Irreducible and complementary semiotic forms

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The problem background and motivation

As a young Research Associate in physics, my first serious thinking about the nature of symbols was stimulated by the physicist Max Born (1965a) in a paper titled 'Symbol and reality', in which he recalls as a young student his own shock when it dawned on him that all our perception and mental imagery, 'everything without exception', is entirely subjective, and that only by the use of symbols can we communicate any objective (i.e., socially consensual) descriptions of our subjective, private experiences. Born's condition for the consensual use of symbols is 'decidability', a term he coined to express the function of experiment. If a symbolic expression lacks empirical decidability it has no necessary relation to reality.

My second motivation for understanding the nature of symbols arose from the origin of life problem. I had just completed my doctoral research on X-ray optics used to study biological structures. At the time I was a strong reductionist, as were my colleagues in biology. Discovering the physical structure of nucleic acids and proteins was still a major focus of molecular biology. It was apparent, however, that self-replication of such complex structures was an entirely different type of problem. Recalling Born's explanation of symbol function, I realized that reliable self-replication also requires objective communication of whatever structure is replicated. In other words, for evolution to be possible, any description of a 'self' must be communicated objectively to all descendent cells no matter what particular 'self' is being replicated. If that is the case, then the origin of life, as genome-code-cell, coincided with the origin of descriptive systems, as symbol-interpretant-referent.

I had tried several self-organizing schemes using automata models for generating and replicating simulated copolymer sequences (Pattee 1961, 1965a, 1965b), and it became clear that the evolutionary potential of all these models was very limited. I eventually recognized a fundamental

Semiotica 134–1/4 (2001), 341–358 0037–1998/01/0134–0341

problem in all such rule-based self-organizing schemes, namely, that insofar as the organizing is determined by fixed rules, the generated structures will have limited potential complexity, and insofar as any novel organizing arises by chance, the generated structures have no possibility of reliable replication without a symbolic memory that could reconstruct the novel organization.

I found support for the necessity of symbolic description, as distinct from dynamical construction, in von Neumann's (Neumann 1966) discussion of the logic of self-reproducing automata. He argued that in order to achieve what he saw as, 'this completely decisive property of [evolvable] complexity', replication must be controlled by a description that is distinct from the constructions it controls. He gave two reasons why he felt that a logically separate description was necessary. First, without a description, an evolvable construction would have to inspect itself to make a copy, and he felt that complete self-inspection would lead to a logical paradox as do many well-known self-referent statements. Second, detailed self-inspection in an active dynamical system would interfere with its normal operation while a 'quiescent' memory-stored description would not.

Von Neumann's argument was largely intuitive and left many questions unaddressed. In particular, he did not pursue the possible physical implementations of his logic, although he was fully aware that by restricting his study to logical (axiomatic) models he was not asking what he called, 'the most intriguing, exciting, and important questions of why the molecules … which in nature really occur … are the sort of things they are' (1966: 77). He did not address the problem of the necessary physical conditions that would allow molecules obeying physical laws to function both as 'quiescent' symbolic descriptions and as actively dynamic controlled constructors. In other words, von Neumann chose to restrict his study of self-replication to only symbolic models (cellular automata) and not to deal with reality. In Born's words, his models lacked decidability. The potentially decidable questions that von Neumann avoided, about why the molecules of life are the sort of things they are, and what is required for a law-abiding molecule to also exhibit semantic content have motivated much of my subsequent thinking.

At Conrad Waddington's Bellagio meetings on theoretical biology (1966–1971) I took up what appeared to be a reductionist question: What are the most elementary physical requirements for molecules to function as symbols? It turned out that expressing these requirements for even the simplest known case, the gene, required irreducibly complementary descriptions. This primeval symbol/matter distinction is, in fact, the first instance of the notorious epistemic cut, as are the higher level distinctions between the subject and object, the knower and the known, and the mind and the brain (Pattee 1972a).

It was also at the Bellagio meetings that the philosopher Marjorie Grene (1974) introduced me to Michael Polanyi's insights on the failure of all our symbolic expressions, even formal mathematical expressions, to achieve the ideal of objectivity. Polanyi's (1958) anti-reductionist arguments show how all of our explicit symbolic descriptions must be grounded in a reservoir of ineffable subsidiary knowledge. In a later article Polanyi (1968) also shows that biological complexity must be associated with boundary condition structures or constraints rather than with the dynamics of physical laws, and he recognizes the irreducibility of evolved functional hierarchical levels of complexity (Pattee 1969a).

The meaning of irreducible and complementary

I mean by irreducible only that a precise description at one level is not derivable from, or reducible to, a lower level without additional principles. Furthermore, complementary descriptions differ by some essential elements that cannot be usefully integrated into one consistent description. The classical physics example is reversible and irreversible dynamics. Irreducibility and complementarity are not properties of reality but of our symbolic descriptions of reality. This also conforms to Robert Rosen's (1985: 322) concept of complex system that depends on the number of non-equivalent, irreducible descriptions we require to comprehend the system. While I do consider the probable evolutionary sequence of forms and their dependence on brain structures as empirically decidable, I regard their ontological status as empirically undecidable and therefore a metaphysical question over which, in my opinion, there is a vast wasteland of polemic literature. I discuss only three distinguishable types of irreducible forms: *hierarchic*, *nonlinear*, and *epistemic*. There are certainly other irreducible forms that emerge at higher levels of function, cognition, and natural language.

Hierarchical irreducibility

Polanyi (1968: 1310) describes a concept of hierarchy '… in which each higher level represents a distinctive principle that harnesses the level below (while being itself irreducible to its lower principles) …'. Irreducibility does not mean that higher levels do not have a correct lower level description. The point is that such 'correct' descriptions may have no value. When asked whether everything has a correct scientific description, Einstein replied, 'Yes, that is conceivable, but it would be of no use. It would be a picture with inadequate means, just as if a Beethoven symphony were presented as a graph of air pressure' (Born 1965b). As my examples also will show, some aspects of the lower level forms must remain tacit if the higher level description is to be efficacious. For this reason, complementary descriptions are necessary for understanding inter-level behavior. The interaction between levels must also be described as both restrictive and generative. Higher levels do not evade the more detailed laws of lower level forms, but are insensitive to details, thereby gaining some degree of autonomy by constraining lower level forms (e.g., Pattee 1973). I mention only the hierarchical levels that are essential for grounding the simplest symbolic behavior (i.e., there are higher and lower levels). My broadest distinctions between levels are (1) physical forms, (2) structural forms, (3) naturally selected forms, but each of these can have levels within them.

1. Physical forms. These forms are well-known. They arise directly from physical laws and have many 'partially decomposable' levels of description depending largely on energy, space, and time scales (e.g., Simon 1996). Most laws are expressed as differential equations (time derivatives) in which forms can be understood as various types of more or less stable solutions. According to this level of description laws are universal and inexorable. Nothing evades these laws, but this does not justify reductionism.[1]

A. Elemental forms. Solutions that are the most stable (stationary states) lead to the atoms and molecules that are the basic forms *within the energy domain of living systems* (I omit the lower level fundamental particles from this discussion). They are elemental in the sense that one atom or molecule of a given form is as good as another in building higher level structures. In other words, the stability of these forms is such that their local environmental *history is irrelevant* and can play no role in their description. It is also at this level where complementary descriptions of the wave/particle duality are an empirical necessity.

B. Aggregate forms. At the next level are forms made up of elemental forms. They are more complex but less stable. This is the level of macromolecules and crystals that may have a timeless overall symmetry, but that also show innumerable detailed shapes that depend on their individual local environmental histories. Snowflakes are a good example. Every individual is unique because of its history, but all forms have an overall symmetry. Aggregate forms have a lawful elementary description, in principle, but their complete structure is not reducible to the laws of elementary forms because their individual environmental *history* is not in the language of the elementary forms. Although the variety of aggregate forms appears endless, the differences between forms appears to be discrete, that is, they are countable.

C. Statistical dynamical forms. Statistical dynamical descriptions of large populations ignore the detailed forms of the individuals and describe only macroscopic averages. At this level complementary descriptions of reversible and irreversible behaviors are necessary. Statistical description also contains new assumptions sui generis that are not derivable from the lower level description.[2] Statistical forms are more difficult to define because they appear to change continuously and often have weak stability. Dissipative structures like Bénard cells, whirlpools, and tornadoes are classic examples. These detailed shapes change constantly with time but maintain a recognizable form (a family resemblance). Clouds may be included in this class. They change shapes continuously, but can still be classified by pattern forms (e.g., nimbus, cumulus, cirrus, etc.).

2. Structural forms. Unlike forms based on physical laws, concepts of structural forms have been introduced in many disciplines and at many levels, and consequently they have no consensual definitions or usages. Structural descriptions arose first in the linguistic, psychological, and social sciences where there is little apparent relation to physical forms. There is the general view that structural forms go beyond, are deeper than, or are unrelated to, physical laws. However, structural description has now taken root in some approaches to complexity theory and evolution theory.

Structural forms are usually considered to be abstract or implicit (e.g., Uexküll's Planmässigkeit), and sometimes even Platonic. When the description of forms becomes more abstract and formal, as has occurred in physics notably in the last century, there is often less attention to the observable physical forms and more focus on the possible mathematical forms and topologies. In some cases this is an example of what Emmeche (1994: 158) has described as a cultural trend he calls 'postmodern science' in which material forms have undergone a 'derealization'. However, there is nothing unscientific about abstract models as long as they are empirically decidable. What is postmodern is the increase in undecidable structures that amount to dogmatic derealization.

I resist this trend by restricting the term 'structural forms' by the decidability test. In other words, I have nothing to say about them until they emerge at some place and time embodied in physical structures that can have an observable effect. The belief that implicit or eternal Platonic forms are the ultimate source of order that appear materially as only simulacra I regard as an undecidable metaphysical view.

I recognize structural forms by some new autonomous logical or topological structure or closure that provides additional stability to the stability of energy-based physical forms or on the persistence of naturally selected forms. I do not mean that structural forms are independent of these other forms, but only that they require an emergent condition that is not derivable from these other forms. A simple example is a catalytic cycle. The catalysis itself is normal chemistry; the only structural contribution is the emergence of a topological closure. By far the most significant example of a structural form is a symbolic code like the present genetic code. The present structural form of the genetic code is so complex that it must have evolved from simpler structural forms that have yet to be discovered.

The origin of life problem is difficult because the simplest imaginable code still appears to be too complex to emerge either by chance or from any known physical forms. Because emergent structural forms have this element of novelty or autonomy they are not derivable from physical forms without some new condition being added. If structural forms are stable enough, they constrain the forms from which they emerged and at the same time generate new forms that require new descriptions that are complementary to the descriptions of the lower levels.

3. Naturally selected forms. A coded symbolic form began life as we know it. Natural selection implies the entire neo-Darwinian process of evolution that in turn requires a symbol-controlled replication. In more detail, this means (i) hereditary construction, i.e., synthesis of functioning components under control of a symbolic memory (the genotype), (ii) semiotic closure, i.e., the code mechanism that reads symbols must also be described by the gene and constructed by the cell, (iii) variability, i.e., the memory can change and is open-ended, and (iv) selection, i.e., the populations of organisms (the phenotypes) that are replicated have different stabilities (rates of survival) in their environments (Pattee 1995). Variation may include both random and various degrees of controlled mutation (e.g., King and Soller 1999). To put it as briefly as possible: natural selection is a statistical bias on the stabilities (rates of survival) of a variable heritable population distribution (e.g., Williams 1966: 22). According to this definition, naturally selected forms require as preconditions the existence of physical, structural, and symbolic (coded semiotic) forms.

The persistence of selected forms is not determined by the stability of either the supporting physical forms or structural forms alone. However, as with all hierarchical levels, the domain of potential selected forms is both generated and restricted by the physical, structural, and symbolic forms. In a similar way, the semantic potential of natural language is both generated and restricted by lexical and syntactic forms. Discovering the restrictions of lower, self-organizing levels on the higher, naturally selected forms is a difficult empirical problem because of nonlinearity (see next section). The same difficulty occurs with the nature/nurture problem. There are obviously many physical restrictions on specific biological forms, such as strength of materials, topology of morphogenesis, and rate of energy consumption. However, at the level of possible semiotic forms expressible in memory, viable or not (pre-selection), the physical restrictions appear minimal, as must be the case for any memory structure with high information capacity.

General theories of possible universal restrictions from lower forms on biological forms, such as statistical restriction on natural selection (e.g., Kauffman 1993) and thermodynamic theories (e.g., Brooks and Wiley 1986) appear at present to be undecidable since they provide no well-defined observables. As yet they have had little effect on the progress of empirical studies of evolution. Thermodynamic theories that attempt to relate entropy to evolution have also been criticized as a misapplication and misunderstanding of thermodynamics (e.g., Morowitz 1986; Berry 1995). Many discussions have focused on the relation between information and entropy. This has often led to misleading interpretations because of the use of Shannon's definition of information that is independent of meaning, fitness, or semantic value. This definition has little relation to biological evolution where the adaptive or survival value of information is all that counts. There has also been a large literature on the delicate dependence on energy dissipation when measured information is used for control of the entropy of a system, as in the case of Maxwell's demon (e.g., Leff and Rex 1990), but there is no evidence that this dependence is significant for genetic information or natural selection.

Nonlinear irreducibility

The title of one of my first articles, 'How does a molecule become a message?' (Pattee 1969b) asked the important question, but the article gave no good answer. I did assume that a molecule acting as a symbol must have a code structure, by definition, to indicate the symbol's meaning or referent.[3] It was also clear that a symbol does not occur in isolation. There must be a functionally complete set of symbols and referents to enable open-ended constructions. In this sense, codes and symbol sets are irreducible. I concluded then that this is a more difficult question to answer than can be usefully approached from normal physical analysis because, '… *a molecule does not become a message because of any particular shape or structure or behavior of the molecule. A molecule becomes a message only in the context of a larger system of physical* *constraints which I have called a "language"*' (1969b: 8). It was then also obvious that any such system of physical constraints forming a language code presupposes an organism's semantic interactions with its surroundings (Uexküll's Umwelt). Without this interaction there would be no function for a language since there would be nothing for a language to construct, control, or describe. Consequently, the irreducibly complex problem then became even more complex.

This general type of irreducible complexity is now often called *nonlinearity*, meaning that the whole is more than the sum of its parts. More precisely, it means that there exists some significant behavior of the system as a whole that cannot be adequately explained or modeled if any part of the system is neglected. (It does not mean that other behaviors within the system cannot be usefully modeled.) One of the simplest well-known examples in physics is n-body gravitational dynamics. In biology this type of irreducible coherent interaction occurs at all levels from cells to societies.

Epistemic irreducibility

All of our symbolic expressions, all of our languages, whether cellular, natural, or formal, have now evolved so far from the origin of life and the first genetic symbols that the study of semiotics does not appear to have any necessary relation whatsoever to physical laws. As Hoffmeyer and Emmeche (1991: 134) state, it is generally accepted that, '*No natural law restricts the possibility-space of a written (or spoken) text*', or in Kull's (1999: 386) words: 'Semiotic interactions do not take place of physical necessity'. We must use rule-based symbolic expressions to describe universal laws, but we never use these laws to describe syntax or symbols. This suggests the question: Why is physical theory ever of any interest to semiotics? This also raises a problem: In what kind of physical system, every detail of which obeys inexorable universal laws, do there exist rule-based interactions that do not take the place of physical necessity?

This apparent paradox[4] between the determinism of objective natural laws and subjective freedom of choice or control arises from the fact that we think of lawful events as if they could not occur otherwise. This is correct as far as it goes, but the laws say nothing about initial conditions and boundary conditions. As Polanyi (1968) pointed out, universal dynamical laws cannot describe any local non-dynamical structures that act as boundary conditions or constraints. Laws are valued because they express the maximum possible regularity of events. Symbols, by contrast, are valued as information carriers, and information capacity is measured by the minimum regularity of events.

I give two fundamental examples of epistemic irreducibility that illustrate this matter/symbol complementarity in more detail. The first is the process of determining initial conditions by observation or measurement. Measurement is a process that maps a state-of-matter to symbols. The second is the process of self-replication. This is the converse process of mapping symbols to a state-of-matter. These two processes, observation and natural selection, are the only processes that can originate new semantic information (excluding the undecidable possibility of divine revelation).

1. Epistemic irreducibility of dynamical laws and symbolic measurements. Dynamical laws would be moot without the special constraints of measuring devices that must be employed to determine the initial conditions of the dynamical equations describing the laws. The explicit function of a measurement is to obtain an initial condition that must be expressed as a symbolic result that can be used in computation. However, the biological function of the structural constraints of the measuring device is to extend the natural senses, i.e., enlarge our Umwelt. In fact, the origins of modern sciences can be traced to measuring instruments. For example, modern chemistry, biology, and physics began with the analytical balance, the microscope, and the telescope, respectively. For this reason, measurement function cannot be usefully reduced to a description by dynamical laws. For example, telescopes and computation are required to confirm laws of celestial dynamics, but these laws do not explain telescopes or computation.

The most convincing general argument for this irreducible complementarity of dynamical laws and measurement structures comes again from von Neumann (Neumann 1955). He calls the system being measured, S, and the measuring device, M, that must provide the initial conditions for the dynamic laws of S. Since M is also a physical system obeying the same laws as S, we may try a unified description by considering the combined physical system (S + M). But then we will need a new measuring device, M′, to provide the initial conditions for a larger system (S + M). This leads to an infinite regress; but the main point is that even though any measuring device, M, can in principle be described by the universal laws, the fact is that if you choose to do so you will lose the *function* of M as a measuring device. This demonstrates that laws cannot describe the *semantic function* of measurement even if they can correctly and completely describe the physics of the measuring device.

This type of epistemic irreducibility arises when a distinction must be made between an observer and what is observed,[5] or in semiotic terms, when a distinction must be made between a symbol and its referent. Without this epistemic cut the whole process of symbolization is vacuous. As is also the case in the genotype/phenotype mapping, this epistemic complementarity also appears as a sharp functional separation between syntax and semantics. When physicists (or other scientists) use mathematics to describe events, they tacitly assume that the formal syntactic manipulation of the mathematical symbols they are using are not in any way causally influenced or restricted by physical laws ('Semiotic interactions do not take place of physical necessity'). On the other hand, when measuring the initial conditions for a particular system, the symbolic results (the semantics) of the measurement must be assumed to be directly caused by the physical state of the system and not in any way influenced by the formal syntax of the mathematics. Consequently, the complex physical forms of the measuring device must remain hidden if the symbolic results are to be functionally effective. As I shall describe below, in a converse sense, the complex details of molecular interactions must remain hidden if the symbols of genetic instruction are to be functionally effective.

2. Epistemic irreducibility of self-replication. As I stated above, there is a logical sense in which genetic expression is the converse of measurement. Measurement is the process of mapping a physical form (the state of the system) to a symbolic form (the result of the measurement), while the genetic control of protein synthesis is the converse process of mapping a symbolic form (base sequences) to a physical form (proteins). Genetic expression is a symbol/matter mapping, while measurement is a matter/symbol mapping. However, there are also enormous differences as you would expect with symbol systems separated by billions of years of evolution. Most significant is that the genotype/phenotype pair needs no higher level semiotic forms to replicate, while all physical theory, its formal mathematical language, and its measuring devices need natural language for comprehension as Bohr[6] forcefully pointed out.

Stated in a very brief form, the genetic code mechanism (transferRNA, aminoacyl synthetases, ribosomes) reads all the genes of the cell and maps (decodes) the DNA base sequences as symbols and constructs the amino acids sequences as proteins. The cell is reconstructed first by a mapping: [gene (symbol) code (interpretant) protein (referent)]. However, for self-replication the cell must have genes that also copy the code itself, and, finally, the genes themselves must be copied. The coding structures are copied by describing the code as before: [code symbols code coding structures]. Finally, the gene itself must be copied. How can this be done? A little thought reveals that there is no symbolic description of the gene that will copy the gene structure itself using the code. In fact, to copy and to code are mutually exclusive actions. Copy means do not code (i.e., look at the structure itself; do not interpret it). Consequently, there are genes for enzymes that help copy the genome directly by the well-known template base-pairing that has no relation to the code.

This epistemic complementarity appears to be very much like the strict separation of syntax and semantics in measurement so that the complex physical forms that actually execute the syntax (translation) are hidden from the message itself (base sequences). Consequently, the function of the code cannot be derived from the detailed physical description of coding mechanisms, while a useful description of the code itself gives no clue to the particular physical implementation. Yet we require both descriptions for a full understanding of how cells replicate. This is one reason there appears to be little possibility at present of an organism evading or modifying the code syntax in order to better adapt. The code appears today as if it were a syntactic frozen accident. On the other hand, in the early course of evolution the code syntax must have been improved by variation and selection to reach the present level of complexity.

There are in addition to the epistemic forms many nonlinear forms that are necessary to support the relatively simple and explicit syntactic and semantic functions of the gene. These include the metabolic, sensory, and motor structures of the entire cell or organism and its interactions with its surroundings. There are also other essential physical forms that must be satisfied for molecules (or any physical structures) to function as symbols and codes. In order that symbols do not interact of physical necessity they must have structures that do not differ significantly in energy. These are called energy degenerate (or symmetric) structures, a requirement for all good memories. This is necessary for information capacity of any type, which is why information and energy are complementary concepts. A code, on the other hand must remove degeneracy (symmetry-breaking) to give explicit physical consequences or meanings to symbols. This removal of degeneracy cannot be described by the same dynamics that produced the degenerate states in the first place, which is why the code must be described separately as a (non-integrable) constraint (e.g., Pattee 1972b).

The quality of symbolic expression and control

The forms described above are only the necessary pre-conditions for symbolic control. These forms reveal nothing about the quality or ultimate survival of organisms and ideas (genes and memes). Quality of genetic expression is an umbrella concept that ultimately is measured by fitness or survival. These concepts are impossible to pin down with complete precision because they are fundamentally unpredictable and open-ended. Yet these are the most important concepts in evolution. We speak of good and bad descriptions in natural language depending on how well they communicate ideas or events. We also speak of good or bad instructions depending on how effectively they communicate some action or performance. Without a clear statement of a desired function, quality is not definable.

One of Born's functions of symbols besides objectivity was to allow precision in descriptions. To achieve this precision physicists at least since Galileo have adopted descriptive symbol systems with increasingly sharp separation of the syntax and semantics. This is called *formalization* in mathematics, and it raises the question: Does the gain of precision by explicit separation of syntax and semantics have a cost? Does the explicit omission of any reference to the observer's evolutionary, cultural, and mental history avoid or introduce an unknown bias? The importance of this omission is today a major issue. How influential are those tacit forms that are not referenced explicitly in the so-called objective descriptions of experience? This is a more controversial issue in the biological and social sciences, but even physical theories and formal mathematical proofs have subjective elements of clarity, conciseness, and aesthetics in their expression that affect their quality (Pattee 1993).

Natural language syntax and semantics are both much richer, more creative, and more ambiguous than that of genetics and physics. This results in part from the fact that normal use of natural language does not clearly separate syntax and semantics. For example, the parts of speech (e.g., nouns, verbs, prepositions, etc.) correspond to semantic categories (objects, actions, relations, etc.). Furthermore, natural language syntax is not strict. In fact, the richest meanings in natural language arise from figures of speech and metaphors. Figures of speech are often defined as deviations from literal syntax (e.g., Quinn 1982), and metaphors are a deviation from literal semantics.[7]

One of the earliest and most persistent criticisms of Darwinian theory is that there is a vanishing probability that blind search for genetic sequences could discover so many successful complex species. However, there is now growing evidence that the genetic instructions do not arise simply from random search and selection from an immense symbolic sequence space. First, as I have already mentioned, biological structures are generated by the entire hierarchy of forms and it is remarkable how little information is explicitly coded. Genetic instructions explicitly control only the linear sequences that make up the primary (linear) structure of nucleic acids and proteins. All the complex folding and self-assembly of these molecules that is required for their function is left to the physical dynamics and structural forms acting under these simple sequence constraints. Polanyi (1968) describes this aptly as 'harnessing the laws'. It is also important to understand that genetic control in organisms is not one-way, but is always contingent on the nonlinear network of coordinated constraints of the organism that also controls the expression of the genes.

A second striking quality of genetic instructions is their effectiveness in search. The genetic sequence space available for search is exponentially so immense that finding the sequence for a specific protein would indeed be virtually impossible. But many parts of these sequences are redundant or insensitive to detail so that the number of sequences that code for a particular function is also immense. Furthermore, these functionally equivalent sequences are likely to be distributed in the sequence space so that they are relatively easy to locate (e.g., Schuster 1994). So instead of a search for the one needle somewhere in a haystack, the search is for any needle in a haystack full of needles spread uniformly throughout the entire stack.

The point I want to emphasize is that the quality of simplicity that we see in the explicit genetic symbols is possible only because of the efficiency with which a few symbols can harness the complex physical and structural interaction of folding and self-assembly within the interpreting organism. This is the converse type of simplification that occurs in the measurement process where it is only because of enormously complex devices (designed, not naturally selected) that a measurement results in simple symbols.

Current controversies over dynamics and semiotic forms

I believe that these irreducible physical, nonlinear, and epistemic complementarities must hold for all levels of semiotic descriptions of complex systems, especially biological systems that are themselves semiotic systems. If this is the case, then disputes over the best form of description is not a productive exercise. This is especially true of those complementary binary oppositions that arise from the modes of perception that have evolved over billions of years, such as discreteness and continuity that are necessary for recognizing objects and motion, matter and energy, or particles and waves. These and many other binary oppositions, like determinism and chance, reversible and irreversible, subject and object, have become deeply embedded in language and generated undecidable controversies since Zeno. The important questions are not about promoting one or the other opposition, but how these irreducible complementary forms can be usefully coordinated.

The relatively new field of complexity theory is exploring many new approaches to the nature of life, including nonlinear dynamics, many forms of computer simulations (artificial intelligence, artificial life, artificial neural nets), and robotics. Many of these approaches to biological complexity are promoted as if they were exclusive and competitive instead of complementary to the empirically well-established physical, molecular, genetic, developmental, and evolutionary forms of description. All these forms have proven useful for biology. What appears unreasonable is that any one form of description can replace the others. If dynamic description alone cannot describe symbolic measurement in simple physical theory, it is unlikely that it will replace genes or natural selection in evolution as some theorists claim. For example, Goodwin apparently sees dynamic models as an alternative description of naturally selected semiotic instructions. He says, 'We could, if we wished, simply replace the term *natural selection* with *dynamic stabilization*' (Goodwin 1996: 53). Prigogine also apparently sees no complexity limit to his dissipative structures. He says, 'Thus, we have in this perspective the constant generation of "new types" and "new ideas" that may be incorporated into the structure of the system, causing its continual evolution' (Prigogine 1980: 128). Similarly, Bak (1996: 112) claims that,

> Complexity, like that of human beings, which can be observed locally in the system is the local manifestation of a globally critical process. None of the non-critical rules produce complexity. *Complexity is a consequence of criticality.*

Another well-known example is the controversy between supporters of symbol-based logic and dynamics-based network models in artificial intelligence and theories of the brain. Early artificial intelligence was entirely logic-based 'representation' with no attention to the structures of the brain (e.g., Newell and Simon 1972; Pylyshyn 1986). Artificial life studies also began with a purely symbolic approach (e.g., Langton 1989). The basic argument for avoiding the question of 'why the molecules that really occur in nature are the sort of things they are' is that it does not make any difference what they are if they can execute the desired syntax since that is all that semiotic interactions require. The contrary view of the dynamics-based network or connectionist models is that there is no symbolic representation since what we perceive as discrete symbols is only the output of a continuous network dynamics (e.g., Thelen and Smith 1994; Kelso 1995; Port and van Gelder 1995). *By focusing only on either the dynamics or the semiotics, both these approaches completely miss* *the essential function of symbol/matter and matter/symbol transformations that make life and meaning possible.*

I also believe it is counterproductive when structuralists and biosemioticians put so much of their efforts into undecidable philosophical criticisms of molecular genetics and neo-Darwinian evolution theory. In spite of unsolved problems, some overstated claims, and some errors, one should not disregard the enormous volume of empirical results, the explanatory power, and practical applications of these disciplines. To gratuitously polemicize the inherent complementarity of the molecular, cellular, developmental, structural, symbolic, and evolutionary levels of description is tilting at windmills and flogging straw men.

Conclusion

The claim of universality for any description of reality does not imply that such a description is complete, nor does inconsistency between two descriptions imply that one of them does not apply to reality. Comprehension of the elementary process of physical measurement requires irreducible and complementary descriptions of the matter/symbol transformation. The simplest converse process of symbol/matter transformation coincided with the origin of life, but even this simplest case reveals few clues to how the required code arose. Since complementary descriptions are intrinsically irreducible (and even syntactically contradictory) the conceptual integration or coordination of complementary descriptions requires a higher level description that appears as a new hierarchical level of complexity. Thus, the more complex a system the more descriptions are necessary for comprehension. The many subdivisions of the biological and social sciences are pragmatic evidence of this necessity, but the lack of effort, and even resistance, to coordinate these levels does not help our comprehension.

Notes

1. Modern physicists believe in the universality and inexorability of natural laws, but they are generally not reductionist. Sir Arthur Eddington emphasizes (his italics), '*There is nothing to prevent the assemblage of atoms constituting a brain from being of itself a thinking object in virtue of that nature which physics leaves undetermined and undeterminable*' (1929: 260). Max Planck (1931: 612) stated,'… the conception of wholeness must … be introduced into physics, as in biology, to make the orderliness of nature intelligible and capable of formulation'. Neils Bohr once remarked, more bluntly, 'You do not explain a tea party by quantum mechanics'. More recently, see the substantive arguments against reductionism by Phillip W. Anderson (1972).

2. Chance cannot be derived from necessity, nor necessity from chance, but both concepts are necessary. In his essay on dynamical and statistical laws, Planck (1960: 64) emphasizes this point: 'For it is clear to everybody that there must be an unfathomable gulf between a probability, however small, and an absolute impossibility .... Thus dynamics and statistics cannot be regarded as interrelated'. Weyl (1949) agrees: '... we cannot help recognizing the statistical concepts, besides those appertaining to strict laws, as truly original'. And similarly, von Neumann (Neumann 1955: 352) in his discussion of measurement says: 'In other words, we admit: Probability logics cannot be reduced to strict logics'. It is for this reason that our concept of a deterministic cause is completely different from our concept of a statistical cause.
3. The literature of semiotics uses many terminologies, often conflicting (e.g., Nöth 1990). For my discussion it is essential to distinguish at least a symbolic language and a sign or symptom. Briefly, by a symbol I mean a localized, discrete structure (within a language) that has an arbitrary, nonobligatory, or conventional relation to its referent, whereas I use sign (in its restricted sense) as having some intrinsic physical causal relation to its referent. For example, I would say a cloud may be a sign of rain, but the words 'rain', 'pluie', 'lluvia', etc. are symbols for rain. (I need this distinction to make the point that *symbols are a sign of life*.) Consequently, unlike signs, symbols require a defining convention that maps the symbol to its proximate referent. This mapping or 'proximal interpretation' is called a code. Higher level interpretive codes may emerge as symbols acquire more meaning in larger organizations.
4. This is one form of an old philosophical question: 'Again, if all movement is interconnected, the new arising from the old in a determinate order if the atoms never swerve so as to originate some new movement that will snap the bonds of fate, the everlasting sequence of cause and effect what is the source of the free will possessed by living things throughout the earth?' (Lucretius 1952: 67).
5. Notice that epistemic and nonlinear are converse in the sense that epistemic implies separation of descriptions while nonlinear implies no separation is possible. In quantum theory, measurement appears to be both an epistemic and a nonlinear process because the observer or measurement device cannot formally be separated completely from the system being measured. On the other hand, the final result of measurement must be in classical terms (see note 6) in which the epistemic cut between observer and observed system is crisp. This is called the 'measurement problem' and as yet there is no consensus on an explanation (e.g., Wheeler and Zurek 1983), except as a higher level of complementarity.
6. Bohr made the point that no matter how we depend on mathematical or technical expression, objective communication must ultimately rely on natural language: '... even when the phenomena transcend the scope of physical theories, the account of the experimental arrangement and the recording of observations must be given in plain language, suitably supplemented by technical physical terminology. This is a clear logical demand, since the very word "experiment" refers to a situation where we can tell others what we have done and what we have learned' (Murdoch 1987: 100).
7. Genetic code syntax has no known semantic content. On the other hand, all higher level syntax clearly does relate to our perception of the world. Natural language syntax has pre-linguistic origins in the evolution of feature detectors in brains. Edge detectors for recognizing discrete objects and continuous motion detectors of objects go back at least hundreds of millions of years. These irreducible and complementary modes of perception must have arisen together because neither would have any function or meaning without the other. Even formal mathematics that is based on sets, operations, and relations, appears to be abstracted from natural language categories like nouns, verbs, and prepositions.

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