A Semiotic Approach to Complex Systems

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1 Introduction

A key topic in the work of Burghard Rieger is the notion of meaning. To explore this notion, he and his collaborators developed a most sophisticated approach combining theoretical ideas and concepts of semiotics with empirical and numerical tools of computational linguistics (see [31] for a most recent comprehensive account). In the present contribution, relations of Rieger's achievements to some issues of interest in the physics and philosophy of complex systems will be addressed.

The notion of meaning will first be introduced in the framework of the Cartesian distinction between mind and matter or, more precisely, between states and properties of mental and material systems as well as their dynamics. In this dualistic framework, meaning can be formulated in terms of a reference relation between a descriptive term (in a model or a theory) and an object (or a set of objects) in the material world.

Such a reference relation can be considered from a semiotic point of view first proposed by Peirce. Within the semiotic triad of syntactics, semantics, and pragmatics, the notion of meaning forces us to leave a purely syntactic level of discussion and include questions of semantics and pragmatics.

The significance of the semiotic triad in a relatively new field of modern physics, the study of complex systems, will then be outlined. The crucial point is that the concept of complexity can be defined in a way permitting a straightforward semiotic interpretation. This interpretation may be conversely used to discuss basic methodological cornerstones of traditional physics in view of some of its novel developments.

Some speculative perspectives toward an implicit, non-dualistic kind of meaning without explicit reference relations conclude this contribution. This reflects Peirce's conviction that semiotics is ultimately holistic. In terms of Rieger's approach, it reflects the idea that mental processes "not only cut across the distinction of mind and matter but can even be considered to underlie and allow for this distinction" ([31], p. 352).

2 The Cartesian Distinction

In the night from November 10 to 11, 1619, close to the German city of Ulm, the French soldier René Descartes had a series of dreams.[3] According to virtually all biographers of Descartes, these dreams were of key influence for his future philosophical insights and achievements. Waking up the morning of November 11, he was left with the persistent question of how he could ever know for sure whether he was indeed awake or still dreaming. Major parts of his philosophy were motivated by the crucial question of how to reliably distinguish between dream and reality, including the most fundamental issue of the reality of one's own existence. Descartes' solution of this problem is reflected in his famous "cogito ergo sum", one of the most-cited quotations of European philosophy.

Roughly speaking, this solution rests on Descartes' proposal to distinguish material and mental domains of reality, leading to Cartesian dualism as an essential part of his philosophy. Of course, this dualistic stance does not characterize his thinking exhaustively. Descartes' philosophical writings are very rich, they are partially incoherent, and they cover much more than the split of matter and mind. Nevertheless, it is correct to speak of a "Cartesian" distinction at least insofar as some of Descartes' successors, notably those who contributed to the development of the natural sciences, compactified and simplified Descartes' thoughts considerably. For this reason the notion of a Cartesian distinction, or Cartesian cut [28], should be considered as a central term of "scientific Cartesianism".

Since Descartes' time, the Cartesian distinction turned out to be an extremely powerful tool for reducing the arbitrariness inherent in the allegorical and speculative schemes of late scholasticism and Renaissance neoplatonism; it provided the possibility of a rational, consistent description of reality. In Descartes' terminology, the Cartesian distinction splits the entirety of reality into a material component (*res extensa*) and a non-material component (*res cogitans*) [14]. These labels, literally translated, characterize the realms of "extended substance" and "thinking substance". The notion of extension in *res extensa* refers to the fact that material reality is extended in its spatial location and in its temporal duration (although Descartes himself did not put much emphasis on the latter). The notion of cognition in *res cogitans* is probably best characterized as referring to conscious activity in general rather than "thinking" in the narrow sense of cognitive capabilities.

[3] Baillet [6] reported this series of three dreams in his biography of Descartes. Especially the second and third dream contain elements clearly referring to the issue of distinguishing between realistic chains of events and unrealistic chains of events as they are typical for dreams. Of course, much more material is contained in Baillet's report which has been analyzed in a number of accounts. For a detailed interpretation of Descartes' dreams, together with an overview concerning other accounts, see [16].

The Cartesian distinction can therefore be regarded as a conceptual border between a material and a mental domain. Without any reasonable doubt this is of central significance for the world view Western science and philosophy have developed. On the other hand it is obvious that this cut is nothing more than a conceptual tool – it is itself not an object in the material world, but belongs to the non-material world of *res cogitans*. Although Descartes himself thought he had *discovered* the cut as an ontological fact superior to the realms it separates, it is today much more appropriate to say that he *invented* it. So the question arises as to whether there might be modes of mental activity (i.e., operations within *res cogitans*) reducing the relevance of the Cartesian distinction, or even avoiding it completely, at least in its rigorous interpretation of a prescribed and impenetrable border.

This question receives additional motivation by the fact that this border is simply not recognized during many kinds of mental activity as it operates in practice. Who does explicitly and consciously distinguish between what he sees (as a fact) and what he thinks he sees (as his model of this fact)? Is it possible to make this distinction at all, and, if yes, how can it be cognitively realized? Moreover – a bit apart from everyday experience, but still close to the subject of this article – each abstract scientific model contains terms which refer to objects in the material world of concrete, empirical, material facts. The corresponding relation of reference is crucial for the possibility to check the validity of a model [4]. Reference relations of this kind express the interpretation or, more colloquially, the meaning of conceptual terms with respect to objects in the material world. In this sense they are relations across the Cartesian distinction.

In other words, issues of meaning are primary candidates for the connection of material and mental domains of reality, and they are of fundamentally relational character. In the following section, another, more recent approach to address meaning will be outlined.

3 The Semiotic Approach

The father of present-day semiotics is Charles Sanders Peirce. He developed semiotics as a theory of signs which is always embedded in a framework of relations. In [27] (vol. 2, §274), he says:

> A *Sign*, or *Representamen*, is a First which stands in such a genuine triadic relation to a Second, called its *Object*, as to be capable of determining a Third, called its *Interpretant*, to assume the same triadic relation to its Object in which it stands itself to the same Object. The triadic relation is *genuine*, that is its three members are bound together by it in a way that does not consist in any complexus of dyadic relations.

This quotation expresses the basically holistic significance that Peirce ascribed to the semiotic triad. Nevertheless, contemporary semiotic approaches often, maybe even typically, distinguish the semiotics areas of syntactics, semantics and pragmatics. Syntactics deals with (grammatical or stylistic) interrelations among signs, e.g. in a code. Semantics deals with interrelations between signs and what they designate, i.e. their meaning. And pragmatics addresses relations between signs and their users. Correspondingly, one can conceptually distinguish syntactic, semantic and pragmatic information [26]. In contrast to Peirce's quotation above, their demarcation may be justified from an abstract, analytical viewpoint where signs can be considered without their relational context. From a phenomenological ("lifeworld") point of view, concrete signs are never context-free: concreteness requires context. In this sense, the notion of concreteness entails some type of holism, lifting the conceptual separation inherent in the distinction between syntax, meaning, and usage.

With respect to models or theories, the syntactic component can be considered to refer to their formal codification, the semantic component addresses their interpretation, and the pragmatic component comprises their range of applications. From this example, it is evident that a formal codification without interpretation and application is possible only in an abstract sense. The concrete development of a theoretical concept is never isolated from its meaning and, ultimately, usage. Every element of syntax is inseparably linked to semantic and pragmatic aspects.

Nevertheless, the history of semiotic aspects of information has shown that it can be methodologically helpful to distinguish them analytically. For particular technical problems of communication through noisy channels, aspects of syntactic information were extensively studied in the influential publication by Shannon [33], which explicitly omits any reference whatsoever to meaning-related or pragmatic issues. Shannon-type information is purely syntactic insofar as it quantifies by which amount a message carrying information reduces the uncertainty of a receiver as compared to his/her state before receiving that message. Weaver's contribution in [33] already pointed out that this syntactical component of information requires extension to semantic and pragmatic aspects (for more details see [3]).

Shortly after Shannon's work, Bar Hillel and Carnap [8] proposed to quantify semantic information based on a receiver's ability to draw logical consequences from a message. If a message contains a huge amount of syntactic information, which is not or cannot be understood by its receiver, then he/she cannot draw conclusions from it. But yet the problem remains how to evaluate, or operationalize, an understanding of information. Clearly, self-reports may be insufficient for this purpose, not only since they may be mistaken, but more importantly for the reason that they can hardly be normalized and, thus, are uncomparable.

At this point, the significance of pragmatic information becomes clear. If semantic information, i.e. meaning, is understood, then it triggers action, e.g. changes efficiency, or leaves some other imprint on the behavior of its receiver. (In this sense, focusing on pragmatic information resembles a particular kind of behaviorism.) A corresponding concept has been proposed by von Weizsäcker [38] and further developed in [24, 17].

It relies on the two notions of *primordiality* ("Erstmaligkeit") and *confirmation* ("Bestätigung"). Weizsäcker argued that a (redundant) message that does nothing but confirm the prior knowledge of a receiver will not change its structure or behavior. On the other hand, a message providing only material completely unrelated (primordial) to any prior knowledge of the receiver will also not change its structure or behavior, simply because it will not be understood. In both cases, the pragmatic information of the message vanishes. A maximum of pragmatic information is assigned to a message that transfers an optimum mixture of primordiality and confirmation to its receiver. For the limiting case of complete confirmation, purely syntactic Shannon information and pragmatic information vanish coincidentally. If primordiality is added, Shannon information increases monotonically.

4 Concepts of Complexity

In recent decades, complexity has become an extremely popular notion covering a huge variety of different kinds of behavior. From a scientific point of view, such a colorful concept is useful only in combination with a clear-cut definition. However, there is a plenitude of different concepts of complexity. A systematic orientation among them requires a reasonable classification. There are several approaches that can be found in the literature: two of them are (i) the distinction of structural and dynamical measures [36] and (ii) the distinction of deterministic and statistical measures [13]. Another, epistemologically inspired scheme (iii) assigns ontic and epistemic levels of description to deterministic and statistical measures, respectively [2, 32].

In addition to these approaches, a purely phenomenological criterion for classification can be given by the functional behavior in which a complexity measure is related to measures of randomness.[4] Within such an approach (for an early reference see [37]), there are two classes of complexity measures: (iv) those for which complexity increases monotonically with randomness and those with a globally convex behavior as a function of randomness (cf. Fig. 1). It turns out that classifications according to (ii) and (iii) distinguish measures of complexity in precisely the same manner as (iv) does: deterministic or ontic measures behave monotonically, and statistical or epistemic measures are convex. In other words: deterministic (ontic) measures are essentially measures of randomness, whereas statistical (epistemic) measures are not.

The class of monotonic measures of complexity contains, e.g., algorithmic complexity [23], various kinds of Rényi information [7] (among them Shan-

[4] It is worth mentioning that randomness itself is a concept that is anything but finally clarified. In the framework of the present paper we use the notion of randomness in the broad sense of an entropy.

non's information [33])), multifractal scaling indices [21], or dynamical entropies [22]. The class of convex measures of complexity contains, e.g., effective measure complexity [18], ϵ-machine complexity [13], fluctuation complexity [10], and variance complexity [5]. See also [25, 15] for further discussion.

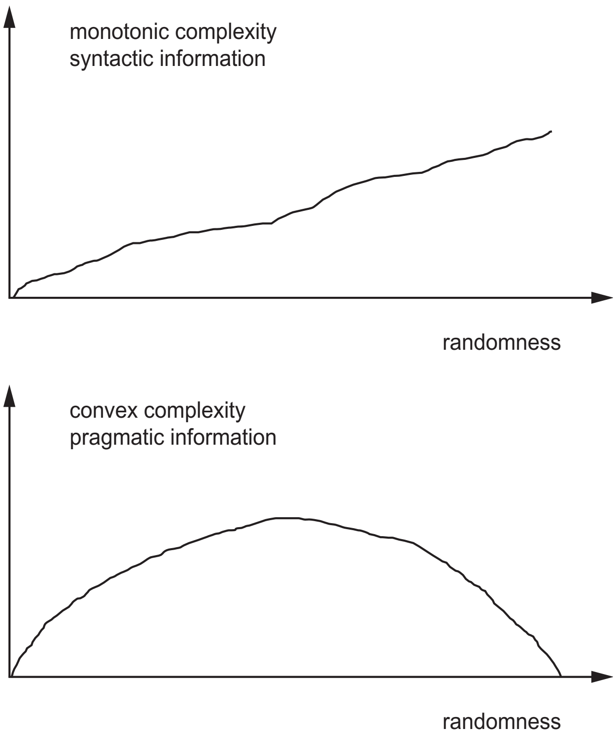

Fig. 1. Schematic illustration of two different classes of complexity measures, corresponding to different information measures and distinguished by their functional dependence on randomness.

A most intriguing additional difference (v) between both classes can be recognized if one focuses on the way statistics is implemented in each of these measures. The crucial point is that convex measures, in contrast to monotonic measures, are *meta*-statistically formalized, i.e. effectively represent (in one or another way) second-order statistics in the sense of "statistics of statistics". Fluctuation complexity is the standard deviation (second-order) of a net mean information flow (first-order); effective measure complexity is the convergence rate (second-order) of a difference of entropies (first-order); ϵ-machine complexity is the Shannon information with respect to machine states (second-order) that are constructed as a compressed description of a data stream (first-order); and variance complexity is based on the variance (second-order) of the mean of many individual variances (first-order) of a distribution of data. To our knowledge, there is no monotonic complexity measure providing such a two-level statistical structure. Although it would be desirable to have a theorem for the corresponding relationship between convex complexity measures and their two-level statistical structure, such a theorem is not yet available.

5 Complexity and Information

Since so many complexity measures bear an intimate relation to information theoretical concepts, it is interesting to see whether first-order and second-order complexity measures can be related to corresponding information measures. For this purpose, let us now consider some examples.

Applying a proper algorithm in order to generate a regularly alternating, periodic pattern, the corresponding generation process is obviously recurrent after the first steps, i.e., after the generation of the first elements of the pattern. Considering the entire generation process as a process of information transmission, it presents only confirmation of its first time steps once they have passed by. In this sense, a regular pattern, exhibiting no complexity, corresponds to a process of information transmission that has vanishing pragmatic information (or "meaning") after an initial transient phase (the first time steps). This applies to both notions of complexity, the deterministic as well as the statistical one.

For a completely random pattern the situation is more involved, since deterministic complexity and statistical complexity lead to different viewpoints. Deterministically, a random pattern is generated by an incompressible algorithm which contains as many steps as the pattern contains elements. The process of generating the pattern is not recurrent within the length of the algorithm. This means that it never ceases to produce elements that are unpredictable, except under the assumption that the entire algorithm was known *a priori*. Such knowledge, however, would imply that the pattern itself were known, since the algorithm is nothing but an incompressible description of it. Hence, the process generating a random pattern can be interpreted as a transmission of information completely lacking confirmation, and consequently with vanishing pragmatic information.

As a consequence, there is indeed a strong conceptual similarity between complexity measures and information measures. Pragmatic information is as convex as second-order complexity, and syntactic information is as monotonic as first-order complexity (compare again Fig. 1). In this context, it is worthwhile to mention that quite a number of authors have emphasized that the concept of meaning, reference, or intentionality is essential to a definition of complexity [18, 1, 12, 2, 11, 20]. For instance, Grassberger wrote [19]:

> Complexity in a very broad sense is a *difficulty* of a *meaningful task*. More precisely, the complexity of a pattern, a machine, an algorithm, etc. is the

> difficulty of the most important task related to it. [...] As a consequence of our insistence on *meaningful* tasks, the concept of complexity becomes *subjective*. We really cannot speak of the complexity of a pattern without reference to the observer. [...] A unique definition with a universal range of applications does not exist. Indeed one of the most obvious properties of a complex object is that there is no *unique* most important task related to it.

This quotation can be assessed in more detail if the two classes of complexity measures and associated information measures as discussed above are taken into account. Since monotonic, first-order measures of complexity are related to purely syntactic information, they can only be used to characterize systems in a way disregarding meaning. If meaning is to be considered explicitly, one has to proceed to semantic or pragmatic information and associated convex, second-order measures of complexity. Corresponding definitions of complexity provide the validity domain to which Grassberger's quotation applies.

In this respect, a conceptual framework relating second-order complexity measures to the notion of second-order models of complex systems has been outlined recently [4]. This approach is motivated by the idea that any reference relation between models and data, e.g. meaning, can only be explicitly addressed from the perspective of a meta-model, or second-order model. This move implies interesting consequences, some of which are explored in [4].

Two points should be stressed at the end of this section. First, the fact that monotonic complexity is not related to meaning does not imply that corresponding measures are useless or ill-defined. It is obvious that there are many interesting applications of first-order complexity measures, and their benefit is that they do not lead to the complications which second-order complexity entails. Second, it should be kept in mind that, in contrast to syntactic information, semantic and/or pragmatic information are not defined as precisely as desirable. Hence their relation to second-order complexity cannot be demonstrated as clearly as the relation between monotonic complexity and syntactic information. Nevertheless, their common feature of convexity is prominent enough to conjecture an intimate connection between convex complexity and semantic/pragmatic information.

6 Implicit Meaning without Explicit Reference

Complexity is a concept that has its origin in the study of physical properties of material systems. Meaning, on the other hand, originates in human concerns. It has become a topic of philosophy and, more recently, cognitive science, and is discussed as pertaining to a non-material domain. From this viewpoint, the concept of meaning is prior to the complexity of the brain as the material carrier of mental states.

From a material perspective, however, the complexity of a system is prior to its capability to constitute and understand meaning. In fact, it seems plausible to expect that a certain degree and kind of complexity is a precondition for the capability of a system to constitute and understand meaning. Although it is still unclear what the exact criteria are in this respect, it would certainly be far too anthropocentric to fix them such as to exclude non-human beings.[5] It is even an open question to what extent meaning might be a reasonable concept for non-living systems. Atlan [1] has proposed distinguishing different types of complexity and to assign the notion of meaning only to a specific one among them. Approaches like those of von Weizsäcker [38] or Crutchfield and Young [13] do not restrict the notion of meaning in this manner.

Focusing back on the convexity of both second-order complexity and pragmatic information, it is remarkable how the perspectives of physics (complexity) and of cognitive science (meaning) show an explicit *complementarity* [2, 4]. As Casti states [11], "the impression of complexity often appears as something like the expression of an experience of meaning". And Sheriff, interpreting Peirce, writes similarly [34]:

> We might say that the unlimited complexity of the object that the representamen [sign] denotes is the "external", and the indefinite continuity of consciousness that the interpretant of the sign signifies is the "inward" view of a sign.

A complementarity relation between two (or more) concepts typically indicates that the respective concepts share important features at a level of description underlying that at which the complementarity relation applies. With respect to the notions of complexity and meaning this can be taken as a hint to look for a common ground at which they are *implicitly* embedded and from which they emerge as *explicitly* different concepts under particular conditions. A top candidate for such conditions is the need for distinctions in order to gain epistemic access. In this sense, the Cartesian distinction can be regarded as a tool that generates the complementary concepts of complexity and meaning, which are unseparated without that distinction.

Another way to look at scenarios like this, motivated by physical examples, uses the terminology of symmetry breakings and contextual representations [29]. Insofar as symmetries (also called invariances) express indistinguishability, breaking symmetries means nothing else than introducing distinctions.[6] As Primas [29] has discussed in detail, symmetry breakings, leading to emergent properties, always require contextual conditions to be fixed. Such contexts

[5] Nevertheless, notions of meaning intended to apply beyond human beings (e.g., animals or AI systems) are often configured by analogies or similarities with our everyday notion of meaning.

[6] For instance, consider the homogeneity and isotropy of a property of a system in space. These two terms express translational and rotational symmetry in such a way that the considered property is indistinguishable with respect to translations and rotations in space. Breaking the translational symmetry generates distinguishable (local) positions, breaking the rotational symmetry generates distinguishable (local) directions.

are often introduced by the environment of a system, allowing a contextual representation of its states and properties that is different from a less specific (more general) representation of the system without the chosen context.

Introducing new contexts and breaking symmetries is, therefore, a viable approach to understand the emergence of complexity in physical systems. Stepping back from the material domain of physics, it is tempting to use the same idea to describe the emergence of this domain as such versus its non-material counterpart. This means to apply the notion of a distinction as a, or even as *the*, basic tool to achieve epistemic access, i.e. gather knowledge.[7] In this way, the Cartesian distinction of material and mental domains of reality plays a significant role for the distinction of complexity and meaning.

To the same extent as the distinction between complexity and meaning is blurred, we have to face a reality in which mind and matter are not as unrelated as they appear from the viewpoint of traditional science and its established methodology. Possible modifications with respect to cornerstones of scientific methodology have been proposed and discussed elsewhere [4]. Particularly interesting in this context is the notion of reproducibility, a basic requirement for using empirical facts and data to reject or confirm models and theories. This presuposes a well-defined reference relation between theoretical terms and empirical data, which can be addressed in a second-order modeling framework as it is necessary for complex mind-matter systems. For more details, see [4].

Questioning the unrestricted assumption of a perfect Cartesian distinction, it becomes problematic to develop or maintain a clear-cut understanding of complexity and meaning in terms of reference relations between separate mental and material domains. This leads to the question of how meaning could be conceived without an explicit decomposition of the semiotic triad, i.e. within the holistic framework of Peirce's original ideas.

This has been and is a central issue in Rieger's work. His starting point within the field of linguistics, as far as I can reconstruct it (see, e.g., [30]), received major input from the development of "situation semantics" (see, e.g., [9]). This approach emphasizes the difference between abstract and concrete reference relations as discussed above. It focuses on the concrete aspects in terms of the embodiment and situatedness (and related concepts) of cognitive systems. Their environmental constraints serve as contexts of different degrees of generality, thus leading to nested systems of corresponding contextual knowledge representations.

Explicitly emphasizing the concrete side of semiosis, the traditional paradigm of cognitive information processing becomes *semiotic* in the sense of Peirce's original intention. Using fairly sophisticated formal instruments and

[7] In a pronounced way, Spencer-Brown proposed such a procedure as the basis of all cognitive activity in [35]: "We take as given the idea of distinction and the idea of indication, and that we cannot make an indication without drawing a distinction."

concepts, Rieger developed a wonderfully refined framework allowing him to define and model the constitution and understanding of meaning on the empirical basis of natural language structures. Readers interested in details will especially enjoy sec. 5 in [31], which is compactly summarized in Fig. 6 of [31].

It is evident that modeling concrete aspects of semiotics requires a second-order approach insofar as any model of those concrete aspects is inevitably abstract. Therefore, a natural extension of semiotic cognitive information processing models is the concrete implementation of these models in terms of "agents" capable of constituting and understanding meaning. Indeed, successful first steps into this direction have been reported in sec. 7 of [31]. Although these first steps are still fairly simple, they allow us to hope for further insight into the fascinating problem of how meaning can emerge from an implicit, holistic domain to an explicit reference relation.

I do not know a comparably viable and promising approach to address the problem of meaning, as related to mind-matter relations in general, with such detailed knowledge and broad relevance. Rieger's work is so attractive because it combines the merits of being philosophically informed, conceptually convincing, formally elaborated and empirically grounded. He has initiated and achieved continuing progress concerning our understanding of the notion of meaning – one of the most difficult and most interdisciplinary topics of consciousness research. Independent of the hustle and bustle of contemporary "scientific business" and all its ramifications, this work will endure.

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