ([1903a], 224), which is a further confirmation of the fact that deduction is a limiting case of abduction.

Conversely, when we do not have a rule that is able to explain a situation, we are sometimes forced to make an induction.

A related point is that, as I have said, it can be taken as certain that living organisms are able to perform inferences and use semiotic processes. It is probable, however, that, while the first mode of semiosis can be universally found in all living beings, the second mode—addressing—is only typical of multicellular animals, of social insects, for instance. Moreover, I have stressed that the third form can be found only in highly evolved animals such as monkeys and apes.

This does not mean, however, that beings at the first level of semiosis are only able to perform deductions. In fact, learning, an ubiquitous feature in the living world, requires the ability to perform at least some abduction. In fact, deduction functions well only when we are confronted with foreseen situations or with situations for which we are genetically programmed. We may be confident, therefore, that there must also be some rudimentary form of abduction and induction even in the most primitive forms of life.

Furthermore, since deductions can be taken as automatic forms of responses, they can be seen as successive crystallization of experience. In other words, when we have repeatedly faced the same experience—or better yet, similar experiences that fall under the same category—we can translate our accumulated knowledge into an almost automatic inference. This explains in what sense there is a continuity between deduction on the one hand, and induction and abduction on the other.

This has also a surprising consequence. Since deduction is a terminal point of experience, it means that inductions and abductions are, to a certain extent, primary in the experience of living beings. Therefore, the ontogenetic sequence between the three forms of reference is reversed relative to the three forms of semiosis, which must reflect a phylogenetic order: whereas the first mode of semiosis is basic and chronologically first, orderly followed by the second and third modes, in reasoning deduction follows induction and abduction. On the other hand, since many forms of deductive inferences are part of any being's biological treasure—"triggered" reactions for instance—then, once deductions are selected and inherited, they may be considered also ontogenetically as primary.

The above considerations about the relationship between the three forms of inference lead me to a final consideration. The three forms of inference and at least the first semiotic mode may be understood, to a certain extent at any rate, as examples of Boolean state cycles (Kauffman [1993], 441–522), i.e. of cyclic structures in which a stable state is obtained regardless of the truth value of the elements. Suppose, for example that we make this inference:

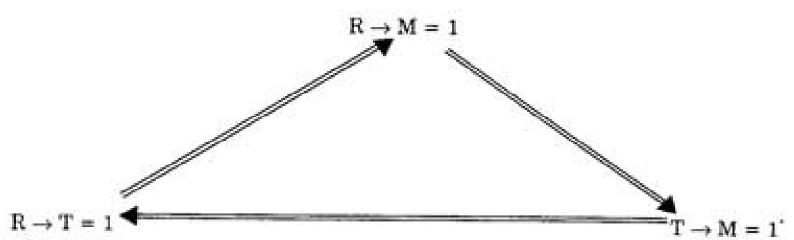
CASE	An animal's traces may explain a certain mark on the ground ($T \rightarrow M$).
RULE	Rabbits leave this type of trace ($R \rightarrow T$).
RESULT	Therefore, a rabbit must have caused this mark ($R \rightarrow M$).

Moreover, suppose that (1) we apply the right rule to the right case. It follows that we obtain also the desired result—we catch the rabbit, for instance. Suppose, instead that (2) we use the right rule but misunderstand the case—for instance, they are not traces at all, or they are traces of a different animal. The result is that we do not catch the rabbit but, perhaps, encounter a lion. Given a false result, we must reconsider the premises and try to find the error. If, after careful inspection, we find that the case was misunderstood, we must change this assumption. We might say: "Aha! They were traces of a lion". In this case, we have made an abduction. The result is satisfactory insofar as we have found the source of error and can apply the old rule to future cases upon closer inspection. Perhaps we have also better learnt to identify traces of lions. If (3) only the rule is false, we again do not obtain the desired result. After inspection of the case, we must conclude that we have falsely associated this type of trace with rabbits. This, and similar future cases, will force us to inductively develop a new rule that can be applied in such cases. Again, the result may be quite satisfactory; we have learnt something new, perhaps made a new association between certain trace and an animal that was previously unknown to us. We may also succeed in formulating a correct rule for catching rabbits. If, however, (4) we have both applied the false rule *and* misunderstood the case, the situation is much more difficult. By changing the rule, we are still far from the desired result. This is also true if we only change the interpretation of the case. If we are clever, however, after some trial and error we might hit upon the right answer, i.e. that both rule and case must be changed. Even with that knowledge, it could remain very difficult to arrive at a positive conclusion. I wish to stress that in this fourth case we cannot find an inferential relationship between the preceding failure and new possible results. Perhaps the only thing that can be done is to concentrate our attention on the traces, and try to find similar traces in the future. Once we are sure that we have developed a proper typology of this mark on the ground, we can again try to inductively establish a relationship between these traces and a particular animal or agent. Given these limitations on the fourth case, it is still possible to assume that, in all four cases, we might, at a later time, obtain a value that is true for the three propositions, and so catch a rabbit. This can represented formally as:

(1) $T \to M = 1$, $R \to T = 1$, $R \to M = 1$, then nothing changes.
(2) $T \to M = 1$, $R \to T = 0$, $R \to M = 0$, then $\neg(R \to T)$. Try to find another rule and see if the result fits.
(3) $T \to M = 0$, $R \to T = 1$, $R \to M = 0$, then $\neg(T \to M)$. Try to find another interpretation of the case and see if the result fits.
(4) $T \to M = 0$, $R \to T = 0$, $R \to M = 0$, then try first to modify the interpretation of the case. If there is still no result, try to modify the rule. If, there is still no result, reset and try again.
The resulting representation is shown in the following table:

$T \to M$	$R \to T$	$R \to M$	
1	1	1	NO CHANGE
1	0	0	$\neg(R \to T)$
0	1	0	$\neg(T \to M)$
0	0	0	RESET

We can thus see that, to a certain extent, an intelligent combination of induction, abduction, and deduction gives rise to a set of correct inferences as a sort of attractor. This set will, depending on the specific result that is desired and giving some restrictions that we may be forced to impose on our powers of generalization, correspond to the four fundamental forms of deduction seen above. If the organism manages to internalize this process completely, it can be schematized as in the following figure:



which shows a circuit with a classical flow of information throughout. In this case, we no longer have an inference. In fact, it is not a deduction, because the arrow going from $T \to M$ to $R \to M$ is inverted relative to the previously presented scheme of deduction. This shows that when we succeed in completely translating a given inference into a mechanical device, we wind up loosing the very inferential character itself.

The mechanical device may in fact be instructed to react in a given manner to a given sign; for example, a rocket may follow the path of an object with a given temperature. In this case, it performs an *analogue* of deduction as it has been programmed to do. However, it never infers a certain cause—an airplane—from a given effect—the heat trace. It only *imitates* this procedure by always going from a determined cause to a determined effect: the heat triggers a sensory device, which activates a certain procedure, and this procedure finally triggers the target. The trick here is simply in the mechanical procedures, in the program, that is built so as to react in a manner that can substitute a human agent. However, this is only the case in highly repetitive and restricted circumstances. This example shows that, though deduction is a repetitive mode of inference and is for this reason quite similar to a classical flow of information, it does not coincide with it without loosing its inferential character. Again we see that the classical flow of information may be seen as a limiting case of the combination of all forms of inferences when the knowledge grows so much to allow mechanical operations to substitute inferential extrapolations.

It is true that connectionist networks may produce results that are similar to inductive inferences, and therefore it may seem that these networks are able to learn (Amit [1989]; Churchland [1995]). However, they require training through a human "teacher". A living being can succeed also without teacher. On the other hand, no physical device has shown the ability to combine all forms of inferences typical of living organisms.

In conclusion, the set of correct inferences can be seen as the result of a process of stabilization, of an effort to finally obtain a mechanical and predictable answer to any problem. In Peirce's words ([1868], 232–33; [1903b], 235), inference aims toward the establishment of a habit. All living beings probably have an innate tendency to mechanical and repetitive behaviour. The reason is that any true inference costs effort. This is probably the reason why any behaviour that humans can completely master—e.g. to drive a car—becomes almost automatic and unconscious.

However, the process of mechanization can never be completely accomplished without sacrificing the procedure's inferential character. In this case, a living being would completely loose its plasticity. Before this happens, however, changes in the organism's experience will repeatedly reshuffle the cards so that the organism is repeatedly forced to have recourse to other forms of inferences. The "mechanic" set, then, must be considered as an ideal case to which the organism tends in the complex interplay between it and its environment.

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