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ORIGINAL ARTICLE

Towards the emergence of meaning processes in computers from Peircean semiotics

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Abstract In this work, we propose a computational approach to the triadic model of Peircean semiosis (meaning processes). We investigate theoretical constraints about the feasibility of simulated semiosis. These constraints, which are basic requirements for the simulation of semiosis, refer to the synthesis of irreducible triadic relations (Sign–Object–Interpretant). We examine the internal organization of the triad S–O–I, that is, the relative position of its elements and how they relate to each other. We also suggest a multi-level approach based on self-organization principles. In this context, semiosis is described as an emergent process. Nevertheless, the term 'emergence' is often used in a very informal way in the so called 'emergent' computation, without clear explanations and/or definitions. In this paper, we discuss in some detail the meaning of the theoretical terms 'emergence' and 'emergent', showing how such an analysis can lead to improvements of the algorithm proposed.

Keywords Meaning · Semiosis · Emergence · Simulation · C. S. Peirce

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1 Introduction

Computational-based methodologies have been used to design virtual experimental protocols, where it is possible to simulate the predictions derived from theoretical models (Bedau 1998; Parisi 2001), in particular those describing semiotic processes in artificial systems. Computer simulations can be used to study different levels of the organization of semiotic processes (Gudwin and Queiroz 2006; Loula et al. 2004, 2006; Cangelosi and Turner 2002; Parisi and Cangelosi 2002; Perfors 2002). These levels include the simulation of syntactic structures (Batali 1994, 1998; Kirby 1999), morpho-syntactic compositionality (Ellefson and Christiansen 2002), lexicalization phenomena (Hurford 1991; Steels 1999; Cangelosi and Parisi 1998; Steels et al. 2002), symbolic competence (Cangelosi 2001), communication (Hutchins and Hazlehurst 1995; Steels 1997; Steels and Kaplan 1999; Kvasnicka and Pospichal 1999), and meaning creation in communication (MacLennan 2001; Smith 2002).

Here we propose a computational model of C. S. Peirce triadic notion of meaning processes (or semiosis). In order to synthesize artificial systems able to perform some sort of simulated semiosis, we (1) introduce some principles of Peirce's philosophy of sign, (2) define the major theoretical constraints required to semiosis simulation, (3) specify a computational strategy to implement semiosis according to the aforementioned constraints, (4) describe the conditions a process such as semiosis should fulfill in order to be characterized as 'emergent'.

2 Principles of Peircean semiosis

The Peircean list of logical/phenomenological categories (firstness, secondness, thirdness) constitutes an exhaustive system of hierarchically organized classes of relations (monadic, dyadic, triadic) (Houser 1997: p. 14; Brunning 1997). This system is the formal foundation of his architectonic philosophy (Parker 1998: p. 60) and of his model of semiosis (action of signs) (Murphey 1993: pp 303–306; Kent 1997: p. 448). Peirce defined semiosis as an irreducible triadic relation (EP 2:171)[1] between Sign–Object–Interpretant (see Burch 1991; Brunning 1997; CP 1.363, 8.331, 7.537). According to Peirce, any description of semiosis involves, in a non-intuitive way (Deacon 1997: pp 69–70), a relation constituted by three irreducibly connected terms (S–O–I), which are its minimal constitutive elements (MS 318:81, CP 2.242, 2.274).

> A Sign is anything which is related to a Second thing, its Object, in respect to a Quality, in such a way as to bring a Third thing, its Interpretant, into relation to the same Object, and that in such a way as to bring a Fourth into relation to that Object in the same form, ad infinitum (CP 2.92).

[1] We will follow here the practice of citing from the Collected Papers of Charles Sanders Peirce (Peirce 1931–1935, 1958) by volume number and paragraph number, preceded by 'CP'; the Essential Peirce (Peirce 1992, 1998) by volume number and page number, preceded by 'EP'. References to the Annotated Catalogue of the Papers of Charles S. Peirce (1967) will be indicated by 'MS', followed by the manuscript number and pages.

For the purpose of this work, we must consider an important sub-division on the nature of the object:

> We must distinguish between the Immediate Object, - i.e. the Object as represented in the sign, - and the Real (no, because perhaps the Object is altogether fictive, I must choose a different term, therefore), say rather the Dynamical Object, which, from the nature of things, the Sign cannot express, which it can only indicate and leave the interpreter to find out by collateral experience (CP 8.314, 8.343).

In the next section, we investigate these definitions and identify the major theoretical constraints required to simulate semiosis.

3 Peircean semiotic constraints

We divide our discussion on the theoretical constraints into two parts. The first one investigates the relative positions of the elements in semiosis, and the second, the relations of determination between them.

3.1 Relative positions of S–O–I

Let a chain of triads be $T = \{..., t_{i-1}, t_i, t_{i+1}, ...\}$, where $t_i = (a_i, b_i, c_i)$ and $i \in N$. Then, the following conditions must hold:

$$\forall i\colon a_i = c_{i-1} \tag{3.1}$$

$$\exists d\ \forall i\colon \mathrm{ImmediateObject}(b_i, d) \tag{3.2}$$

where the logic predicate ImmediateObject (b_i, d) denotes that b_i is an immediate object of a dynamic object d. It is of paramount importance to notice that the equality expressed in Eq. 3.1 means that, in fact, c_{i-1} and a_i are just aliases for the same thing—c_{i-1} and a_i are roles played by this ‘‘thing’’ within triads t_{i-1} and t_i, respectively. See Fig. 1 for details.

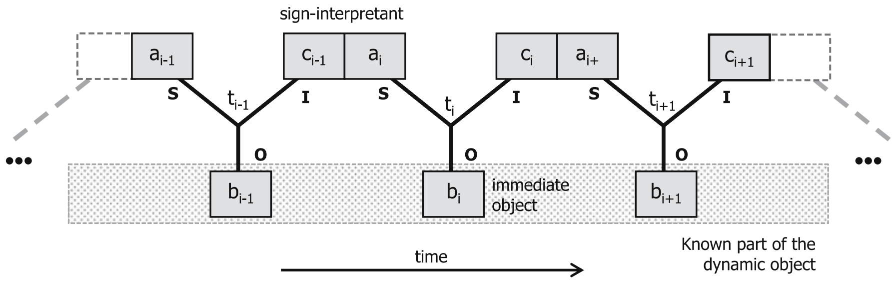

Fig. 1 Model of relative positions of S–O–I. S, O and I are depicted as roles played by the elements. In this sense, for example, a single element may be regarded either as I or S depending on the side from which it is observed

The constraints represented by Eqs. 3.1, 3.2 mean that, given any triad $t_i = (S_i, O_i, I_i)$ in a chain T: (1) its first term (S_i) must be equal to the third term of the preceding triad (I_{i-1}); (2) there exists at least one dynamic object (whole gray area at the bottom in Fig. 1) such that all second terms (O_i) are immediate objects of it; (3) its third term (I_i) must be equal to the first term of the subsequent triad (S_{i+1}); and (4) a triad $t_i = (S_i, O_i, I_i)$ can only be defined as such in the context of a chain of triads $T = \{..., t_{i-1}, t_i, t_{i+1}, ...\}$. First terms are Signs, second terms (O_i) are Objects, and third terms are Interpretants.

3.2 Relations of determination

Determination provides the way triad elements are arranged to form a sign. According to Peirce

> The sign is determined by the object relatively to the interpretant, and determines the interpretant in reference to the object in such a way as to cause the interpretant to be determined by the object through the mediation of the sign (MS 318:81).

These determinations can be rewritten as: (1) O determines S relatively to I and (2) S determines I relatively to O. According to Ransdell (1983: p. 23), determination encompasses both a *causal* and *logical* idea. In this context, how do these causal and logical modes operate? What does a triadic relation expressed as ''*X determines Y relatively to Z*'' means? A computational approach to this problem will be provided in the following sections.

4 Preliminary approach to semiosis

Consider the assumption that semiosis is a dynamical process that happens in time. Hence, each new (simulated) triad is appended to the chain of triads according to the constraints given in Sect. 3, that is:

$$\ldots \rightarrow (S_{i-1}\ O_{i-1}\ I_{i+1}) \rightarrow (S_i\ O_i\ I_i) \rightarrow (S_{i+1}\ O_{i+1}\ I_{i+1}) \rightarrow \ldots$$

We define this level as *focal-semiosis*, because it is the notion of semiosis as described in the previous section, which is, in turn, directly inspired by Peircean semiotics itself. At the focal level, each chain of triads is simulated, and possesses some crucial properties, such as being potentially infinite (unlimited semiosis) and always referring to the same dynamic object. In the work of Peirce and many of his followers, this is the closest we get to the understanding of semiosis as a dynamic process. From a computational viewpoint, in turn, this resolution per se does not provide sufficient knowledge on how to effectively realize the evolution of chains in a computer. So, in order to observe this sort of dynamics, we propose that semiosis operates at three distinct levels, including a level below the focal level, called micro-semiotic, and another level above, called macro-semiotic (see Fig. 2 for details).

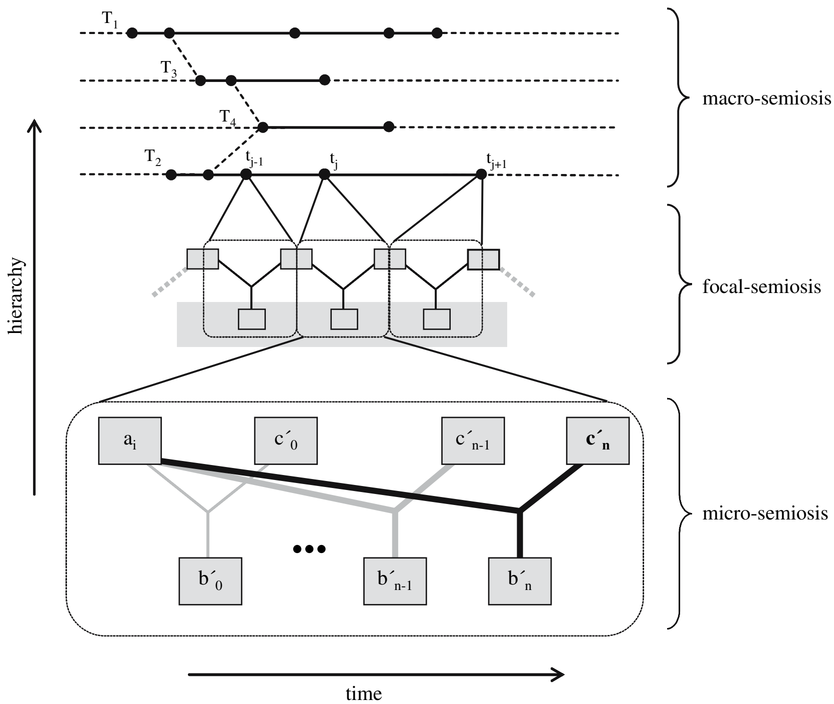

Fig. 2 The three levels of semiosis

At the *macro-semiotic* level, we have a network of evolving chains of triads. These chains interfere with each other. In a sense, this is what Peirce sometimes calls collateral experience, and resembles the idea of system.

At the *micro-semiotic* level, relations of determination between triad elements (S–O–I) are simulated. An important consequence is that S–O–I triadic relations may be created (or simulated) by means of an iterative process. This view is suitable for implementations based on typical computational strategies, as most techniques (neural networks, genetic algorithms, etc.) are based on iterative algorithms. A relation of determination (that connects S, O and I) may be, in this sense, gradually refined until it reaches an adequate trade-off between the computational resources required and the conformity with the theoretical constraints.

5 Proposal for an algorithm

This section presents a computational strategy to implement simulated semiosis within digital computers (see also Gomes et al. 2003a, b). The iterative algorithm proposed here relies on the notions of micro-, focal- and macro-semiosis stated earlier. The level of detail provides a general framework in which computational techniques, such as neural networks, genetic algorithms, classifier systems, and so on, can be applied to effectively simulate semiosis.

5.1 General definitions

There are three modalities of the relation between a first (Sign) and a second (Object)[2]:

1. *intrinsic quality* of S (first term dependent)—such as the relation between a photograph of a cat and the cat itself. The Sign (photograph) shares an intrinsic quality (shape of the body, color, etc.) with the Object (cat), which means that the photograph, in a certain way, represents the real cat;
2. *S–O relational quality* (first-second relation dependent)—such as the relation between smoke and fire. The Sign (smoke) shares an efficient causal relation with its object (fire), because we had a previous experience in which we perceived fire just after we perceived smoke. This means that smoke, in a sense, represents fire; and finally
3. *imputed quality by I to S–O* (third term dependent)—such as the relation between the word ''car'' and its meaning, a typical car. The sign (word ''car'') represents the object (car) by a convention or habit (here given by I).

We should also define the notions of potential Signs, Objects, and Interpretants. A *potential Sign* is something that may be the sign of an Object (*stand for*) to an Interpretant. A *potential Object* is something that may be the Object of a Sign to an Interpretant. A *potential Interpretant* is something that may be the Interpretant of a Sign (*stand to*). A potential Sign becomes a Sign only when submitted to a mediative relation of determination between Object and Interpretant. Being determined by the Object, the Sign is constrained by it. This means that the Sign can only assume its role as a Sign if attested as such by the Object. By determining the Interpretant, the Sign constrains it.

5.2 Algorithm

Consider the statements: (1) O determines S relatively to I, (2) S determines I relatively to O. Arbitrarily, let us start by the first statement. From a computational viewpoint, the first question is: which term comes first in time? If we read determination as a causal process, we will be tempted to say that S = f(O, I). One of the problems with this view is that O is not available before S, and I is not available before O.[3] The fact that O determines S relatively to I means that S assumes its condition because of O (O causes S) and I, but does not mean that either O or I are available. This claim may lead us to a sort of dead-end because it provides no starting point. However, if determination is seen as a logical-causal constraint, there may be alternative ways to perform this process.

Assume that S′, which is available at a certain time *t*, is a potential Sign. S′ has an *interpretive potential*, that is, the faculty of being potentially interpretable (I) as a

[2] This is usually referred to as the second trichotomy of relations (icon, index and symbol), CP 2.247–249.

[3] From Fig. 1, we can see that Si (a_i in the i-th triad) is obtained from I_{i-1} (c_{i-1} in the preceding triad in the same chain).

Sign of something (an Object). Then, we need to find an Object O′ and an Interpretant I′ that assume a triadic relation with S′. If the theoretical constraints (Sect. 3) are satisfied, then we can say that they form a Sign (at a time $t' > t$).

We devised a very general algorithm to realize the process of finding candidates to S–O–I. Roughly speaking, it finds candidates to S and then finds candidates to O and I based on the possible types of relation between Sign and Object. The interesting thing is that a triad may be gradually constructed by means of an iterative process, that is, the simulation of a Sign does not need to be atomic.

It presupposes the notions of 'environment' and 'agent'. The synthetic environment represents the reality that is being forced upon the agents' sensors. The environment is infinitely complex (from the viewpoint of the agents[4]). Agents, who are immersed in the environment, are able to perceive and act on it.

The steps of the algorithm to simulate a triad are as follows:

1. *Choose* a collection of potential signs $\boldsymbol{S}' = \{ s'_i \}$;
2. *Choose* one potential sign s' from this collection;
3. *Propose* a potential object o' and a potential interpretant i', such that there exists a *relation* in one of the three *possible modes* (see above for intrinsic, relational, and imputed qualities). Then, we say that o' determines s' relatively to i'.

As anything can be seen as a sign, the collection of potential signs may encompass virtually everything, including all data gathered by the agent's sensors. The idea here is to provide some sort of focus of attention. It is quite reasonable to propose some sort of *selection mechanism* to increase the quality of the selection of potential Signs.

Step 3 requires some sort of emergent behavior because it is the result of the interaction forces of micro-semiosis and macro-semiosis acting on focal-semiosis. These hierarchies form a complex system of relations. Micro-semiosis represents the potentiality of things to be part of a semiosis, the initial conditions. Macro-semiosis represents boundary conditions, referring to the notion of context. Further details on these levels will be provided in the next section.

In order to implement this algorithm, one must first define some sort of cognitive architecture for the agent, in which sensors and effectors are specified. In this work, many details are deliberately left out. A number of required concepts for simulating semiosis will be treated in detail in a future work.

6 Levels of semiosis

We discuss in this section a model for the emergence of semiosis based on Salthe's (1985) basic triadic system (see Queiroz and El-Hani 2006a, b; El-Hani et al. 2006). Salthe emphasizes that, in order to describe the fundamental interactions of a given entity or process, we need (1) to consider it at the level where we actually observe it (focal level), (2) to investigate it in terms of its relations to its parts, at a lower level (usually, but not necessarily always, the next lower level), and (3) to take in due

[4] This means that the agent is able to perceive only part of its ''reality''.

account entities or processes at a higher level (also usually but not always the next higher level), in which the focal entity or process is embedded. Both the lower and the higher levels have constraining influences over the dynamics of the processes at the focal level. Constraints allow us to explain the emergence of processes (e.g., semiosis) at the focal level. At the lower level, the constraining conditions amount to the possibilities or initiating conditions for the emergent process, while constraints at the higher level are related to the role of an (selective) environment played by the entities at this level, establishing the boundary conditions that coordinate or regulate the dynamics at the focal level. Emergent processes at the focal level are explained as the product of an interaction between processes taking place at lower and higher levels.

It was in conformity with this model that we described above 'micro-semiosis', referring to the relations of determination within a triad; 'focal-level semiosis', corresponding to a given chain of triads; and 'macro-semiosis', amounting to networks of chains of triads, in which each individual chain is embedded. Focal-level semiosis emerges as a process at this level through the interaction between micro- and macro-semiotic processes, i.e., between the relations of determination within each triad and the embedment of each individual chain in a whole network of sign processes.

Micro-semiosis establishes the initiating conditions for focal-level semiotic processes. The domain of micro-semiosis is the domain of potential Signs, Objects, and Interpretants. As there are other determinative relations than the lower-level ones, namely, boundary conditions, the micro-semiotic level cannot fix the actual triads by itself.

The macro-semiotic environment establishes the boundary conditions for the actualization of focal-level semiotic processes. To define a triad $t_{\mathrm{i}} = (\mathrm{S_i}, \mathrm{O_i}, \mathrm{I_i})$, we should consider how it is embedded within both chains of triads $T = \{..., t_{\mathrm{i}-1}, t_{\mathrm{i}}, t_{\mathrm{i}+1},...\}$ and networks or systems of chains of triads $ST = \{T_1, T_2, T_3,..., T_n\}$ that provide the context for the actualization of potential determinative relations within each chain. A given chain of triads $T_{\mathrm{i}} = \{..., t_{\mathrm{i}-1}, t_{\mathrm{i}}, t_{\mathrm{i}+1},...\}$ at the focal level is formed by the actualization—under the regulative influence of the macro-semiotic level—of a series of potential triads engendered by the micro-semiotic level.

The emergence of semiotic processes at the focal level is explained in this model as resulting from an interaction between the possibilities established by the micro-semiotic level and the selective, regulatory influence of the macro-semiotic level. The first step in the algorithm to perform micro-semiosis proposed above, (1) choose a collection of potential signs $S' = \{s'_{\mathrm{i}}\}$, can be interpreted in terms of the establishment of a collection of possibilities or initiating conditions, the set of permutations of possible Signs that can form a chain of triads at the focal level. The actualization of a chain of triads demands, however, steps 2 and 3 in the algorithm, in which a potential sign is chosen and put into relation to a potential Object and a potential Interpretant. Then, boundary conditions established by the network of chains of triads ST, as an environment for a chain of triad T_i, should enter the scene.

7 Emergence of semiosis

Semiosis is described here as an emergent process in a semiotic system. In the context of the sciences of complexity, the concept of 'emergence' has become very popular, to the extent that these fields are often designated as 'emergent computation'. Nevertheless, the precise meaning of the terms 'emergence', 'emergent', etc. is rarely discussed in these fields (for critical commentaries, see Cariani 1989; Bedau 2002; El-Hani 2002).

The notion of emergence employed in the so called 'emergent' computation is so vague that we can find proposals such as that of Ronald et al. (1999), namely, that a subjective reaction of 'surprise' could constitute a test for emergence in a computer simulation. But could not it be the case that this test would rather indicate that there is no emergence in such computer simulations, that what takes place when external observers see allegedly higher-level patterns emerging in the simulation is nothing but a subjective impression? Is the emergence in the simulations themselves or in the eyes of the beholders, or in both?

We intend to use the idea of emergence in a precise way in this paper. For this purpose, we will employ a systematic analysis of emergence theories developed by Stephan (1998, 1999a, b) (see also Queiroz and El-Hani 2006a).

The term 'emergence' should be used in the sciences of complexity in a technical sense. In this sense, emergent properties or processes constitute *a certain class* of higher-level properties or processes related *in a certain way* to the microstructure of *a class of systems*. The reason why such a broad definition, with open clauses, seems at first more adequate than a definition with more content and precision has to do with the fact that the concept of emergence and its derivatives are employed in the most diverse fields. Consequently, a more detailed definition is likely to apply to some fields but not to others. It is here that an emergence theory should enter the scene to fill in the open clauses in the above definition (shown in italics) so as to give it more content and precision in a particular field, providing, among other things, an account of which systemic properties or processes of a class of systems are to be regarded as "emergent" and offering an explanation of how they relate to the microstructure of such systems. Accordingly, the following set of questions should be initially answered in order to apply the concept of emergence in an understanding of semiosis: (1) what is a semiotic system? (2) How can we describe the levels in such systems? (3) Can semiosis be described as a systemic process?

A semiotic system is a system that produces, transmits, receives, computes, and interprets Signs of different kinds (Fetzer 1997). A three-levels model to describe and explain semiotic processes was presented in the previous section, which can be seen, as a whole, as an answer to the second question. As regards the third question, semiosis should be regarded as a systemic process because, as we saw in the previous section, the actualization of potential triads depends on boundary conditions established by a macro-semiotic level, amounting to networks of chains of triads. Therefore, although semiosis is instantiated at the focal level, it can be described as a systemic process.

There is no unified emergence theory. Nevertheless, it is possible to recognize in the diversity of emergence theories a set of central characteristics (Stephan 1999a, Chap. 3).

First, emergentists should, in a scientific spirit, be committed to *naturalism*, claiming that only natural factors play a causal role in the evolution of the universe. Even though naturalism and materialism philosophically do not coincide, in the current scientific picture, a naturalistically-minded emergentist should also stick to the idea that all entities consist of material parts. This thesis can be labeled '*physical monism*': there are, and will always be, only materially or physically constituted entities in the universe, and any emergent property is instantiated by systems that are exclusively physically constituted. A fourth question can be posed, then, regarding the nature of the systems showing semiosis: (4) Are these systems exclusively physically constituted?

Semiotic processes can only be realized through physical implementation or instantiation (see Ransdell 1977), and, thus, semiotic systems should be materially embodied. Sign processes are relationally extended within the spatiotemporal dimension, so that something physical has to instantiate or realize them (Emmeche 2003; Deacon 1999: p. 2).

Another characteristic mark of emergentism is the notion of *novelty*: new systems, structures, entities, properties, processes, and dispositions are formed in the course of evolution. A fifth question can be then proposed: (5) Do semiotic systems constitute a new class of systems, instantiating new structures, properties, processes, dispositions, etc.?

We adopt here an epigenesis view about the origin of systems capable of producing, transmitting, receiving, computing, and interpreting Signs. We assume that, before the emergence of semiotic systems, only reactive systems existed, which were not capable of using Signs. Surely, there were things in the world to which materially embodied natural systems reacted, but these systems were not able to use something as a Sign for something else. Within this reasonable set of assumptions, we can say that semiotic systems constitute a new class of systems, with a new kind of structure, capable of producing and interpreting Signs, and, thus, of realizing semiosis, as an emergent process.

Emergence theories require, also, a distinction between *systemic* and *non-systemic properties* and an assumption of a *hierarchy of levels of existence*. Both issues were addressed above.

Another characteristic of emergence theories is the thesis of *synchronic determination*, a corollary of physical monism: a system's properties and behavioral dispositions depend on its microstructure, i.e., on its parts' properties and arrangement; there can be no difference in systemic properties without there being some difference in the properties of the system's parts and/or in their arrangement. Another question to be addressed, then, is the following: (6) in the context of a Peircean approach to semiosis, in what sense can we say that semiosis is synchronically determined by the properties and arrangement of the system's parts?

To examine the idea of synchronic determination, we have to focus our attention on the relationship between chains of triads, at the focal level, and individual triads, at the micro-semiotic level. Semiosis is synchronically determined by the microstructure of the individual triads composing a chain of triads, i.e., by the relational properties and arrangement of the elements S, O, and I. There cannot be any difference in semiosis without a difference in the properties of S, O, and I and/or in the arrangement S–O–I.

Although some emergentists have subscribed to indeterminism, one of the characteristics of emergentism (at least in the classical British tradition[5]) is a belief in *diachronic determination*: the coming into existence of new structures was regarded in this tradition as a deterministic process governed by natural laws (Stephan 1999a: p. 31). This is certainly one feature of classical emergence theories which is incompatible with Peirce's theoretical framework, as he rejected determinism, maintaining that an element of indeterminism, spontaneity, and absolute chance is present in the natural world (CP 6.201). But this does not hamper the treatment of emergence in connection to a Peircean account of semiosis, as there are also emergence theories committed to indeterminism (e.g. Popper, in: Popper and Eccles (1977, 1986).

The concepts mentioned above are sufficient for the proposal of a weak emergence theory, compatible with reductive physicalism. Emergentists, however, usually aim at non-reductive physicalist accounts, which demand two additional notions as a ground for stronger emergence theories: irreducibility and unpredictability.

Stephan (1998, 1999a, b) distinguishes between two kinds of irreducibility. The first notion is based on the behavioral unanalyzability of systemic properties: (I_1) [Irreducibility as unanalyzability]. Systemic properties which cannot be analyzed in terms of the behavior of the parts of a system are necessarily irreducible. A second notion of irreducibility is based on the non-deducibility of the behavior of the system's parts: (I_2) [Irreducibility of the behavior of the system's parts]. A systemic property will be irreducible if it depends on the specific behavior the components show in a system of a given kind, and this behavior, in turn, does not follow from the components' behavior in isolation or in other (simpler) kinds of system[6] A seventh question is the following: (7) in what sense should we understand Peirce's claims about the irreducibility of semiosis?

The semiotic triadic relation is regarded by Peirce as irreducible, in the sense that it is not decomposable into any simpler relation (e.g. CP5.484). As Peirce himself specifically discusses the irreducibility of triads, we will consider in the following arguments what we defined above as the micro-semiotic level. For Peirce—if we interpret his ideas correctly, it is not the case that the semiotic relation is irreducible because the condition of analyzability is violated. That is, Peirce would accept that from the behavior of the elements of a triad it must follow the properties the triad possesses, including the very property of being a semiotic process. We can understand why a semiotic relation is irreducible, in a Peircean framework, on the

[5] on british emergentism, see Blitz (1992), McLaughlin (1992), Stephan (1999a).

[6] it is here that the notion of downward causation (DC) enters the scene: there seems to be some downward causal influence of the system where a given emergent property *P* is observed on the behavior of its parts, as we are not able to deduce this behavior from the behaviors of those very same parts in isolation or as parts of different kinds of system (see El-Hani and Emmeche 2000). Nevertheless, we will not deal with the problem of DC here, for reasons of space.

grounds of the second notion of irreducibility discussed above. In this case, we should show that the specific behavior of the elements of a triad is irreducible because it does not follow from the elements' behavior in simpler relations (i.e., monadic or dyadic relations). This is indeed the case: according to Peirce, if we consider only a dyadic relation, S–I, S–O or I–O, or an element of a triad in itself, we cannot deduce how they would behave in a triadic relation, S–O–I (EP 2:391).

Strong emergence theories can also be based on the ''in principle theoretical unpredictability'' of novel properties or structures. The notion of 'genuine novelty' then enters the scene: a genuinely new property or structure cannot be theoretically predicted before its first appearance. A systemic property can be unpredictable in this sense for two different reasons (Stephan 1998: p. 645): (1) because the microstructure of the system exemplifying the property for the first time is unpredictable; (2) because it is irreducible, and, in this case, it does not matter if the system's microstructure is predictable or not. The second case of unpredictability offers no additional gains beyond those obtained in the treatment of irreducibility. For this reason, we will focus on the first condition. We should ask, then, (8) whether the structure of semiotic systems can be in principle theoretically unpredictable?

The structure of triads and chains of triads can be regarded as unpredictable in a Peircean framework, because Peirce held the view that an element of indeterminism, spontaneity, and absolute chance is present in the natural world. Then, the behavior of the elements in a semiotic process is unpredictable from their behavior in simpler systems, and, therefore, semiosis, as an emergent process, is theoretically unpredictable.[7]

We hope the conditions which should be fulfilled for semiosis to be characterized as an emergent process in semiotic systems were made clear in this section, contributing to a more precise account of emergence in the context of the simulation of semiotic processes in digital computers. The arguments developed in this section lead to the conclusion that, in the case of semiotic processes, a strong theory of emergence can hold, including a concept of irreducibility based on the non-deducibility of the behavior of Signs, Objects, and Interpretants in triadic relations from their possible behaviors in simpler relations, and on the theoretical in principle unpredictability of the structure of semiotic processes.

8 Conclusions

Currently, there is no tractable computational model based on a strict definition of Peirce's semiosis. The research reported in this paper strives for a solid understanding on how to simulate Peircean semiosis (meaning processes) within computers. We have developed in this article a brief overview of Peircean semiotics, and pointed out two fundamental constraints required to simulate

[7] notice that the two reasons for the unpredictability of systemic properties have very different status, while the second is empirical in nature, particularly if irreducibility is interpreted in terms of non-deducibility, the claim of in principle theoretically unpredictability in the peircean framework depends on a metaphysical approach committed to fundamental indeterminism, which a thinker can clearly reject.

semiosis, namely, the relative position of the elements of a triad and the relations of determination between them. A model for explaining the emergence of semiosis grounded on Salthe's (1985) basic triadic system was employed to establish another set of theoretical constraints. Based on both sets of constraints, we proposed a general algorithm to accomplish artificial semiosis. This proposal still lacks many details, but sketches a general framework to design experimental semiotic systems. We also established the conditions which should be fulfilled for semiosis to be characterized as an emergent process in semiotic systems. Further developments will include a more detailed algorithm, and an implementation of artificial semiosis in digital computers.

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