# The Semiotics of “Postmodern” Physics

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## 1 Introduction

Where does modern physics end? Where does postmodern physics start? The adjective “postmodern” has very special connotations of a new age, different from the previous modern age. Indeed the opinion is expressed that modern physics characterized by the emergence of quantum mechanics and its application to all aspects of microscopic phenomena may be terminating. John Horgan has given an account of this endzeit in his recent book *The End of Science*, see Horgan (1996). He describes his encounters with great physicists of our times, who give evidence for his hypothesis: “If one believes in science, one must accept the possibility—even the probability that the great era of scientific discovery is over. By science I mean not applied science, but science at its purest and grandest, the primordial human quest to understand the universe and our place in it. Further research may yield no more great revelations or revolutions, but only incremental, diminishing returns.”

The physicist A. Sokal has tried to ridicule philosophers who interpret physics in postmodern terms, see Sokal (1996), pp. 217–252. With a long list of references he examplifies the misinterpretations of current physical concepts by relativists and social constructivists who emphasize the context in which science is conceptualized. He wrote the text in such a way that the editors of the journal did not realize his hoax and published the text as if it were serious. A transgression of boundaries is a risky enterprise, and any understanding of physical concepts which contain everyday words like relativity or chaos is bound to lead to interpretations beyond the meaning of these concepts in the physical theories. This is nothing new and occurred before with relativity theory and quantum mechanics.

In fact, M. Beller recently reminded us that the grandfathers of modern quantum mechanics themselves, namely Bohr and Heisenberg, give abundant examples for exporting physics concepts like complementarity to areas like politics or philosophy, see Beller (1998), pp. 29–34. It seems like a practical joke that they wanted to found an Institute of Complementarity, which investigates this concept in all disciplines of human thinking and action. On the contrary, a transdisciplinary approach is a prerequisite in a culture which searches to understand human efforts in the humanities and sciences at the same time. This attempt needs a common vocabulary which suits both enterprises. I propose to explore contemporary physics in semiotic terms. One may debate whether semiotics is a useful tool. Signs and signals are concepts which come from communication theory, a discipline which is intimately related to telegraphy and electrodynamics invented in the 19th century and unthinkable without the chips and computers of the 20th century. So there is some relationship of the philosophical term "sign" with natural science and technology. The concept of symbol is more used in the context of language. Symbols are analogues or metaphors standing for some quality of reality that is enhanced in importance or value by the process of symbolization. The following article will not differentiate strongly between these two terms, and in particular it will use the word "symbolization" also for the semiotic process.

In Sect. 2, I will discuss characteristic new developments in postmodern physics. As examples I have chosen the science of complexity, computer simulations and physical mathematics. I will try to show in which aspects these disciplines go beyond modern 20th century physics. In Sect. 3 the dictionary of communication theory with signs and symbols is introduced. Section 4 interprets the new physics with the help of these concepts and traces the evolution of the sign language in physics. One could also say it investigates the process of symbolization at its very early stage. Apparently these branches of physics are unfinished, they represent work in progress, which means that their scientific character has not yet unfolded itself fully. Therefore this essay ends with a pragmatist attitude to "wait and see" how these modern fields will develop. The philosophical discourse adds awareness, I doubt that it can direct the acting scientists how to proceed. A cross disciplinary dialog which awakens nonscientists to the problematics of scientific progress, however, can improve analytic thinking in the sciences themselves. The possibility of a contract with nature can be established in as far as the perception of nature is concerned, see Serres (1990). This gives more mutual information to the partners underwriting this contract. M. Serres asks in very romantic words[1]: "How much do we give back to the objects of our science, from where we take our knowledge? Whereas in former times the peasant gave back to the earth via the beauty of his undertaking what he owned to the soil (My translation)". In that sense the semiotics of postmodern physics is not only an epistemological endeavour but also a practical and aesthetic one.

## 2 Postmodern fields of physics

In his book *The Dreams of Reason*, H. R. Pagels focuses on the science of complexity as the most outstanding new discipline emerging in recent years, see Pagels (1989). M. Gell-Mann, an eminent elementary particle physicist, has founded the Santa Fe Institute which is devoted to research in adaptive agent simulation, biological networks, cognition, computational molecular biology, economics, evolving cellular automaton project, theoretical immunology and

[1] Que rendons nous, par exemple, aux objets de notre sciende, à qui nous prenons la connaissance? Alorsque le dultivateur, autrefois, rendait en beauté, par son entretien, ce qu'il devait à la terre ... (Serres 1990, p. 68.)

neurobiology. All these subjects are very complex. The definition of complexity is not easy. “If we try to move towards a mathematical definition, we must realize that the concept of complexity, like entropy, is of probabilistic nature and it can be more precisely defined if we try to define complexity of ensemble of objects of the same category ... ”, says Parisi (1988), and he continues in a related article “The variety of the macroscopic description will be taken as an indication of complexity. An example that is easy to visualize is a heteropolymer, i.e. a polymer composed by a sequence of many different functional units. ... If the polymer may fold in many different ways, we can consider each folding as a different phase and such a system is a complex system.” (see Parisi (1994)). He envisages an ambitious program where in a first step all the possible manifestations of the system, can be represented in metric space, i.e. similar configurations classified in clusters, a tree of such clusters constructed, and in a second step the probabilities of the distances in the network of clusters be calculated. In neural networks physicists have been able to establish a connection between physiological behaviour and the dynamics of abstract spins with two states (on and off). The learning rule associates with a small number ($p$) of patterns a special choice of the coupling matrix between spin states of different synapses. The system provides associative memory if these $p$ patterns are indeed dynamically stable configurations of the larger system. Also here an ensemble of characteristic pattern states plays a major role (see Hopfield (1982)).

Phil Anderson, who was one of the strongest opponents of the SSC, the biggest accelerator project planned in the US, has published his credo in an article with the title “More is different”, see Anderson (1972), where he claims that all reductionist approaches to nature have a very limited ability to explain the world. All levels are to some degree independent, and each level demands the same creativity and inspiration to be explained as the other. J. de Rosnay says: “Today we are confronted with another infinite: the infinitely complex... We need a new instrument. As valuable as were the microscope and the telescope in the scientific exploration of the universe. I call this instrument the macroscope. It is a symbolic instrument, constructed from an ensemble of methods and techniques borrowed from very different disciplines.” (see de Rosnay (1975)). Here a biochemist speaks and one can see the somewhat different perspective. Whereas the physicist adheres to the well known methods of a mathematical description with or without computers, a scientist of another discipline is more prone to mix methods in order to get a global vision this way. The physicist prefers the techniques of statistical mechanics of disordered systems, where the system obeying deterministic laws of nature is subjected to a random component. It is hopefully the random component which allows for the variety in the manifestations.

In general, it is more difficult to convey to a young student the importance of a complex system than the importance, e.g., of gravity and cosmology, because the latter disciplines are considered to be fundamental. They are relevant to understand our universe. If you take a specific macromolecule and its manifestation in a water solution. How does it coil up? Can one attach to different realisations in different solutions a fundamental importance? Can there be ever new fundamental laws in complex phenomena? Note, physics has constructed with statistical mechanics a basic discipline which governs the laws of large number of particles in large systems. Gell-Mann, the initiator of the Santa Fe Institute, is sceptical about the possibilty to discover similar laws about complex systems. If fundamental means expressible in a simple equation or other mathematical calculus, then complex phenomena may not be of that form. Some physicists of complexity have proposed that such systems can only be described by computational codes, where the complexity of the system is related to the length of the code. They claim that complexity is related to the miminal length of the code. The science of machine algorithms goes back to A. Turing (1936) who founded the modern theory of computers. Turing machines are universal machines which combine units for reading and writing code on different arrays of a storage medium under the control of a processing unit. These Turing machines are extremely simplified theoretical models which help to formulate computations in an organized manner. In this sense also computational approaches to complexity are part of mathematics. It is only in recent years that a coherent attempt has been made to study complex phenomena with experimental and theoretical tools which preserve a holistic view of their components. Especially for biological systems methods are important, where the mechanism of mutual interaction is not obscured by the isolation of the components.

One of the most exciting developments of modern physics are large scale computations which simulate theories with infinitely many degrees of freedom. After the Second World War, new experimental techniques associated with the development of radar allowed the hydrogen atom to be investigated on a level which is much more accurate than the theoretical description of the atom by the Schroedinger equation. The electromagnetic field acts not only as a binding potential for the opposite charges, the positive proton and the negative electron, it also modifies the energy levels of the electron as an radiation field. Since the fine structure constant $(1/137)$ is a small parameter, these effects of the quantized electromagnetic field are of higher order in the fine structure constant and calculable term by term.

On the contrary, strongly coupled systems are not available for a perturbation theory in a small parameter. Should one therefore give up quantitative predictions? No, if one supplements analytical methods by numerical high speed computing. Discretizing the world in an artificial lattice of three dimensional space and one dimensional imaginary time, one can handle the infinite continuum with a finite number of lattice points. The calculation becomes reasonable, once the transition to infinite many points i.e. to the continuum is understood and controllable. Large scale lattice simulations have become a very important discipline in modern theoretical physics. The building block of the nucleus, the nucleon is on the edge of being deciphered in this world of bits and strings of code. Not only quantum phenomena can be simulated this way also thermal fluctuations can be computed adequately. Modern computers simulate phase transitions where a qualitative change of the symmetry of the system is triggered by varying the temperature. The progress of computational facilities with parallel computers and fast Teraflop units leads to an improved understanding of many facets of up to now not comprehensible dynamics of strongly interacting systems. The quantitative change of computing power from early desktop mechanical calculators to present computers has lead to a qualitative change. Along a normal numerical calculation each step produces numbers, which after a fixed time and more numerical operations yield the final result. In numerical simulations, so called configurations of the system are generated in a probabilistic way and stored on computer disk as encoded realizations of the system. With the help of these manifestations of the system more detailed questions can be asked about the mechanism generating the system. Note that the system is produced via a certain prescription. In general this prescription is simple, the outcome of the simulation, however, is something complicated. Therefore it may pay off to understand it in a different way. In the same way as the experimentalist installs a certain detector the computer analyst can add additional code to his simulation to ask pertinent questions about the system which may bring more insight into the dynamics of the strongly interacting system. Let us assume there exists a certain analytical solution of the theory which we call the x-ton. This solution may or may not play an important role among the fluctuating quantum realizations of the fields. Now the simulator takes his numerical configurations and checks whether he can identify these pseudoparticles using a filter which eliminates the quantum noise. Some progress has been achieved in this way, the conclusions are associated with a certain vagueness, since cause and circumstantial evidence cannot be clearly separated.

The development of postmodern physics is unthinkable without the technology of high speed computers, a technology which physics has triggered. The other rapid theoretical growth occurs on the borderline between physics and mathematics. Both mathematics and physics have always coexisted and mutually benefitted from a vivid exchange of ideas and concepts. The common discipline of mathematical physics has developed around this cooperation. Mechanics is associated with the names of, e.g., Laplace, Hamilton and Lagrange. Quantum mechanics, i.e. modern physics with, e.g., Hilbert, Weyl and Lie. In postmodern physics the emphasis shifts from physics to mathematics. Whereas historically mathematics has been a tool to solve acute problems in physics, the number of burning problems in parts of physics has been decreasing to a certain degree. Theoreticians have “time off”. This is e.g. true of the physics of elementary particles, which has been claiming the forefront for a long time. The standard model paired with perturbation theory and numerical lattice techniques has been extremely successful to predict and explain the data produced during the last twenty years.

Only the big problem remains, how to unify the hierarchy of different interactions with the weakest interaction gravity. Perhaps the enormeous progress in the exploration of space and time with telescopes even outside of the earth has helped to stimulate a cosmological turn. String theory wants to connect microscopic elementary particle theory with gravity. It appeared in the late 60 ties as an attempt to understand the interaction of protons, it hibernated and reappeared in 1984 as superstring theory. This theory lives in 10 dimensions and has a lot of freeway to reduce to our 4 dimensional world. Physicists entered the jungle of mathematics to find guiding principles. Two comments have to be made: Once mathematics has undergone axiomatic formulation, mathematics means clarity and transparency. Here, however, we talk about "physical mathematics" conceived on the way of its discovery, one may say. The second remark is that the guiding principles for a physical theory are searched in the platonic world of mathematics, much less so than in experimental phenomena. In this spirit, everything which is a beautiul idea will also be realized by nature.

Modern physics conceived point particles as waves, i.e. new quantum mechanical objects when they are studied at microscopic dimensions. Postmodern physics abandons the zero dimensional point particle, be it wavy or not, in favor of one dimensional strings, two dimensional membranes or higher dimensional p-branes. A trajectory in space time, called the world line, describes the history of the point particle. Sheets characterize strings propagating and their topology becomes a much more important category than before. The quantum features are built into the theory by the integration over all configurations, in one dimension these would be paths, now they contain the genus, which is the number of handles on the surface of the world sheet. Various divergence problems of common field theory disappear. There is an infinity of string modes corresponding to masses of particles on the order of the Planck scale, which at $10^{-5}$ g is $10^{17}$ times larger than the largest masses of the vector bosons. These states contribute as virtual particles to produce subtle cancellation patterns that soften the large momentum behaviour of scattering integrals. It is rare in physics that such a giant step in scales can be taken without some other structures appearing. The practitioners of this field compare explicitly their endeavour to the invention of Quantum Mechanics or to the formulation of the theory of general relativity by Einstein in 1916. One must say, however, that the first experimental verification of the predictions of general relativity came already in 1919 with the observation of the bending of light rays in the gravitational field during a solar eclipse. The observation of gravitational radiation in a detector is expected in the next millenium. Although some historical aspects are similar between the postulate of general relativity and superstring theory, one totally different circumstance is the time scale when this new theory is supposed to come into observational reach. Opinions on this matter are split, but the last fifteen years have not seen the goal in closer distance.

There is another speculative aspect in superstring theories, which is supersymmetry. In models of supersymmetry all the known particles of the standard model possess a partner with a spin reduced by 1/2. The bosonic photon with spin 1 should be accompanied by the photino with spin 1/2, which is a fermion. The fermionic quark would have a partner which is a spin zero particle, the squark. One finds supermultiplets. If local gauge invariance, a feature known from the electromagnetic and strong interactions, comes together with supersymmetry then electric charges and magnetic charges have related strengths and a relationship can be established between the masses and charges of particles. The mathematical concept of supersymmetry leads to a saturating coupling in the infrared and constrains the quantum corrections to the masses for particles fulfilling the minimal bound.

In this area a spectacular connection to the confinement phenomenon in strong interaction physics has been established by Seiberg and Witten. The condensation of charged Cooper pairs in superconductivity, which is at work in low temperature solids, has a mathematical analog with the condensation of magnetic charge in supersymmetric QCD. Magnetic flux is confined in superconductors, in the dual theory color electric flux, i.e. the quarks are trapped. Here a connection to accelerator laboratory physics appears. The confinement phenomena have experimental starting points. Albeit this happens in the supersymmetric theory with more degrees of freedom than the “real” world. One should not draw the lines of speculation too narrow, we may witness an interesting turning point of physics. It is characteristic that a large number of natural scientists abandon for a sizeable time the phenomenological world in favour of the world of mathematical ideas. This postmodern development will be analysed in more detail in the fourth section.

## 3 The semiotics

Historically the concept of sign and symbol goes back to Helmholtz and Hertz, see Dosch. There is nothing postmodern about natural scientists going beyond empirical sensations to abstract information inherent in these. Thus starting from a physiological basis the concept of sign as a neural completion of the physical sensation to a meaningful entity was borne. As an example, sounds are not perceived as a physicist’s analyis would conclude with the intensities distributed over the spectrum given by a frequency analyser, but the software in our brain develops a sensation of harmony or roughness related to the frequency spectrum. Hertz adds to these perceptions (see Hertz (1894)) “our imaginations of the things which have as essential coincidence with the things to fulfill the above explained requirement.” This requirement is to produce a chain of symbols (Abbilder) which is related to the chain of events in nature. It is ascribed to Hertz to introduce symboles, which go beyond copies or maps of the physical world into a mathematical universe. These new "signs" become operands by themselves, they enter into chains of "equations" which result in predictions with correpondences in nature. E. Cassirer has elaborated extensively on the concept of symbol, which he sees as "center and focus of the whole physical science of epistemology" (see Cassirer (1954) p. 25). In general symbols are more difficult to understand than signs and to define, because unlike signs they are intricately connected to a person or a number of persons sharing the same nationality, civilisation or environement. So there is not one lexicon of symbols but many. Signs are more simple, the messages they convey are more mundane. E.g. traffic signs have become quite international and have unique meanings. For a down to earth analysis of physics they seem to be more useful.

The theory of signs precedes the theory of symbols if one takes C. S. Peirce "Syllabus of Certain Topics of Logic", see Peirce (1993), as constitutive text of such a theory. "A sign is everything which is related to a second thing, which is called its object, in such a way that the sign can determine a third thing, which is called its interpretant, to be related in the same triangular relation to the object, as the sign is related to the object." Next he postulates that this relation is reversible: "This means that the interpretant is a sign by itself , which determines the sign of the (same) object."

The easiest way to come to a concise and clear definition is to use a well known example of classical physics to explain the terminology and use it to set up the triangle of relations which is so characteristic of semiotics. Take an object like an apple on a tree which is about to fall. The subject calls the apple opposite to him the thing to which the sign refers, therefore the object serves as a referent, there may me more than one referent. Studying the distances the apple covers in certain time steps with a fast camera, one can obtain data about the falling apple. If the experimenter is interested in this aspect of the apple he considers these data as significant data about falling apples. Next he comes to another tree with a different fruit, namely pears and takes similar pictures of falling pears. He compares the coordinate of the traversed distance $x$ with the time $t$ in a graphical plot. If these two plots have a similar parabolic shape, they do not depend on the type of fruit. At this time it is useful to speak of apples and pears as something new, say point particles, which obey a law. After some work which has taken quite a long time in mechanics he may come up with a simple equation of motion. He calls the coordinate $x(t)$ a sign for the position of the massive object above the ground, which is associated with the mathematical equation of motion $d^2x/dt^2 = g$, i.e. the sign is part of a sign language which in the physical sciences is the language of mathematics. In the reverse way the sign determines its interpretants which are the data to be related to the object in the same way as the sign is related to the object. The interpretants can not add more to the sign than there is already in the sign, they cannot include data about the temperature of the objects. In its original sense this separation of the sides of the triangle corresponds to the separation into a theoretical and experimental subdiscipline of physics. But one may also apply this separation to higher or lower levels of abstraction. Pierce, see Pierce (1986), has built into his epistemological process an infinite regression when he says: “It is essential for the things, that we can only approach them, they can only be represented. The object which a sign wants to represent is a sign by itself.” He enjoys this infinite process and the reflection process which makes his terminology sometimes obscur.

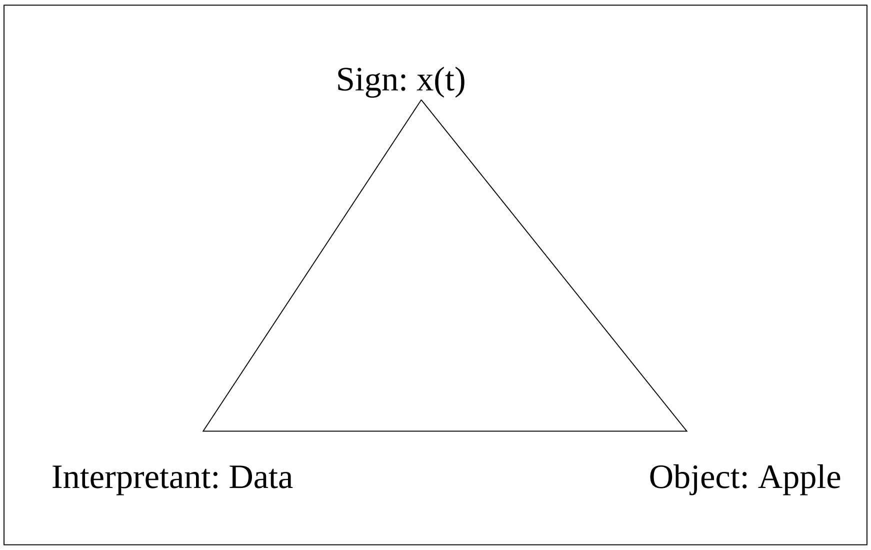


**Fig. 1.** Triangle representing the different concepts of the semiotic process

With justification C.S. Pierce can be considered as the founder of semiotics. A philosopical discussion of his work appears in a separate essay by E. Rudolph in this collection. Here, I will only resume some aspects of Pierce’s extensive work on signs, introducing some of his terminology and adding my own interpretations as they seem necessary. I will later refer to this discussion in the fourth section, where a semiotic analysis of “postmodern” physics is attempted. Pierce differentiates between three different types of signs: The simplest type of sign is the “icon”. The first view from the ship approaching the harbour in a tropical country shows palm trees, lightly covered people going after their various business, etc. This is cited by Pierce as an icon of the tropics, and he adds: “All icons from mirages to mathematical equations are similar to themselves, as they do not determine anything, nevertheless they are the sources of all knowledge.” In a more prosaic style these icons present sort of intuitive understanding which precedes a scientific understanding in physics. So in this sense geometrical or mathematical constructs belong to iconography as long as their relation of their content to experimental reality is not established. The second type of sign is the "index". It signifies the place where something can be found in a book. An indicated object is referred to by the index and is put in the context of other objects. So the relation of the index to the object is more direct than the relation of the icon to the object. The raised "index-finger" suggests a certain direction to the interpretant. In many situations the interpretant is a real person, to whom something is indicated. I do not find it necessary to have persons as intermediaries to interprete natural phenomena in symbolic forms. Mechanically stored date may serve the same purpose, sometimes more objectively. The third type of sign is the symbol which is different from the two other signs, in the way that it relates to its object solely by the interpretant. Pierce even claims that the symbol determines its interpretant. The symbol conveys a message which depends on convention, usage or on the natural inclination of the interpretants. In this way symbols may be found in various branches of the humanities like literature, history and art. Note, we allow data as interpretants of objects. Data restrict the symbols available for the objects to specific aspects of these objects. The apples have mass, but no temperature in the framework of classical mechanics, where we measure time and coordinates.

Pierce has a mystic attachment to the number three. The position of the sign in a threesome or triad consisting of "sign-interpretant-object" is a very determining factor in the definition of his semiotics. In his framework which I support a dual relationship between the world of objects and the world of mathematical symbols would narrow down our understanding of the scientific achievements. We would only see one part of the semiotic triangle which would present us with the dichotomy between a real and imagined world reflected in the wider context of the philosophy of science under the names scientific realism or social constructivism. In my opinion the historical development of the natural sciences favours a different picture: Masses of empirical data have driven scientific curiosity on a very premathematical basis independently of theories. I call the data interpretants since they give a quantitative picture of the objects and at the same time they interpret the symbols giving them meaning beyond their position in a mathematical context. The data connect the level of real objects with the abstract signs making the semiotic triangle complete. If the data can be organised into noncontradictory mathematical symbols, these symbols appear as invariant signs of the objects which are represented by their data. In this aspect signs differ from the changing data interpreting different experiments. If there is a law, mathematics will be able to decipher it. Pierce see C. S. Pierce, (MS 694) says in Regeln des richtigen Raesonierens,: "It can be shown to be proven, that no degree of complexity, even if it is infinite, can exceed mathematical imagination."

The threesome or triad of “sign-interpretant-object” can be modified in various aspects. The human interpretant who is outside of the triad may enter the triad. Or there are times where the triad develops quasi automatically. Then the community of scientists become actors who perform a play whose text is prewritten. There are also times where there is intervention, fights and struggles because the semiotic process has become contradictory. T. S. Kuhn has coined the term “scientific revolution” for such changes in the relations of triads. In my opinion, two triads collide with each other. Mechanics and wave theory are in conflict with the description of the same object, the electron. This is not simply a conflict of experiment and theory. It is the whole threesome , the signs and interpretants which differ in relation to the same object.

Other structures emerge when a new triad is built on top of the sign of the original triad. The sign becomes the interpretant of a new triad with new objects and sign. In literature “myth” is such a second level triad. It treats its low level abstractions, the words as interpretants of a narrative. Take the myth about the foundation of Rome. The wolf, a wild unpleasant animal nourrishes Romulus and Remus. The wolf assumes motherlike functions, it transforms itself into a new interpretant signifying the beginning of a civilisation out of nature. R. Barthes calls this a shift to a second order semiological system, see Barthes (1972). Note in this second system an inversion of meaning goes hand in hand with the new position of the “wolf” in the created triad. R. Barthes continues: “Everything happens as if myth shifted the formal system of the first signification sideways. . . . It can be seen that in the myth there are two semiological systems, one of which is staggered in relation to the other: a linguistic system, the language which I call the language object, because it is the language which myth gets hold of in order to build its own system, and myth itself which I call metalanguage in which one speaks about the first.” On the second level the meaning of the “wolf” is distorted from wild to motherlike. In a picture one can show this shift in the following way:

Semiology is a developed discipline with many conflicting terminologies, see Eco (1973). At first sight it looks like a schema which then can be applied to almost everything, but does it guarantee deeper understanding? More accurately the place of the sign in this process starts to rotate and change position from the signified to the signifier. Pierce sometimes uses the index function of the interpretants to point to deeper meaning in the semiotic process. So the active element shifts inside the triad. It is not impossible that also the objects claim more attention than the historical evolution of signification has allowed them.

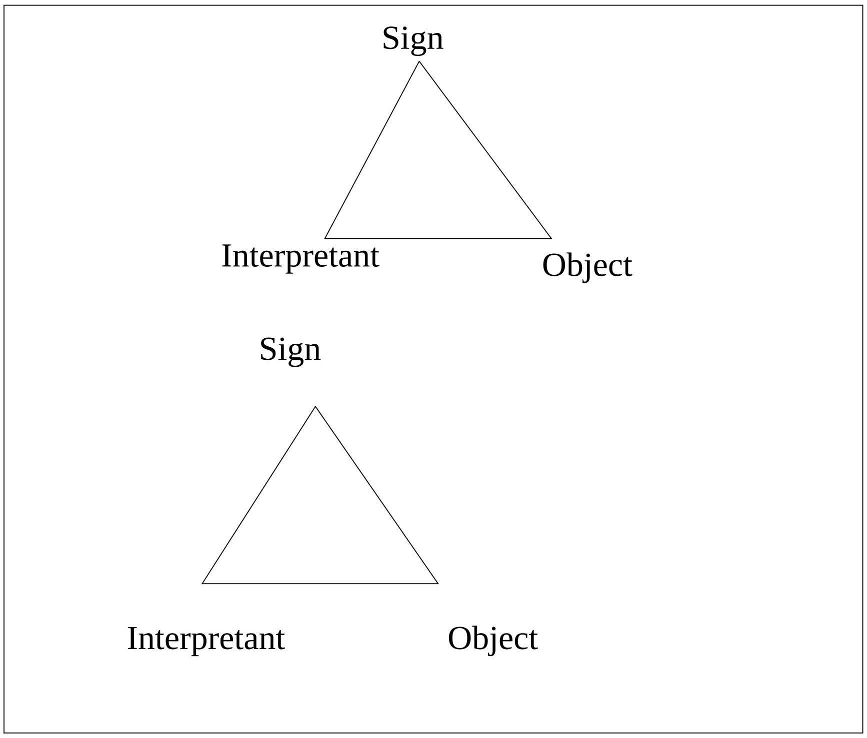


**Fig. 2.** Schema showing the two levels of triads overlapping in the sign becoming interpretant.

## 4 The Semiotics of Postmodern Physics

The semiotic process is very like an expedition without destination. It is roaming around searching for something. The triad itself is always unfinished. The semiotic process has many features in common with searching the missing corner of the triangle composed of sign, interpretant and object. It is definitely different from scientific research, which is more focussed, conscientious and limited. In the first section, I tried to show that many nowadays scientists sense that there may be a significant simplicity beyond apparent complex phenomena. Material sciences in the 20th century started with hard materials, the physics of the solid state. But more recently evolution tends towards the soft polymers, soaps, liquid crystal, mixed forms of materials, where order is rarely quantum mechanically determined but by the thermal fluctuations. The theory of random surfaces has made a considerable impact to understand the dynamics of blood cells of tenths of micrometres. Biological objects are envisaged by the physicists as referents of significant new data. In my opinion the science of complexity is mostly engaged in the lower two corners of the triad, gathering possible objects of study and measuring them, i.e. trying to find the key interpretants of these objects. Many experiments have in effect already been done, but the outcome of these series of experiments is so overwhelmingly rich in variety, that one speaks of complex phenomena.

Measurement means introducing for these phenomena a new meter stick which allows comparisons between different morphological characters. As an example may serve the categorization of macromolecules. L. Holm and C. Sander, see Holm and Sander (1996), p. 505, have proposed various mappings of molecules to relate protein shapes in a higher dimensional space. I remind the reader the work of Parisi cited before. A tree can be established for complex phenomena where similar to Linnes plant classification the first name is the family name, the second the genus and the last name the species. When the configurations can be organized into a tree in such a way that the distance between two configurations depends on the position in the tree, the space of configurations is metric. Complexity can then be defined as a generalization of entropy or neginformation, namely as a double sum of the probability distribution times its logarithm over probabilities and distances in this metric space. It is interesting how the particle physicist G. Mack, see Mack, approaches the same problem using the language of gauge theories. "Gauge theory can describe complex adaptive systems, i.e. anything alive in the widest sense, especially autopoietic systems which make themselves in an approximately autonomous fashion."

The sign level for the complex system is each time taken over from another existing field, either condensed matter physics or elementary field theory. An attempt is made to adapt it to a new base of interpretants and referents. In the second case one feels to be at the very initial stage of a signification process, in which even for the practitioner of gauge theory the analogy is not apparent. It is appropriate to cite E. Cassirer, see Cassirer (1994), Vol 1, p. 4, and compare to his interpretation of the process of symbolization: " Whereas a realistic view of the world ("Weltansicht") rests on a somehow final substantiality of things, as basis for all cognition, idealism transforms exactly this substantiality into a question of thinking. ....Also here (in the individual disciplines of science) the way of thinking does not go from facts to laws and from these laws onward to axioms and fundamental concepts. Axioms and concepts appear at a certain stage as the last and complete expression of the solution, but they must again become a new problem at a later stage. Consequently the object of science annot be considered any longer as simple analysable facts, but each new way or direction of observation opens up a new aspect. "

To come back to the subject of biology and complexity, we find that biology has developed an existing "Weltansicht" for the existence of macromolecules, which is to a large extent focussed on the concept of function. Physics has been used as an experimental tool of structural analysis, but can contribute even more insight into the stability and structure of biological forms.

The words of Cassirer cited above sound convincing even to the simple minded physicist. The practical scientist will be more scecptical reading in the chapter on subjective and objective analysis, see Cassirer (1994) p. 53,:

"Thinking experiences its own form through the existence of signs, via the possibility to operate and connect signs in a specific way following fixed and consequent rules. In this process, thinking reasures itself of its theoretical self. The retreat to the world of signs prepares the decisive breakthrough with which new thoght conquers his own world, the world of ideas." Here Cassirer explicitly leaves the method of scientific inquiry into another world of the ideal form "des objektiven Geistes", which one may have problems to follow.

In another aspect is the postmodern physics involved in a semiotic pattern hitherto unknown in modern physics: The large computer simulations of physical theories. Here the transposition of an existing sign in one triad into an interpretant of a new triad occurs. In my opinion these simulations prepare the shift to a second order semiological system which happens in full analogy to the formation of myth in language as has been described in chapter 2. Let me concretize the situation by an example from elementary particle physics: Here large scale simulations form part of a triad, which includes the proton as elementary object constituent of the atomic nucleus, together with a large class of experiments showing the compositeness of exactly this proton as being made up from quarks and gluons. We all know this from the Russian dolls, where one doll is sitting in the next and so on. At the current stage of physics these quarks and gluons are really elementary quanta, the dynamcis of which is described by a fundamental theory called Quantum Chromo Dynamics. This quantum field theory gives a Lagrangian function, which determines the basic equations of motion.The dynamics can be formulated also in computer code and simulated on large number crunchers. The output of these computer calculations is a collection of so called configurations where the gluon fields have certain values, typically 5 000–10 000 of these configurations are generated. With these configurations certain properties of the proton can then be calculated e.g. its mass, or better its mass relative to another elementary particle. This ratio can then be compared with the experimental ratio and the circle closes in an approximate way at least.

So far so good. There remains the problem of understanding the unfolding of the dynamics which is entirely formulated by one simple Lagrangian in one line, but whose realization after the computer's work does go above our intuitive understanding. Here enteres the second triad. It consists of approximate pseudoparticles previously called x-tons which are analytical solutions of an approximation to the QCD Lagrangian. Perhaps these x-tons can explain the outcome of the simulation? Aha, let us take the gluon field variables as signs of the first triad and work with them. The first triad contains the proton as object and the measurements about the proton as its interpretants. The signs of the first triad will be shifted to a second new triad where they play the role of an interpretant of this new object x-ton, note a theoretical object. They will be analysed in a new program which eliminates certain fluctuations from the original simulation, it may undo quantum effects and indeed x-tons appear as proposed. One can test whether these x-tons play a significant role by checking whether the presence of these x-tons is correlated with certain properties of the proton, which may be the spatial correlation of one of the quarks with the residual quarks. The computer plays now the role of manipulated nature to spit out a metatheory, i.e. an abstract simplified explanation of the theory of the proton. This formation of "myth" where the original signs become interpretants of a new narrative is quite common in the field of numerical large scale simulations. The computers present a powerful instrument to test theoretical simplifications which make the workings of basic physical theories pallable to the human mind.

In spite of the simplicity of the underlying Lagrangian which governs the dynamics of these in general highly nonlinear strongly coupled field theories, the implications go beyond a simple understanding. A narrative has to be constructed which forms the missing link between the computer and our brain in the same way as in prelogical times myth mediated between the gods and limited human consciousness.

Large scale simulations also dominate the more difficult branch of forecasting. "The limits to growth", predictions of the Club of Rome, are an outgrowth of a combination of first order matrix differential equations with a large number of coefficients which govern physical growth and decay processes like, e.g., in a radioactive decay chain of nuclei, see Meadow and Meadows (1974). Once the coefficients are fitted to previous time histories, the computer extrapolates the solution to the future. There are four main interlocking blocks, namely population, capital, food, nonrenewable resources and pollution in this program. These influence each other with possible time delays and positive or negative feedback. The method is based on System Dynamics, in particular the work of J.W. Forrester ,see Forrester (1968) . Here the object is a virtual world which lives in the computer. The real world is represented by the input key figures.

The process of symbolization is the modeling of the differential equations, which will be shaped from structural interdependences and then tuned in a repetitive way, i.e. the respective solutions will be examined until some reasonable output data are obtained. In general the output data themselves are not significant only their interdependences are of value, see Meadows and Meadows (1974): "This process of determining behaviour modes is prediction only in the most limited sense of the word. ... These graphs (i.e., the pictorial results of the model) are not exact predictions of the values of the variables at any particular year in the future. They are indications of the systems behavioral tendencies only." For the empirically minded physicist the triangle is not closed, there is a limited possibility of rejection, gross failures may be visible, the difference between the virtual world and the real world in simulations is not the same as between an idealized experimental set up and nature in physics. One talks about computer experiments, because the computer replaces a system in nature or society as object of our knowledge by a computational schema . We learn more about our possiblities to mimic, to represent the world, but less how to understand it.

Only in the second step, which I call semiological shift to a second order semiological system, when the output data are taken as new elements of another triad they become interpretants of the real world with a signification attached to them which is used to support a new set of believes and concepts. This building of the second level triad is characteristic of the social sciences where the purely empirical information is mostly insufficient as a trigger for political action. A scenario i.e. a simulated interpretant of the future has to be constructed which sends a strong message. The collapse scenario of the Club of Rome had an incredible impact on the public for the following next twenty years.

Postmodern physics reaches out to the limits of scientific inquiry in many other cases. Artificial intelligence and the theory of cognition are other far out systems which have become playground of physicists. Physical mathematics is more abstract and aims to a more profound level. A very recent straightforward and simplified introduction to the subject is given by J. Polchinski. (See Polchinski 1998.) String theory is really a realm of physics where new mathematical entities are constructed like new "icons". I use the expression "icon" exactly in the sense discussed in section 3, namely as a sign not yet connected to a specific object. Strings or membranes (more precisely noncritical strings) as mathematical objects have their nearest realization in soft matter theory, like blood cells in biology. Superstring theory does not (yet) have any objects to represent besides the graviton, perhaps. Here the physicists are in search of an object. They have the symbolization, they have worked out the iconography for something they do not know. They sense that gravitation may be tightly interconnected to it. But they cannot make the connection.

In order to keep up the awareness for something lurking outside they look for bridges to other theoretical signs in other triads. They try to build bridges down from the very infinitesimally tiny to the infinitesimally small. These would-be-bridges extend from string theory to supersymmetric theories and to the Standard Model, which is testable everyday at the big Labs in Chicago and Geneva. Theoretical bridges on the sign level of the icons connect the string icon to the field icons of the standard model which are significant interpretants of data. Here the physicists search for interpretants. The string theory has got all kinds of mathematical symbols—what to do with them? In a big archeological effort, relics from the early universe like monopoles, strings and domain walls are searched for. Here the large energy density of the still small universe can make up what human built accelerators cannot yet achieve. This looks again like a search for objects. Note such searches have been successful in the past in the field of elementary particle physics. Purely built on theoretical grounds of renormalizable interactions unifying the weak and electromagnetic phenomena, the postulated W- and Z-particles have indeed been found. So such a hope may not be futile. The signs in the math picture books are leading to the discovery of real things.

The most interesting bridge from these new theories which is in the process of being constructed aims to include gravitation with the other fundamental interactions. There is now a good circumstantial evidence that each of a number of compact x-ray sources in our galaxy contains a black hole of a few solar masses in orbit around a somewhat more massive normal star. On a larger scale there may be black holes of a few thousand solar masses at the centers of globular clusters. When quantum effects are taken into account black holes are not entirely black, they are emitting Hawking radiation, which in simple terms is the capture of one part in a particle-antiparticle fluctuation of the vacuum by the black hole, whereas the other partner is escaping and looks like being emitted. The black hole is therefore in general not a ground state, it will become hotter radiating its mass away. If the black hole also has a charge associated to it, the black hole will stop radiating when its charge in suitable units equals its mass. This type of extremality condition corresponds to states in supersymmetric theories which as BPS states also satisfy a similar bound as discussed before. By a miraculous coincidence it has been possible to calculate the entropy of black holes, i.e. roughly the number of realizations by counting string states. This for the first time is a link of the up to now unattached frameword of string signs to the gravitational field. It still presents a puzzle, but shows the far reaching possibilities in this field.

## 5 Conclusions

J. Horgan, see Horgan (1996) in his apocalyptic essay on the end of science speaks about the ironic mode of doing science: "to pursue science in a speculative, postempirical mode, that I call ironic science. Ironic science resembles literary criticism in that it offers points of view, opinions, which are best interesting which provoke further comment. But it does not converge on the truth. It cannot achieve empirically verifiable surprises that force scientists to make substantial revisions in their basic descriptions of reality." Protagonists in all the fields described would definitely not consider themselves as such postmodern ironic physicists. Therefore I have put the adjective "postmodern" in quotation marks in the headline of the article.

This article has tried to show how contemporary physics examplifies the construction of semiotic processes. The discussed fields of physics are unfinished systems of symbolization, and symbolization is only one of the many aspects of their scientic development. Nevertheless I feel that the study of present day science injects into the philosophical debate new aspects untouched in a historical analysis. History always separates the successes from the flops. Post facto one may want to know why this happened and whether it could not also have failed. Contemporary science is in a disordered state, it presents crossroads, alternatives. The sciences influence our culture indirectly and in a still rather unreflected way. Here a dialog with philosophy may be fruitful. Because of the speed at which the modern sciences develop, some of its outside interpreters have seen signs of postmodern indeterminism, fragmentation and dissolution. This article does not agree with this categorizaton. It accepts one property of postmodern thought, however, namely immanence. The scientific process is of this world and two of the corners of the semiotic triad, the objects and representants, are very much connected to experimentation and data handling, i.e. everyday things. The understanding we presume or gain may finally be connected to other enterprises of culture. The process of symbolisation links the natural sciences with language and thought in other fields. It wonderfully illustrates Einstein's remark, "The most incomprehensible thing about nature is that it is comprehensible". To develop a deeper understanding of this question is and will be one of the outstanding tasks in philosophical thinking.

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