On the Origin of Language
A Bridge Between Biolinguistics and Biosemiotics

Marcello Barbieri

Abstract Thomas Sebeok and Noam Chomsky are the acknowledged founding fathers of two research fields which are known respectively as Biosemiotics and Biolinguistics and which have been developed in parallel during the past 50 years. Both fields claim that language has biological roots and must be studied as a natural phenomenon, thus bringing to an end the old divide between nature and culture. In addition to this common goal, there are many other important similarities between them. Their definitions of language, for example, have much in common, despite the use of different terminologies. They both regard language as a faculty, or a modelling system, that appeared rapidly in the history of life and probably evolved as an exaptation from previous animal systems. Both accept that the fundamental characteristic of language is *recursion*, the ability to generate an unlimited number of structures from a finite set of elements (the property of 'discrete infinity'). Both accept that human beings are born with a predisposition to acquire language in a few years and without apparent efforts (the innate component of language). In addition to similarities, however, there are also substantial differences between the two fields, and it is an historical fact that Sebeok and Chomsky made no attempt at resolving them. Biosemiotics and Biolinguistics have become two separate disciplines, and yet in the case of language they are studying the same phenomenon, so it should be possible to bring them together. Here it is shown that this is indeed the case. A convergence of the two fields does require a few basic readjustments in each of them, but leads to a unified framework that keeps the best of both disciplines and is in agreement with the experimental evidence. What is particularly important is that such a framework suggests immediately a new approach to the origin of language. More precisely, it suggests that the brain wiring processes that take place in all phases of human ontogenesis (embryonic, foetal, infant and child development) are based on organic codes, and it is the step-by-step appearance of these brain-wiring

M. Barbieri (✉)
Dipartimento di Morfologia ed Embriologia, Via Fossato di Mortara 64a, 44121 Ferrara, Italy
e-mail: brr@unife.it

codes, in a condition that is referred to as *cerebra bifida*, that holds the key to the origin of language.

Keywords Biolinguistics · Biosemiotics · Cognitive development · Organic codes · Origin of language

Introduction

Biosemiotics and Biolinguistics are two young disciplines that have been developed independently since the 1960s under the inspiration and guidance respectively of Thomas Sebeok and Noam Chomsky. The two fields are still largely identified with the ideas of their chief architects, so it is from these ideas that we have to start in order to evaluate and compare the two disciplines.

Thomas Sebeok has introduced three major innovations in semiotics: (1) in 1963, he founded the new research field of *zoosemiotics* by proposing that semiosis takes place not only in our species but in all animals (Sebeok 1963, 1972); (2) in the 1980s and 90s he led the movement that recognized the existence of semiosis in all living systems (*biosemiotics*), and formulated the foundational principle of biosemiotics with the idea that "life and semiosis are co-extensive" (Sebeok and Umiker-Sebeok 1992; Sebeok 2001); (3) throughout his academic life, Sebeok engineered the revolution in semiotics that eventually replaced the dualistic model of Saussure with the triadic model of Peirce (Sebeok 1979, 1988, 1991).

Noam Chomsky has profoundly influenced the study of language, and his contribution too can be summarized in three innovations: (1) his review of Skinner's *Verbal Behavior* overturned the behaviourist paradigm and fuelled the 'cognitive revolution' in psychology (Chomsky 1959); (2) he made universally familiar the idea that language depends on an innate generative mechanism called 'Universal Grammar' (Chomsky 1957, 1965, 1975), and (3) his campaign for the *Principles and Parameters* program led to an explosion of inquiry into different languages and to an investigation into the architecture of language that has become know as the 'Minimalist Program' (Chomsky 1995, 2005, 2006).

Both Sebeok and Chomsky regarded the study of language as a branch of biology, and the concepts that they proposed on the definition and on the evolution of language are not incompatible. What is radically different, in them, is the mechanism that lies at the heart of language.

Sebeok claimed that language is a semiotic activity and that 'interpretation' is its most distinctive feature. Chomsky argued that syntax is the crucial component of language and that syntax is based on very general principles of economy and simplicity that are similar to the *Principle of Least Action* in physics and to the rules of the *Periodic Table* in chemistry.

Biosemiotics and Biolinguistics have been built in this way on different foundational principles and have become two increasingly different research programs. At the same time, they both advocate a *scientific* study of language (Augustyn 2009) and should be able therefore to reach similar conclusions. The purpose of this paper is precisely to show that such a convergence is possible. As we will see, the discovery of many organic codes in the living world provides the crucial

data and ideas that were missing in both Biolinguistics and Biosemiotics, and leads to a unified framework where something is accepted and something else is rejected in both disciplines. The organic codes, furthermore, suggest immediately a novel approach to the origin of language and a new model in that field. In order to illustrate these points, the paper has been divided into two parts. The first describes the building of a bridge between Biolinguistics and Biosemiotics, whereas the second illustrates the new model on the origin of language.

PART 1 — A Bridge Between Biolinguistics and Biosemiotics

Chomsky's Definitions of Language

In modern linguistics, any verbal communication system (English, Russian, Chinese, etc), is often referred to as *External Language* (E-language), whereas the faculty that is responsible for it is called *Internal Language* (I-language). In everyday life, the term 'language' is normally used in the first sense, whereas in academic life and in scientific research it is mostly used in the second sense and has become virtually synonymous with I-language (Bever and Montalbetti 2002).

Another important distinction is between language and *speech*. Speech is the actual verbal activity that takes place between individuals, whereas language is the faculty, or the 'organ', that makes speech possible. Ever since Aristotle, speech has been regarded essentially as an activity that links *sound and meaning*, and requires therefore the coordination of two distinct systems: a phonetic system that receives and produces sounds (the *sensory-motor* component of language) and a cognitive system that gives meaning to sounds (the *semantic* component of language). Recently, however, it has been widely acknowledged that a third system must exist in order to perform an additional type of processing. This third component of the faculty of language is the system responsible for *syntax*, the set of rules that all combinations of sounds must follow to be accepted as valid linguistic expressions.

Chomsky repeatedly underlined that syntax and semantics are intimately interrelated, but at the same time he showed that they are distinct entities. He demonstrated this point with the classical sentence *"colorless green ideas sleep furiously"*, which is nonsense in terms of meaning and yet it is correct in terms of syntax. Most importantly, Chomsky recognized that it is this third component of language that is capable of generating an unlimited number of expressions from a finite set of elements. It is syntax, in other words, that is responsible for *recursion*, and for that reason one can rightly regard it as the generative engine, or the computational machine, of language.

The very special role that syntax plays in language has induced Hauser et al. (2002) to propose two distinct definitions of language. The faculty of language in the broad sense (FLB) is formed by all three systems mentioned above (phonetics, semantics and syntax), whereas the faculty of language in the narrow sense (FLN) contains syntax alone. The rationale of this proposal is that "FLN is the only uniquely human component of the faculty of language", whereas the other two come from our animal ancestors. According to this proposal, in short, all animals are capable of communication, but language exists only in our species because only humans have evolved the generative engine of syntax.

Sebeok's Definitions of Language

Thomas Sebeok reached his conclusions on language by elaborating the concepts proposed by Jakob von Uexküll (1864–1944) and by Juri Lotman (1922–1993).

Von Uexküll was regarded by Sebeok as a precursor of biosemiotics (a "cryptosemiotician") because he had shown that all animals are capable of interpreting the world, and that they do it in species-specific ways. According to Uexküll, every animal perceives the external world with internal means and lives therefore in a subjective environment of its own making that he called *Umwelt*. The mental images of the external world, in turn, are built by an internal system that Uexküll called *Innenwelt*, so it is this 'inner world' that is ultimately responsible for what an animal regards as its surrounding environment (von Uexküll 1909).

Juri Lotman gave the name *semiosphere* to the world of culture, and regarded that term as the cultural equivalent of the name *biosphere* that is often used to describe the biological world. But Lotman was also a follower of Saussure, and inherited from him the idea that language is made of two distinct components: an abstract-universal system called *Langue*, and a concrete-individual entity called *Parole*. Langue, according to Saussure, is the system that lies at the very heart of culture, and for that reason Lotman called it *"the primary modelling system"* of our species (Lotman 1991).

Thomas Sebeok accepted both the idea of a modelling system proposed by Lotman, and the concept of Umwelt proposed by Uexküll, and argued that there must be a deep relationship between them. Any Umwelt is produced by an Innenwelt, according to Uexküll, and Sebeok realized that the Innenwelt of any animal is essentially what Lotman called a modelling system. From this he concluded that the primary modelling system of man is his ancestral animal Innenwelt, not language. In that case, language was a later evolutionary addition, and Sebeok described it as *the secondary modelling system* of our species.

The concept of modelling system has acquired an increasing importance in semiotics, and Sebeok continued to develop it throughout his life. His last book on that concept, *The Forms of Meaning*, written with Marcel Danesi, appeared just 1 year before his death (Sebeok and Danesi 2000).

It is worth noticing that the 'primary modelling system' of Sebeok is the whole set of brain-modelling faculties that we have inherited from our animal ancestors, and is therefore more general than the 'faculty of language in the broad sense' (FLB) defined by Chomsky. In the same way, Sebeok's 'secondary modelling system' includes all modelling faculties that evolved only in our species and is more general than Chomsky's 'faculty of language in the narrow sense' (FLN). There is, however, no contrast between the definitions of language proposed by Chomsky and by Sebeok, and all we need to keep in mind is that they use different terminologies for largely similar purposes.

The Bone of Contention

Chomsky's most seminal idea is the concept that our ability to learn a language is *innate*, the conclusion that children are born with a mechanism that allows them to learn whatever language they happens to grow up with. That inner generative mechanism has been given various names—first *Universal Grammar*, then *Language Acquisition Device (LAD)*, and finally *Faculty of Language*—but its

basic feature remains its *innateness*. The mechanism must be innate, according to Chomsky, because it allows all human children to master an extremely complex set of rules in a limited period of time. The faculty of language, furthermore, is acquired in a precise sequence of developmental stages, like all biological faculties of our body, and can be regarded therefore as a new organ that for some reasons evolved only in our species.

At the very heart of this new organ, or faculty, is the mechanism of recursion, the apparatus that is capable of generating an unlimited number of structures from a finite set of elements, and it is to this inner generative mechanism that Chomsky gave the name first of "universal grammar", and then of "faculty of language in the narrow sense" (FLN). According to Chomsky, in short, the generative engine of syntax has the characteristics of a physiological organ, and in this respect it is similar to the sensory-motor component of language. There is however one important difference between these two components. The sensory-motor apparatus has an extremely long history behind it and that made it possible that its features were shaped by natural selection (what Chomsky called "Jacobian bricolage"), whereas the apparatus of syntax could not have evolved by that mechanism for at least two reasons. The first is that language appeared only recently in the history of life, and there simply wasn't enough time for natural selection to produce extensive changes. The second reason is that the principles of syntax are regarded as general constraints, like those dictated by logic, mathematics and physics, and natural selection can do nothing about them.

Chomsky concluded that language probably evolved as an exaptation of processes that originally evolved for different functions, and this is a conclusion that Thomas Sebeok did support. He did so by repeatedly underlining that language is first and foremost a modelling system and that only in a second stage it has been redeployed as a verbal communication system.

There is however an issue about which Chomsky and Sebeok reached two very different conclusions. They never had a public debate about it, but that issue has been, and continues to be, the bone of contention between biosemiotics and biolinguistics. The issue is the mechanism that lies at the heart of language. Is the mechanism of recursion a product of universal laws or the result of interpretive processes?

The crucial point, here, is that Sebeok adopted the Peirce model of semiosis, and since this is explicitly based on interpretation, he concluded that semiosis is always an interpretive activity. The Peirce model was formally described in the *Treatise of Semiotics* edited by Posner, Robering and Sebeok, with the statement that: "The necessary and sufficient condition for something to be a semiosis is that A interprets B as representing C, where A is the interpretant, B is an object and C is the meaning that A assigns to B" (Posner et al. 1997).

Sebeok underlined that concept on many other occasions and in no uncertain terms: "There can be no semiosis without interpretability, surely life's cardinal propensity" (Sebeok 2001). In such a framework one is bound to conclude that the generative mechanism of language is an interpretive process, and this is incompatible with the idea that it is the result of universal principles or physical constraints.

This is therefore what divides biosemiotics from biolinguistics. As long as semiosis is based on interpretation and the generative mechanism of language is

based on universal laws, the divide is incommensurable and there is no possibility of a convergence between the two disciplines.

Two Types of Semiosis

Sebeok's conclusion that semiosis is based on interpretation is undoubtedly valid in animals, but not in all living systems. It is not applicable, in particular, to the cell, where the genetic code has been virtually the same for billions of years, which clearly shows that it does not depend on interpretation. The same applies to the other organic codes of the cell. The existence of organic codes is documented by the presence of molecular adaptors, and these molecules have been found not only in protein synthesis (where the adaptors are the tRNAs) but in many other cellular processes. This has revealed the existence of the *splicing codes,* the *signal transduction codes*, the *cytoskeleton codes*, and the *compartment codes* (Barbieri 1998, 2003), whereas similar arguments have brought to light the *metabolic code* (Tomkins 1975), the *sequence codes* (Trifonov 1987, 1989, 1996, 1999), the *sugar code* (Gabius 2000; Gabius et al. 2002), the *histone code* (Strahl and Allis 2000; Turner 2000, 2002), and many others (Barbieri 2008).

The idea that the cell is capable of interpretation has been re-proposed time and again by the followers of Peirce with the argument that the behaviour of the cell is manifestly context-dependent and this is a sure sign of interpretive ability. But let's take a closer look. The genetic code and the signal-transduction code consist of context-free rules, but what happens when they work *together*? The answer was provided by the classic experiments of Jacob and Monod on the regulation of protein synthesis: the cell uses the genetic code to make proteins according to the inputs of the transduced signals, and the result is a context-dependent response (Jacob and Monod 1961). That is all we need to explain the context-dependent behaviour of the cell: two codes working together, two integrated activities of coding-decoding. But there is more than that. In addition to the above two codes, the eukaryotic cells have many other organic codes, and each of them brings an additional level of complexity into the system. The extremely complex behaviour of the eukaryotic cell, in short, is a natural result of the presence of many organic codes in it, and does not require interpretation.

For the first three thousand million years—almost 80% of the entire history of life—our planet was inhabited only by single cells and the behaviour of these cells is fully accounted for by organic codes, or *code semiosis*, i.e., by a form of semiosis that relies exclusively on coding. With the origin of animals, however, a new type of semiosis came into being, a type that is rightly referred to as *interpretive semiosis* because it is specifically involved in the process of interpretation.

Can we justify this conclusion? Can we say that there has been a real macroevolutionary discontinuity between single cells and animals? To this purpose, let us underline that animals do not interpret the world but only *representations* of the world. Any interpretation, in other words, is always exercised on internal models of the environment, never on the environment itself.

Single cells, on the other hand, do not build representations of the outside world. They decode the signals from the environment but do not build internal models of it

and therefore cannot interpret them. They are sensitive to light, but do not 'see'; they react to sounds but do not 'hear'; they detect hormones but do not 'smell' and do not 'taste' them. It takes the cooperation of many cells which have undertaken specific processes of differentiation to allow a system to see, hear, smell and taste, so it is only multicellular creatures that have these experiences. Only animals, in short, build internal representations of the outside world and only these representations allow them to *perceive*, to *feel*, and to *interpret* the world.

The evolution from single cells to animals was far more than an increase in growth and complexity. It was a true macroevolutionary event that gave origin to absolute novelties, to entities that had never existed before such as perceptions and feelings. Interpretation had an origin and a history, like everything else in life, and arose only in multicellular systems. That is what divides animals from single cells, and that is why we need to acknowledge that there are two distinct types of semiosis in living systems: one that depends on coding (*code semiosis*) and one that requires interpretation (*hermeneutic semiosis*). Such a conclusion, furthermore, is based not only on the analysis of the experimental evidence. There are also sound theoretical arguments in favour of code semiosis, so let us briefly examine them before going on to other issues.

The Code Model of Semiosis

Semiosis is usually referred to as *the production of signs* but this definition is too restrictive because signs are always associated with other entities. A sign, to begin with, is always linked to a *meaning*. As living beings, we have a built-in drive to make sense of the world, and when we give a meaning to something, that something becomes a sign for us. Sign and meaning, in other words, cannot be taken apart because they are two sides of the same coin. The result is that a system of signs, i.e. a *semiotic system*, is always made of two distinct worlds: a world of entities that we call *signs* and a world of entities that represent their *meanings*.

The link between sign and meaning, in turn, calls attention to a third entity, i.e., to their *relationship*. A sign is a sign only when it stands for something that is *other than itself*, and this *otherness* implies at least some degree of *independence*. It means that there is no deterministic relationship between sign and meaning. Different languages, for example, give different names to the same object precisely because there is no necessary connection between names and objects. A semiotic system, therefore, is not any combination of two distinct worlds. It is *a combination of two worlds between which there is no necessary link*, and this has an extraordinary consequence. It implies that a bridge between the two worlds can be established only by *conventional* rules, i.e. by the rules of a *code*. This is what qualifies the semiotic systems, what makes them different from everything else: *a semiotic system is a system made of two independent worlds that are connected by the conventional rules of a code*. A semiotic system, in short, is necessarily made of at least *three* distinct entities: *signs, meanings* and *code*.

Signs, meanings and code, however, do not come into existence of their own. There is always an 'agent' that produces them, and that agent can be referred to as a *codemaker* because it is always an act of coding that gives origin to semiosis. In the case of culture, for example, the codemaker is the human mind, since it is the mind

that produces the mental objects that we call signs and meanings and the conventions that link them together. The crucial point is that signs and meanings do not exist without a codemaker and outside a codemaking process. The codemaker is the *agent* of semiosis, whereas signs and meanings are its instruments. We conclude that signs and meanings are totally dependent on codemaking, i.e., they are *codemaker-dependent entities*. This is their qualifying feature, and we can say therefore that signs and meanings exist whenever there are codemaker-dependent entities.

We come in this way to a general conclusion that can be referred to as 'the Code Model of semiosis': *a semiotic system is made of signs, meanings and code that are all produced by the same agent, i.e., by the same codemaker* (Barbieri 2003, 2006). This tells us precisely what we need to prove in order to show that a system is a semiotic system. We need to prove that there are four distinct entities in it: signs, meanings, code and codemaker.

The Cell as a Trinity

The study of protein synthesis has revealed that genes and proteins are not formed spontaneously in the cell but are manufactured by a system of molecular machines based on RNAs. In 1981, the components of this manufacturing system were called *ribosoids* and the system itself was given the collective name of *ribotype* (Barbieri 1981, 1985). The cell was described in this way as a structure made of genes, proteins and ribosoids, i.e., as a trinity of *genotype, phenotype and ribotype*.

This model is based on the conclusion that the ribotype had a historical priority over genotype and phenotype. Spontaneous genes and spontaneous proteins did appear on the primitive Earth but they did not evolve into the first cells, because spontaneous molecules do not have biological specificity. They gave origin to *molecular machines* and it was these machines that evolved into the first cells. The simplest molecular machines were *bondmakers*, molecules that could join other molecules together by chemical bonds. Among them, some developed the ability to join nucleotides together in the order provided by a *template*. Those bondmakers started *making copies* of nucleic acids, and became *copymakers*. Proteins, on the other hand, cannot be made by copying, and yet the information to make them must come from molecules that can be copied, so it was necessary to bring together a carrier of genetic information (a messenger RNA), a peptide-bondmaker (a piece of ribosomal RNA) and molecules that could carry both nucleotides and amino acids (the transfer RNAs). The outstanding feature of the protein-makers, however, was the ability to ensure a specific correspondence between genes and proteins, and that means that the evolution of the translation apparatus had to go hand in hand with the evolution of the genetic code. Protein synthesis arose therefore from the integration of two distinct processes, and the final machine was a *code-and-template-dependent-peptide-maker*, or, more simply, a *codemaker*.

The RNAs and the proteins that appeared spontaneously on the primitive Earth produced a wide variety of ribosoids, some of which were synthetizing ribosoids whereas others were ribogenes and others were riboproteins (or ribozymes). The systems produced by the combination of all these molecules, therefore, had a ribotype, a ribogenotype and a ribophenotype. Eventually, evolution replaced the ribogenes with genes and the riboproteins with proteins but the synthetising

ribosoids of the ribotype have never been replaced. This shows not only that the ribotype is a distinct category of the cell, but also that it is a category without which the cell simply cannot exist.

The ribosoids of the ribotype are the oldest phylogenetic molecules that exist on Earth (Woese 2000) and they firmly remain at the heart of every living cell. Genes, proteins and ribosoids are all manufactured molecules, but only the ribosoids are also *makers* of those molecules. This concept can perhaps be illustrated by comparing the cell to a city where proteins are the objects, genes are the instructions and ribosoids are the 'makers' of genes and proteins, i.e., the inhabitants of the city.

It is an experimental fact, at any rate, that every cell contains a system of RNAs and ribonucleoproteins that makes proteins according to the rules of a code, and that system can rightly be described as a 'codemaker'. That is the third party that makes of every living cell a trinity of genotype, phenotype and ribotype. The genotype is the seat of heredity, the phenotype is the seat of metabolism and the ribotype is the codemaker of the cell, the seat of the genetic code.

In addition to code and codemaker, however, there are also signs and meanings in the cell, because the copying and coding of genes and proteins require sequences and these are codemaker-dependent entities. The sequence of codons in a messenger RNA, for example, is codemaker-dependent because it is *defined* by the scanning mechanism (if the nucleotides were scanned two-by-two, for example, the same messenger RNA would produce a totally different sequence).

We reach in this way two main conclusions. The first is that the cell is a true semiotic system because it has all four defining features of semiosis. The second is that code semiosis is a reality, because it is precisely what is taking place in fundamental processes like protein synthesis, splicing and signal transduction.

The Bridge of the Organic Codes

The idea of the organic codes, or code semiosis, consists of three distinct concepts (Barbieri 2003, 2006):

(1) We can prove the existence of many organic codes by the presence of molecular adaptors. This means that organic codes are *normal components* of living systems, not extraordinary exceptions, and that they appeared throughout the whole history of life and not just at the beginning and at the end of evolution.

(2) The presence of two or more organic codes is enough to explain the context-dependent behaviour of the cells, and there is no need of interpretation at the cellular level. This means that there are two distinct types of semiosis in life: one that depends of coding and one that depends on interpretation.

(3) Any new great step of macroevolution was associated with the appearance of new organic codes.

Biolinguistics and Biosemiotics have both been built without these concepts and it is largely because of this that a divide has existed between them. As soon as we

introduce the idea of the organic codes, in fact, we find that the two main obstacles that so far have divided them can be removed.

(a) The major claim of Biolinguistics is that the development of the faculty of language must be precise, robust and reproducible like the development of any other faculty of the body, and therefore it cannot be left to the vagaries of interpretation. The ontogeny of language, in other words, cannot be explained by interpretive semiosis. Clearly, this obstacle can be removed only by showing that there are two distinct types of semiosis in life, and that one of them does not require interpretation.

(b) The major claim of Biosemiotics is that life is based on semiosis, and this is not compatible with the idea that the rules of syntax are based on universal laws. The ontogeny of language, on the other hand, would be precise, robust and reproducible even if it were based on organic codes rather than universal laws. The genetic code, for example, guarantees precise, robust and reproducible features in all living system, and has properties that are even more universal than those attributed to universal grammar. Language does require rules, but the rules of universal grammar, or the principles and parameters of syntax, are much more likely to be the result of organic codes rather than the expression of universal phenomena like the Periodic Table or the Principle of Least Action. This is because the rules of life are produced by living systems and evolve with them, whereas the rules of mathematics and physics are not subject to historical change.

The idea of the organic codes, in conclusion, immediately removes the two obstacles that so far have divided biolinguistics from biosemiotics, but that of course is not enough for our purposes. Removing a theoretical divide is important, but does not necessarily create a convergence. The organic codes can provide a real bridge between the two disciplines only if they tell us something new and important about the origin of language. That is the major issue that we have in front of us, and that is going to be the object of the remaining part of this paper.

PART 2 — The Code Model on the Origin of Language

The First Step

The idea that man is different from animals is present in all cultures and is generally expressed by saying that only man has 'higher' faculties like consciousness, free will, morality and the creative power to produce art, religion, science, and poetry (together with torture, mass murder, and environmental disasters). Today we have a shorter explanation for all that. All we need to say is that only man has 'language'. The rest is just a consequence of that one faculty, so it is the origin of language that we need to understand if we want to find out what made us human.

Anything in science, however, must be accounted for, including the sweeping generalization that we have just encountered. Are we really sure that 'only man has language'? That animals do not have simpler forms of language? Granted that animals do not talk like we do, they are certainly capable of communicating with

each other, often in highly sophisticated ways, so it seems reasonable to conclude that language is just an evolved form of animal communication. More powerful, yes, but not *qualitatively* different. This is indeed a possibility, but we should not take it for granted because we have learned that genuine novelties did, occasionally, appear in the history of life.

We have therefore a first problem before us: is there a qualitative difference between language and animal communication? And, if the answer is yes, what does the difference consist in? This is the first question that we need to address about the origin of language. There are many other queries after that, but we must deal with that issue first, because it is a precondition for all the other steps.

The Uniqueness of Language

Animals receive signals from the world, transform them into mental (or neural) images and perform operations on these images that allow them to mount a reaction to the received signals. When the signals come from other animals, the reactions can start new rounds of processing and give origin to an exchange of messages that we call 'communication'. The key point is that animal communication usually depends on context, learning and memory, which shows that animals are capable of interpreting the incoming signals. Interpretation, in turn, is an act of semiosis, i.e., an activity based on signs, because the relationship between signals and responses is not determined by physical necessity but by a looser link, by a less deterministic relationship.

According to Charles Peirce, there are three main types of signs in the world, and therefore three types of semiosis and three types of communication (Peirce 1906). The three types of signs are referred to as *icons*, *indexes* and *symbols*, and the processes that are based on them are known respectively as iconic, indexical and symbolic processes. In animals they can be described in the following way.

(1) A sign is an *icon* when it is associated with an object because a *similarity* is established between them. All trees, for example, have individual features, and yet they also have something in common, and this leads to a mental generalization that allows us to recognize as a tree any new specimen that we happen to encounter. Icons, in other words, lead to pattern recognition and to mental categories, and these are the basic tools of perception.

(2) A sign is an *index* when it is associated with an object because a *physical link* is established between them. We learn to recognize any new cloud from previous clouds, and any new outbreak of rain from previous outbreaks, but we also learn that there is often a correlation between clouds and rain, and we end up with the conclusion that a black cloud is an index of rain. In the same way, a pheromone is an index of a mating partner, the smell of smoke is an index of fire, footprints are indexes of preceding animals, and so on. Indexes, in short, are the basic tools of learning, because they allow animals to infer the existence of something from a few physical traces of something else.

(3) A sign is a *symbol* when it is associated with an object because a *conventional link* is established between them. There is no similarity and no physical link between a flag and a country, for example, or between a name and an object, and a relationship between them can exist only if it is the result of a convention.

> Symbols allow us to make arbitrary associations and build mental images of
> future events (projects), of abstracts things (numbers), and even of non-existing
> things (unicorns).

The idea that language is based on arbitrary signs, or symbols, is the legacy of
Saussure, in our times, whereas the idea that animal communication is also based on
signs has been introduced by Sebeok and is the main thesis of zoosemiotics. This
extension of semiosis to the animal world, however, has not denied the uniqueness
of language. On the contrary, it has allowed us to reformulate it in more precise
terms. Such a reformulation was explicitly proposed by Terrence Deacon in *The
Symbolic Species* with the idea that animal communication is based on icons and
indexes whereas language is based on symbols (Deacon 1997).

Today, this is still the best way to express the uniqueness of language. It is true
that some examples of symbolic activity have been reported in animals, but in no
way they can be regarded as simple languages or intermediate stages toward
language. Deacon's criterion may have exceptions, but it does seem to contain a
fundamental truth. A massive and systematic use of symbols is indeed what divides
human language from animal communication, and we need therefore to account for
that divide. Why were animals unable to go beyond icons and indexes? Why didn't
they lean to make an extensive use of symbols?

Two Modelling Systems

We and all other animals do not interpret the world but only mental (or neural)
images of the world. The discovery that our perceptions are produced by our brain
implies that we live in a world of our own making, and this has led to the idea that
there is an unbridgeable gap between mind and reality. Common sense, on the other
hand, tells us that we better believe our senses, because it is they that allow us to
cope with the world. Our perceptions 'must' reflect reality, otherwise we would not
be able to survive. François Jacob has expressed this concept with admirable clarity:
"*If the image that a bird gets of the insects it needs to feed its progeny does not
reflect at least some aspects of reality, there are no more progeny. If the
representation that a monkey builds of the branch it wants to leap to has nothing
to do with reality, then there is no more monkey. And if this did not apply to
ourselves, we would not be here to discuss this point*" (Jacob 1982).

Any animal has a modelling system that builds mental images of the world, and
we have learned from Darwin that natural selection allows organisms to become
increasingly adapted to the environment, i.e., increasingly capable of reducing the
distance that separates them from reality. Natural selection, in other words, is a
process that allows animals to catch increasing amounts of reality. This is because
mental images are not about things, but about *relationships* between things, and
have been specifically selected so that the relationships between mental images
represent at least some of the relationships that exist between objects of the
physical world. To that purpose, natural selection can definitely use relationships
based on icons and indexes, because these processes reflect properties of the
physical world, but it cannot use symbols, because symbols are arbitrary
relationships and would increase rather than decrease the distance from reality.

Natural selection, in short, is actively working *against* the use of symbols as a means to represent the *physical* world.

The world of an animal, on the other hand, does not consist only in the physical environment but also in other organisms, and its modelling system contains therefore models of physical relationships as well as models of psychological relationships. As we have seen, the models of the physical world are necessarily based on icons and indexes because these signs provide the means by which organisms adapt to the environment. The models of the psychological world, in turn, are also based on icons and indexes because these signs lead to pattern recognition, mental categories and learning, which are the basic tools of animal communication. This tells us that icons and indexes are all that was needed to build the physical and the psychological modelling system of animals, and natural selection favours both types of signs.

The animal modelling system, in short, is entirely based on icons and indexes, and the system that we have inherited from our animal ancestors can be referred to as the 'primary modelling system' of our species. In addition to that, however, we have also developed a modelling system that is based on symbols and that can be referred to as the 'second modelling system' of our species. It is precisely this second system that gave us language and it is the origin of that system therefore that we need to understand.

A Juvenile Ape

In 1926, Luis Bolk, professor of anatomy at Amsterdam university, proposed the 'fetalization theory', the idea that the origin of man was due to the extension of foetal or juvenile features to the adult phases of life (Bolk 1926). The idea was not new (Geoffroy Saint-Hilaire had mentioned it in 1836), and the phenomenon had been described in many other species with names such as *paedogenesis* (von Baer 1866), *neoteny* (Kollmann 1885), and *paedomorphosis* (Garstang 1922). But it was Luis Bolk who turned that idea into a compelling doctrine by the sheer number of data with which he supported it.

In all primates, the foetus and the newborn child have big brains in respect to body size, flat faces, thin brow-ridges, small teeth and jaw, light skin and sparse body hair, but only man retains all these features in adult life. Similarly, the front-to-back axis of the head is perpendicular to the axis of the trunk in the foetus and in the newborn child of all primates but only man maintains that angle of the cervical flexure throughout his life, and that is what allows him to have a horizontal line of sight while standing erect, whereas all primates can look around while walking on all fours (Gould 1977).

Big brains, flat faces, reduced body hair and upright posture are unmistakable marks of humanity, and are undeniably present in the foetal stages of all primates, so there is little doubt that an extension of these juvenile features, i.e., a process of fetalization, did take place in our ancestors.

Today, the role of embryonic development in evolution has been documented in so many species and with so many examples that an entirely new science—familiarly known as *Evo-Devo*—has been built to study it. It is known, furthermore, that there are genes specifically dedicated to embryonic development, and that a few changes in them can have enormous consequences on adult bodies. The increase in

size of the human brain, for example, can be accounted for by the activity of just a few homeotic genes (Gilbert 2006).

It is also known that environmental changes can affect development and produce either a retardation or an acceleration of sexual maturity in respect to body growth. In axolot, for example, an abundance of water favours an unlimited extension of the larval stage, whereas a dry climate induces a quick metamorphosis to adult stage (Gould 1977). It is likely, therefore, that changes in the environment provided the initial pressure for changes in the embryonic development of our ancestors and we know that vast climatic changes did take place in Africa in the past 10 million years.

We conclude that the fetalization theory, or its modern versions that come from Evo-Devo, provide a sound theoretical framework for the origin of man. At the same time, however, we must not forget that neoteny and many other processes of heterochrony (changes in timing) have taken place in countless animal species, but have never produced a modelling system based on symbols. Our problem, therefore, is to find out what was it that made the difference in our species. More precisely, among all the evolutionary processes that shaped the human body, we are looking for those that created the conditions for the origin of language.

Fetalization and Brain Wiring

In the 1940s, Adolf Portmann calculated that our species should have a gestation period of 21 months in order to complete the processes of foetal development that occur in all other mammals (Portmann 1941, 1945). A newborn human baby, in other words, is in fact a premature foetus, and the whole first year of his life is but a continuation of the foetal stage.

This peculiarity of human development is due to the fact that fetalization leads to an extended foetal period and therefore to a greater foetus at birth, but this process is severely constrained because the birth canal can cope only with a limited increase of foetal size. During the evolution of our species, therefore, any extension of the foetal period had to be accompanied by an anticipation of the time of birth. The result is that the foetal development of our species became divided into two distinct phases—intrauterine and extra-uterine—and eventually the extra-uterine phase came to be the longest of the two.

It is not clear why this evolutionary result is uniquely human, but it is a historical fact that it took place only in our species. In all other mammals, foetal development is completed *in utero*, and what is born is no longer a foetus but a fully developed infant that can already cope with the environment.

The crucial point is that the last part of foetal development is the phase when most synaptic connections are formed. It is a phase of intense 'brain wiring'. The fetalization of the human body has produced therefore a truly unique situation in our species. In all other mammals the wiring of the brain takes place almost completely in the dark and protected environment of the uterus, whereas in our species it takes place predominantly outside the uterus, where the body is exposed to the lights, the sounds and the smells of a constantly changing environment. In our species, in short, the difference between intrauterine and extra-uterine foetal development created the conditions for two distinct types of brain wiring, and this did have far reaching consequences.

The brain wiring that occurs in the last phase of foetal development provides the neurological basis for the mental models that the organism is going to use throughout its life. If that phase occurs in the highly stable and reproducible environment of the uterus, the operations of brain wiring follow a pre-established sequence of steps and generate a modelling system that has been highly conserved in evolution. In our species, however, the last phases of foetal development have been progressively displaced outside the uterus, in a radically different environment, and that created the opportunity for a radically new experiment in brain wiring. That was the precondition for the evolution of a uniquely human modelling system, but let us not forget that a precondition for language was not yet language. It was only a potential, a starting point.

The Body-Plan of Language

The human brain is about three times larger than the brain of any other primate, even when body weight is taken into account. This means that the primary modelling system that we have inherited from our animal ancestors required, at most, a third of our present brain size. The other two thirds could be explained, in principle, by a further extension of our animal faculties, but this is not what happened. We have not developed a sharper eyesight, a more sensitive olfactory system, a more powerful muscular apparatus, and so on. As a matter of fact, our physical faculties are in general less advanced than those of our animal relatives, so it was not an improvement of the primary modelling system that explains our increased brain volume. It is highly likely, therefore, that the brain increase that took place in human evolution was largely due to the development of those new faculties that collectively make up our second modelling system, the system that eventually gave origin to language.

The main point is that this new system was a genuine novelty, something that no other species managed to evolve. We are facing therefore the same problem that we encounter in all great events of macroevolution: how did living systems give origin to real novelties? A useful clue comes from another macroevolutionary event: the origin of the first animals. In that case the starting point was a population of cells that could assemble themselves in countless different ways, so how did they manage to generate those particular three-dimensional structures that we call animals?

The solutions were obtained by three types of experiments. More precisely by the attempts to form multicellular structures with one, two or three different types of cells. The experiment with one cell type produced bodies that have no symmetry (the sponges); two cell types generated bodies with one axis of symmetry (the *radiata* or diploblasts, i.e., hydra, corals and medusae), and three cell types gave origin to bodies with three axes of symmetry (the *bilateria* or triploblats, i.e., vertebrates and invertebrates) (Tudge 2000).

It turns out that animal cells arrange themselves in a three-dimensional pattern because they receive instructions which tell them that their position is anterior or posterior, dorsal or ventral and proximal or distal in respect to the surrounding cells. These instructions are carried by genes, and are molecules which are referred to as the molecular determinants of the body axes. The crucial point is that there are countless types of molecular determinants and yet all triploblastic

animals have the same body axes. This shows that there is no necessary correspondence between molecular determinants and body axes, and that in turns means that the actual correspondence is based on conventional rules, i.e., on the rules of an organic code.

That is what we learn from the origin of animals, and that lesson can illuminate many aspects of the origin of language. The number of three-dimensional patterns that the first animal cells could form in space was potentially unlimited, and the same was true for the brain-wiring patterns of the neural cells that generate a modelling system in the brain of an animal. It was imperative to adopt a set of pattern constraints in order to generate real bodies, and the same was true for the generation of a real modelling system out of countless different possibilities. The constraints that gave origin to animals are their body-plans, and in a similar way the constraints that gave origin to language can be regarded as the neural body-plan of language (Barbieri 2003). There is no way of building a body without a body-plan and in a similar way there is no way of building a modelling system without the neural equivalent of a body-plan.

The second modelling system that gave origin to language, in short, was the result of an evolutionary process that was similar, in principle, to the building of a neural body-plan, and the most likely solution was, as in many other cases of macroevolution, the development of a new organic code.

The *Cerebra bifida* Model on the Evolution of Man

There is no general agreement on the definition of the genes of language, but it seems reasonable to say that they are genes whose mutations produce heritable changes in the faculty of language. There are many examples of such genes, and the outstanding conclusion that has come out of their study, so far, is that virtually all of them are present also in animals. All known genes of language, in other words, are genes of the primary modelling system that we have inherited from our animal ancestors. Future discoveries may well modify this conclusion, of course, but not much. The reason is that we share 98.8% of our genes with the chimps, so the number of uniquely human genes is bound to be small.

The experimental evidence, in short, tells us that the genes of language do exist, but also that virtually all of them exist also in animals, and this means that our second modelling system was built with the genes of the animal modelling system, not with uniquely human genes. This in turn implies that language was the result of epigenetic processes that operated on animal genes and produced a uniquely human result. That may look like a far-fetched speculation, at first, but let us take a closer look and examine, as a first step, the result of a classic experiment.

In vertebrate embryonic development, the heart arises from two primordia that appear on the right and left side of the developing gut, and then migrate to the centre and fuse together in a single median organ. If fusion of the two primordia is prevented by inserting an obstacle between them, each half undergoes a spectacular reorganization and forms a complete and fully functional beating heart (Fig. 1). The formation of the two hearts, furthermore, is followed by the development of two circulatory systems, and the animal goes through all stages of life in a double-heart condition that is known as *cardia bifida* (DeHaan 1959).
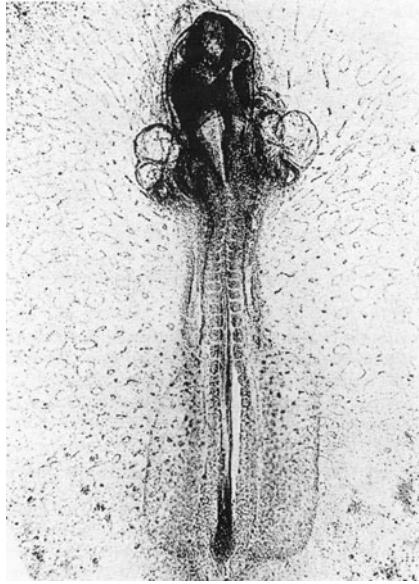
Fig. 1 The heart arises from left and right cardiac primordia that move together and fuse in the midline. If fusion is prevented each half forms a complete and fully functional heart, as seen in this 2-day-old chick embryo, a condition that is known as *Cardia bifida* (DeHaan 1959)

This classic experiment shows that two profoundly different bodies, one with a single heart and the other with two hearts, can be generated *without any genetic change at all*. A modification of the epigenetic conditions of embryonic development is clearly an extremely powerful tool of change, and may well be the key to human evolution. The gradual extension of our foetal period together with the constraint of the birth canal have split the foetal development of our brain into two distinct processes, one within and one without the uterus, whereas in all other mammals it has remained a single process that takes place entirely within the uterus. This splitting of the foetal development of our brain into two distinct processes is a condition that can be referred to as *cerebra bifida*, in some ways analogous to *cardia bifida*, except that in the case of the heart the two organs arise from a separation in space whereas in *cerebra bifida* the two developments are produced by a separation in time.

The *cardia bifida* experiment is illuminating because it shows that no new genes are required for the duplication, and that may well explain why no new genes were necessary for building the second modelling system of our species. The same set of genes could well have produced two different modelling systems simply by operating in two different environmental conditions, a conclusion that can be referred to as 'The *cerebra bifida* model' on the evolution of man.

The faithful reappearance of parental features in the descendants, in other words, can be ensured not only by genes but also by epigenetic processes. It is possible of course that new genes of language did evolve in the course of time, but they were not *essential*. Our two modelling systems could well have been built from the same set of genes that we have inherited from our animal ancestors, and that is probably

what did happen because there doesn't seem to be any other explanation that fits with all known experimental facts.

A Community Code

The classical studies of Jean Piaget on postnatal development have shown that our cognitive faculties (the concepts of object, space, time, causality, number, word, etc.) arise step by step throughout infancy in a sequence of four distinct periods (sensory-motor, preoperational, operational and formal) each of which is subdivided into stages (Piaget 1954, 1960). New neural connections are formed in all periods, and in this respect the cognitive stages are a continuation of the extra-uterine phase of foetal development, except that the intensity of brain wiring tends to decrease with age.

The development of human cognition, in other words, is based on neural connections that are formed *outside the uterus*, where the child is directly exposed to the environment, and this raises immediately a problem: what precisely are the environmental factors that have an influence on our cognitive system? This is a crucial point because one of the major functions of the brain consists precisely in *ignoring* most incoming signals. What are therefore the few signals that are allowed into the system and have the power to shape the development of our cognitive faculties? There are many clues on these issues, but two of them are particularly important. One comes from the study of children raised in the wild by animals (the so-called wolf children, or feral children). Their primary modelling system is perfectly normal, but their potential to learn a language is highly compromised (Maslon 1972; Shattuck 1981). This shows that language is critically dependent upon *human* interactions that take place in the first few years of postnatal development. The second clue comes from the studies of the 'creole' languages, and is the fact that the major role in the making of new linguistic rules appears to be played by children (Bickerton 1981).

We have learned in this way that the development of language crucially depends on interactions that take place first between child and mother and then between child and other children. It is these interactions that induce the brain wiring operations that build our cognitive system, but how can they do it?

It is known that the wiring of the nervous system is achieved by an overproduction of neurons followed by the elimination of all those that do not come in contact with nerve growth factors (Changeaux 1983; Edelman 1987). The death of these cells, however, is not due to injuries or starvation because in every region of the developing embryo there are cells that must die and others that must live. It is due to processes of active suicide (programmed cell death, or *apoptosis*), but all cells contain the genes of apoptosis and these are activated by different molecules in different tissues and in different stages of development, so there must be rules that control their expression.

The wiring of the nervous system, in short, is achieved by the rules of a code, and the results obtained from wolf children and creole languages suggest that this may well be true for the wiring of our cognitive system, except that the rescuing role is exercised not by growth factors but by human interactions. In the case of language, in other words, the brain wiring rules are provided not by *internal* but by *external*

factors, and this may well be the crucial difference that exists between our two modelling systems.

The genes of language are probably the same genes of the modelling system that we have inherited from our animal ancestors, and their expression is again controlled by the rules of a code, but the codemaker of language is not the single individual brain. It is a community of interacting brains that together generate the rules of a new brain-wiring code.

This conclusion is a version of what has become known as *Distributed Language*, the idea that language is not inside the individual head but is 'distributed' in a population (Cowley 2007). Here it is underlined that what is distributed is the *codemaker* of language, and this of course implies the existence of a code. More precisely, it implies the idea that language is based on a community code of brain-wiring rules. What is particularly inspiring about this idea is that it brings the origin of language in line with the other great events of macroevolution which are all associated with the appearance of new organic codes (Barbieri 2003, 2008).

The Code Model on the Origin of Language

The origin of language has undoubtedly its own unique features, but the origin of previous biological novelties can help us to understand its underlying mechanism. In particular, there is an important lesson that we can learn from single cells and animals.

The fact that virtually all cells have the same genetic code but belong to three distinct domains—Archaea, Bacteria and Eucarya (Woese 1987, 2000)—strongly suggests that the genetic code appeared in precellular systems and that the cell organization arose afterwards in three different ways (Woese 2002). We know furthermore that Archaea, Bacteria and Eucarya have different signalling systems on their membranes, which suggests that each cell domain arose by the combination of the genetic code with a different signal-transduction code.

At a very early point in the history of life, however, the cells adopted two divergent strategies and that channelled them into two very different evolutionary directions. Archaea and Bacteris chose a streamlining strategy that prevented the acquisition of new organic codes and have remained substantially the same ever since. The Eucarya, on the contrary, continued to explore the 'coding space' and developed new organic codes (splicing codes, compartment codes, histone code, etc.) throughout the whole three thousand million years of cellular evolution. This turned the eukaryotic cells into increasingly more complex systems, and eventually some of them became complex enough to generate three completely new forms of life, the great kingdoms of plants, fungi and animals (Barbieri 1981, 1985, 2003).

If we now look at the history of life from the organic codes' point of view, we realize that the same pattern is appearing all over again. Any new organic code brings a genuine novelty into existence, but the origin of *a new integrated system* always requires more than one code. A cell requires a genetic code plus a signal-transduction code, whereas a triploblastic animal requires at least three distinct codes, one for each body-axis (top and bottom, back and front, left and right). This

initial set of codes, furthermore, has two outstanding properties (a) it is limited and (b) it is strictly conserved in all descendants. From this general pattern we obtain three main concepts:

(1) The origin of a new integrated system in the history of life (the first cells, the first plants, the first animals, etc,) is produced by a limited set of new organic codes (the foundational set).

(2) The further evolution of the system (eukaryotic cells or multicellular organisms) does not take place by a mere increase of components, but by a step-by-step addition of new organic codes.

(3) The appearance of new organic codes is essential to the further evolution of the system, but equally essential is the *conservation* in all descendants of the foundational codes.

With this in mind, let us now go back to the origin of language. If we accept that it was a biological event, it is not unreasonable to think that it had the same underlying pattern of the other events of macroevolution. This gives us *the code model on the origin of language*, a model that consists of three points.

(1) The *origin* of language was due to a small set of new codes (the foundational event).

(2) The *evolution* of language was due to the appearance of other codes at various stages of development.

(3) The foundational set of codes has been strongly conserved and remains at the heart of the language faculty in all human beings.

Conclusion

The clear neotenic features of our anatomy and the details of our foetal development make it very likely that the preconditions for language were created by a fetalization process. More precisely, by a process that produced an extrauterine phase of foetal development, and gradually extended that phase to the point that it became longer than the intrauterine one. These two sections of foetal development were both the site of intense brain wiring, and created a condition that can be referred to as *cerebra bifida*, in some ways analogous to the condition of *cardia bifida* that is well known from laboratory experiments.

The brain wiring of the intrauterine phase takes place in conditions that are similar in all primates, and leads to the primary modelling system that we have inherited from our animal ancestors. The difference between us and all other primates is that we have also an extensive extrauterine phase of foetal development and they don't. This phase, on the other hand, has exactly the same potential to create a modelling system as the intrauterine one, and that explains why our species has developed two distinct modelling systems, a conclusion that can be referred to as 'The *cerebra bifida* model' on the evolution of man.

There are two types of brain wiring in the nervous system, one between cells and one between synapses, and they are controlled by wiring rules that can rightly be regarded as the rules of different organic codes. It takes at least two codes, in short,

to produce our first modelling system, and that suggests that the same logic was adopted for the development of our second modelling system. All that was required was a new set of wiring rules, a set where the main determinants of neural activity were produced by the interactions first between child and mother and then between child and other children. This is the essence of the code model on the origin of language.

The idea of the organic codes, furthermore, removes the two main obstacles that have divided Biolinguistics from Biosemiotics, and gives us a unified approach to the study of language. More than that. It allows us to prove that the cell is a semiotic system and therefore that there is a real bridge between nature and culture. It makes us realize that semiosis appeared on Earth in the form of organic codes and later evolved into two types of interpretive semiosis: first the iconic and indexical semiosis of animals and then the cultural semiosis of our species. Finally, the code view of life tells us that the organic codes are the great invariants of evolution, the entities that remain constant when everything else is changing. The genetic code has been conserved ever since its first appearance, and the same is true for the organic codes that came later and gave origin to the great events of macroevolution. But this is not because their rules are mathematical principles or universal laws of Nature. They are conserved because living systems actively and continuously eliminate the changes that appear in them, and reconstruct their original components in every new generation.

Life is essentially about creating new organic codes and *conserving* those which have been created. This is what we learn from macroevolution and this is what we should always keep in mind, even when the issue in question is the origin of language, the last episode of macroevolution.

References

Augustyn, P. (2009). Uexküll, peirce, and other affinities between biosemiotics and biolinguistics. *Biosemiotics, 2*, 1–17.

Barbieri, M. (1981). The ribotype theory on the origin of life. *Journal of Theoretical Biology, 91*, 545–601.

Barbieri, M. (1985). *The semantic theory of evolution*. London: Harwood Academic.

Barbieri, M. (1998). The organic codes. The basic mechanism of macroevolution. *Rivista di Biologia-Biology Forum, 91*, 481–514.

Barbieri, M. (2003). *The organic codes. An introduction to semantic biology*. Cambridge: Cambridge University Press.

Barbieri, M. (2006). Life and semiosis: the real nature of information and meaning. *Semiotica, 158*(1/4), 233–254.

Barbieri, M. (2008). Biosemiotics: a new understanding of life. *Die Naturwissenschaften, 95*, 577–599.

Bever, T., & Montalbetti, M. (2002). Noam's Ark. *Science, 298*, 1565–1566.

Bickerton, D. (1981). *The roots of language*. Ann Arbour: Karoma.

Bolk, L. (1926). *Das Problem der Menschwerdung*. Jena: Gustav Fischer.

Changeaux, J.-P. (1983). *L'Homme Neuronal*. Paris: Libraire Arthème Fayard.

Chomsky, N. (1957). *Syntactic structures*. The Hague: Mouton.

Chomsky, N. (1959). Review of 'verbal behavior' by B.F. Skinner. *Language, 35*(1), 26–58.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge: MIT.

Chomsky, N. (1975). *The logical structure of linguistic theory*. Chicago: University of Chicago Press.

Chomsky, N. (1995). *The minimalist program*. Cambridge: MIT.

Chomsky, N. (2005). Three factors in language design. *Linguistic Inquiry, 36*, 1–22.

Chomsky, N. (2006). Biolinguistic explorations: design, development, evolution. *International Journal of Philosophical Studies, 15*, 1–21.

Cowley, S. J. (2007). How human infants deal with symbol grounding. *Interaction Studies, 8*(1), 83–104.

Deacon, T. W. (1997). *The symbolic species: The co-evolution of language and the brain*. New York: Norton.

DeHaan, R. L. (1959). *Cardia bifida* and the development of pacemaker function in the early chicken heart. *Developmental Biology, 1*, 586–602.

Edelman, G. M. (1987). *Neural darwinism. The theory of neuronal group selection*. New York: Basic Books.

Gabius, H.-J. (2000). Biological information transfer beyond the genetic code: the sugar code. *Die Naturwissenschaften, 87*, 108–121.

Gabius, H.-J., André, S., Kaltner, H., & Siebert, H.-C. (2002). The sugar code: functional lectinomics. *Biochimica et Biophysica Acta, 1572*, 165–177.

Garstang, W. (1922). The theory of recapitulation. A critical restatement of the biogenetic law. *Journal of the Linnean Society of London, Zoology, 35*, 81–101.

Gilbert, S. F. (2006). *Developmental biology* (8th ed.). Sunderland: Sinauer.

Gould, S. J. (1977). *Ontogeny and phylogeny*. Cambridge: The Belknap Press of Harvard University Press.

Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language: what is it, who has it, and how did it evolve? *Science, 298*, 1569–1579.

Jacob, F. (1982). *The possible and the actual*. New York: Pantheon Books.

Jacob, F., & Monod, J. (1961). Genetic regulatory mechanisms in the synthesis of proteins. *Journal of Molecular Biology, 3*, 318–356.

Kollmann, J. (1885). Das Überwintern von europäischen Frosch- und Tritonenlarven und die Umwaldung des mexikanischer Axolot. *Verhandlungen der naturforschenden Gesellschaft, Basel., 7*, 387–398.

Lotman, J. (1991). *Universe of the mind: A semiotic theory of culture*. Bloomington: Indiana University Press.

Maslon, L. (1972). *Wolf children and the problem of human nature*. New York: Monthly Review.

Peirce, C. S. (1906). The basis of pragmaticism. In C. Hartshorne & P. Weiss (Eds.), *The collected papers of Charles Sanders Peirce* (Vol. I–VI, pp. 1931–1935). Cambridge: Harvard University Press.

Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.

Piaget, J. (1960). *The child's conception of physical causality*. Paterson: Littlefield & Co.

Portmann, A. (1941). Die Tragzeiten der Primaten und die Dauer der Schwangerschaft beim Menschen: ein Problem der vergleichen Biologie. *Revue Suisse de Zoologie, 48*, 511–518.

Portmann, A. (1945). Die Ontogenese des Menschen als Problem der Evolutionsforschung. *Verh Schweiz Naturf Ges, 125*, 44–53.

Posner, R., Robering, K., & Sebeok, T. A. (1997). *Semiotik/semiotics: A handbook on the sign-theoretical foundations of nature and culture* (Vol. 1, p. 4). Berlin: Walter de Gruyter.

Sebeok, T. A. (1963). Communication among social bees; porpoises and sonar; man and dolphin. *Language, 39*, 448–466.

Sebeok, T. A. (1972). *Perspectives in zoosemiotics*. The Hague: Mouton.

Sebeok, T. A. (1979). *The sign and its masters*. Austin: University of Texas Press.

Sebeok, T. A. (1988). *I think I am a verb: More contributions to the Doctrine of Signs*. New York: Plenum.

Sebeok, T. A. (1991). *A sign is just a sign*. Bloomington: Indiana University Press.

Sebeok, T. A. (2001). Biosemiotics: Its roots, proliferation, and prospects. In K. Kull (Ed.), Jakob von Uexküll: A Paradigm for Biology and Semiotics. *Semiotica, 134*(1/4): 61–78.

Sebeok, T. A., & Danesi, M. (2000). *The forms of meaning: Modeling systems theory and semiotic analysis*. Berlin: Mouton de Gruyter.

Sebeok, T. A., & Umiker-Sebeok, J. (Eds.). (1992). *Biosemiotics: The semiotic web*. Berlin: Mouton de Gruyter.

Shattuck, R. (1981). *The forbidden experiment: The story of the wild boy of Averyron*. New York: Washington Square.

Strahl, B. D., & Allis, D. (2000). The language of covalent histone modifications. *Nature, 403*, 41–45.

Tomkins, M. G. (1975). The metabolic code. *Science, 189*, 760–763.

Trifonov, E. N. (1987). Translation framing code and frame-monitoring mechanism as suggested by the analysis of mRNA and 16s rRNA nucleotide sequence. *Journal of Molecular Biology, 194*, 643–652.

Trifonov, E. N. (1989). The multiple codes of nucleotide sequences. *Bulletin of Mathematical Biology, 51*, 417–432.

Trifonov, E. N. (1996). Interfering contexts of regulatory sequence elements. *Cabios, 12*, 423–429.

Trifonov, E. N. (1999). Elucidating sequence codes: three codes for evolution. *Annals of the New York Academy of Sciences, 870*, 330–338.

Tudge, C. (2000). *The variety of life. A survey and a celebration of all the creatures that have ever lived*. Oxford: Oxford University Press.

Turner, B. M. (2000). Histone acetylation and an epigenetic code. *BioEssay, 22*, 836–845.

Turner, B. M. (2002). Cellular memory and the histone code. *Cell, 111*, 285–291.

von Baer, K. E. (1866). De la découverte de larves qui se propagent. *Bulletin de l'Académie Impériale des Sciences de St. Petersbourg, 9*, 63–137.

von Uexküll, J. (1909). *Umwelt und Innenwelt der Tiere*. Berlin: Julius Springer.

Woese, C. R. (1987). Bacterial evolution. *Microbiological Reviews, 51*, 221–271.

Woese, C. R. (2000). Interpreting the universal phylogenetic tree. *Proceedings of the National Academy of Sciences of the United States of America, 97*, 8392–8396.

Woese, C. R. (2002). On the evolution of cells. *Proceedings of the National Academy of Sciences of the United States of America, 99*, 8742–8747.