Series in BioEngineering

Meir Israelowitz
Birgit Weyand
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Kerstin Reimers *Editors*

# Biomimetics and Bionic Applications with Clinical Applications

Springer

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# Biomimetics and Bionic Applications with Clinical Applications

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*This volume is dedicated to Prof. Kerstin Reimers and the Fadhlaoui Family. During the completion of this work, Prof. Reimers our co-editor sadly succumbed to a terminal illness.*

# Preface

This volume focuses on biomimetic application to the clinical level, while biomimetic itself, mimic nature can be done in twofolds, one external refereeing to the bionic aspects and molecular level interaction the biomimetic. For any technology to have any clinical impact need not only to overcome the technological issues, but regulatory.

Our intent in the volume is not only to create a theoretical foundation but also show direct examples in nature, where can be transformed into therapeutic solutions, but technologies to rise to this level. We are not only showing physical examples, but also biomimetic methods can be implemented in the clinical level.

Accordingly, the chapters follow in fourth categories to underline the biomimetic solutions in the clinical level, the first chapters concentrated on theoretical foundation, challenge, and biomimetic in the surgery level. The second section concentrated specific examples from the bacteria, to especially sensors, into higher biological systems. The third section concentrated on technology which works under biomimetic principals. The last is methods, implement through software implementing biomimetic principles.

The contributors of this volume represent three continents, especially places with a challenge to developed new technologies limited by the resources in the community or the misuse of resources, but because there is not a specific place where biomimetic is specific, the possibility of any location can be developed, since biological systems through evolution had taken place, even in the most austere and challenge place, because this development of biomimetic can be found any location where nature took place. The chapters cover issues from bacterial sensors and complex systems for the development of cells to more advanced therapeutic applications in the clinical level. The software considers as an example is neural networks as a method to mimic to solve clinical and developed therapeutic solutions.

The volume not only demonstrated developments in biomimetic to clinical work but also can be applied to other fields from the biomedical sciences, but everyday technologies, as magnetic detectors, far-infrared detectors, material development, material grow, and software development.

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April 2017

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[1] Late Prof. Reimers succumbed to terminal illness in the process working in the volume.

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# Biomimetics Theoretical Foundation

# Biomimetics: A Biosemiotic View

**Kalevi Kull**

**Abstract** After giving a brief review of different approaches related to biomimetics, we focus on the question of the general mechanisms of problem-solving and self-building in living systems. It is possible to develop a theory of biomimetics in connection with a semiotic approach to understand the workings of living systems. In this case we concentrate on the innovative or knowledge-acquisition aspects and mechanisms of life. This would make it possible to understand why living systems are suitable and specific to be used as models for technological modelling.

**Keywords** Biosemiotic technology · Biosemiotics · Ecosemiotics · History of biology · Sustainable technology · Theory of knowledge

*Biomimetics* is a smart technology that is based on the smartness of life itself. In other words, biomimetics is a technological approach that uses the knowledge acquired by living systems. This is an approach to apply the building principles of non-human life in the design of various technical systems in human culture. Biomimetics uses and remakes what is meaningful (which includes functional[1]) in life's findings.

Biomimetics is based on understanding that life has been able to construct what non-life cannot construct; that life is capable for making discoveries that are hardly accessible otherwise; that living systems, from a living cell to coenoses are capable to acquire and carry knowledge. Everything that humans construct requires the use of knowledge. Likewise, the materials used by organisms and the structures they build, require finding and recognizing substances, and remembering the steps of construction. This is what differentiates life's production from non-mediated chemistry.

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[1] On the relationship between meaning and function, see [11].

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This approach assumes that living systems have certain knowledge, which also means that living systems are capable of acquiring new knowledge. This idea is not new, however, the understanding of these mechanisms and acknowledging its central importance for biology has still only received little attention.

Part of the problem is that the concept of knowledge needs to be defined more clearly. For instance, are the adaptations of fireflies or *Escherichia coli* considered to be knowledge-based? However, if we state that knowledge is just any kind of meaningful information, then the applicability of the concept throughout living systems is feasible.

Both J. B. Lamarck and Charles Darwin can be credited as providing explanations of life's capacity for innovations, or in their terms, as the formation of adaptations. The direct connection of this problem to epistemology, i.e., gaining knowledge, is more the work of the twentieth century: first by J. M. Baldwin (organic selection), then by J. Piaget (genetic epistemology), and H. Maturana (biology of knowledge).

A catalytic role in theoretical biology of the twentieth century has been played by the Theoretical Biology Club (founded in 1932 in England), where J. Woodger (with his interest in logic of biology), C. H. Waddington (studying epigenetics), L. L. Whyte (who introduced the concept of internal factors of evolution), and several others discussed the fundamentals of life [1, 44]. Karl Popper, J. Woodger's friend, also attended this club. In his lecture of 1989, "Towards an evolutionary theory of knowledge", Popper made several remarkable points: "[…] in the biological and evolutionary sense in which I speak of knowledge, not only animals and men have expectations and therefore (unconscious) knowledge, but […], indeed, all organisms. […] All adaptations to environmental and to internal regularities, to long-term situations and to short-term situations, are kinds of knowledge […]. Thus, the origin and the evolution of knowledge may be said to coincide with the origin and the evolution of life" [52: 61, 64]. And he adds that "adapted forms will be some of those forms which responded to a challenge, which solved problems" [53: 133].

Knowledge in any occasion assumes and requires sign relations and meaning-making. Sign relations means that something is *about* something. Sign processes comprise the study area for *semiotics*. Thus the science whose object of study is knowledge is semiotics, while the prelinguistic (i.e., biological) forms of knowledge are the objects of biosemiotics [36].

*Biosemiotics* as a contemporary approach in biology is a study of life's meaningfulness, or rather its processes of meaning-making. Biosemiotics is the theory of how meaningful life works, how it develops its findings, how it makes its searches, how it makes and carries meanings.[2] Biomimetics is a technological approach to make use of understanding of how life does this by mimicking or imitating, or just by being inspired by life's discoveries.[3]

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[2] For a contemporary overview on biosemiotics, see [12, 14, 26].

[3] See the recent reviews of biomimetics, e.g., [2, 5]. Couple of volumes on biomimetics were recently published by Springer: [23, 45, 51] (see also [10]).

Biomimetics also has an epistemological role in developing an understanding of life.[4] By mimicking the mechanisms of organisms it is possible to come closer to the enigma of life. Since the natural epistemology is one of major focuses of biosemiotics, we could say that *biomimetics is a technological biosemiotics*. This aspect is also pointed out by Webb [64] and Rossi and Pieroni [54].[5]

The idea of using the inventions of living systems in the development of technical devices and innovations is more than a century old; there exists an extensive literature on the topic. A semiotic view may add the following: (1) it demonstrates the logical differences between the life-bound products and non-living assemblies; (2) by describing more profoundly how organisms search, find, and build, we can understand their cleverness (for instance, as it occurs, their mechanisms of development and evolution may differ considerably from the algorithms of optimization); and, (3) a semiotic analysis of bio-inspired technological development itself opens up additional cultural, economic and ecologically valuable aspects.

The relationship between bionics and semiotics was noticed by Sebeok [58: 555]: "Our knowledge of basic zoosemiotic processes may also be put to practical uses to supplement existing human information-handling devices, and to advance bionics, a term that designates a rapidly growing field which aims to develop nonliving systems on the analogy of biological information-storing, coding and sorting systems".

Hoffmeyer ([25, 26]; also Bruni [6]) took a further step by emphasizing the importance of developing biosemiotic technology. Hoffmeyer wrote: "we are now finally prepared to complete the project that was initiated in the late Middle Ages with the introduction of windmills and water mills—i.e., to set societal production free of the constraining bonds given by the peculiarities of organic life. The first time around, under the Industrial Revolution, only the dimension of *energy* was set loose from the constraints of organismic life. Therefore, what we are now facing—and to some extent have already engaged in—is the setting free (and harnessing) of the semiotic dimension from its bindings in organic life. This is what I have called the development of *biosemiotic technologies*" [26: 344].[6]

In recent years, the relationship between biosemiotics and biomimetics has been explicitly stated by several authors (e.g., [30, 63]). This does not concern only

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[4] Assuming that the problem-solving by living systems also means some gaining of knowledge, we may shed light on these processes by mimicking life's findings. In a more general sense, mimicking can be a tool for investigation, since mimicking is a kind of modelling.

[5] Rossi and Pieroni [54] write: "In addition to the development of bioinspired artifacts for achieving better performance, another dimension of interest is epistemological. The epistemological approach attempts to test and verify biology-based hypothesis by conceiving and implementing specific bioinspired machines".

[6] Application of semiotics in biomimetics has more aspects. For instance, Camargo and Vega [8: 161] emphasise "the importance of the semiotic theory as an intermediary field in the transposition of natural phenomenon from their original biological field to computational field".

technology—semiotics of bio-inspiration demonstrates a growing popularity also in arts and architecture.[7]

## 1 Biomimetics and Its Relatives

The aim of biomimetics is construction, which links biomimetics to various biomechanical approaches. This assumes a knowledge and understanding of the mechanics of biological samples, and therefore needs to know the biological *logic* of construction.

Over the past five or six decades, there have been differing but overlapping approaches that have focused on living systems and construction discoveries particularly in the overlapping regions between the fields of biology and engineering.[8] These approaches are defined below in an approximate historical order.

**Biomechanics** is a term that has been used since late nineteenth century to denote the study of structure and function of biological systems by the means of mechanics.

**Biontotechnics** is a term and concept proposed in 1902 by Tornier [61] for the field of modifying organisms or for using them technologically [21: 23].

**Biotechnics** was the term used by Raoul Francé in the early twentieth century [17]. It has the same meaning as bionics (and biomimetics) which was coined many years later [50]. The term was also used at the same time by a biologist and urban planner Patrick Geddes [21: 32].

**Synthetic biology** is currently known as “the design and construction of biological parts, devices and systems, and the redesign of existing, natural biological systems for useful purposes” [28: 707]. This term was introduced over a hundred years ago in 1910 by Stéphane Leduc. As mentioned by Bensaude-Vincent [4], Leduc’s program was both synthetic and biomimetic. According to Leduc [39: 147], there is no sharp division between inanimate nature and life.

**Biotechnology** was used as a term by Károly Ereky in 1919, defining it as the production of products from raw materials with the aid of living organisms, and for procedures for modifying living organisms according to human purposes.[9] According to the Convention on Biological Diversity (article 2), ‘biotechnology’ is “any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use”.

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[7] On semiotic approach to mimesis and its relationship to modelling systems, see also [40] and [22].

[8] See also [18].

[9] See a history of biotechnology by R. Bud [7].

**Bioengineering** was coined by British scientist and broadcaster Heinz Wolff in 1954. According to one definition, the mission of bioengineering is “to create a fusion of engineering and the life sciences that promote scientific discovery and the invention of new technologies and therapies through research and education”.[10]

A considerable turn and growth of interest towards biomimetics took place around the early 1960s. This was spawned in part by a series of Macy conferences in New York (1941–1960) in which cybernetics, including its biological and medical aspects, were discussed.

The term **biomimetics** was seemingly coined by Otto Schmitt in 1957 in his doctoral thesis [5: 1] and used in 1969 in the title of his paper [57]. It was defined as “the study of formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones” [54].

The term **bionics** came into use following the first symposium of bionics in 1960 in Dayton, Ohio, USA [60]. It is often used as a synonym of biomimetics. However, if seen as a sub-discipline of biomimetics as mentioned by Rossi and Pieroni [54: 1], ““bionics” is more related to robotics (having an emphasis on biologically based control and intelligence), ethology-based robotics (having an emphasis on constructing robot hardware based on animals), and biomimetic actuators and sensors.”

**Adaptronics** is a study of biologically inspired materials. According to one definition, these are “material systems that have intelligence and life features integrated in the microstructure of the material system to reduce mass and energy and produce adaptive functionality” [31: 1]. The term has been in use since the 1960s.[11]

**Artificial Life** is a field of study as formulated by Christopher Langton in the 1980s. It is a modelling and simulating of life processes, together with realization of concrete systems [48].

**Biognosis** is the term suggested by Rustum Roy (in the early 1990s) and defined as *learning* from living systems (not simply mimicking their form), deriving knowledge from biology to materials science.[12]

**Biomimicry** is another synonym to biomimetics. As defined on the home page of the Biomimicry Institute[13] as “an approach to innovation that seeks sustainable solutions to human challenges by emulating nature’s time-tested patterns and strategies. The goal is to create products, processes, and policies—new ways of living—that are well-adapted to life on earth over the long haul.”

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[10] https://bioengineering.stanford.edu (2015).

[11] The term ‘adaptronics’ appears, for instance, in *Bionics Symposium 1966: Short Paper Pre-Prints*, Dayton (Quashnock, Joseph M., dir., Air Force Systems Command, US Air Force, Wright-Patterson Air Force Base, Ohio), paper by Cary W. Armstrong 1966 (pp. 1–9), p. 1—which is earlier than assumed in Janocha [31: 5] that relates it to VDI Technology Centre that was established only in 1978.

[12] *MRS Bulletin*, March 1995, p. 48.

[13] https://biomimicry.org/what-is-biomimicry/ (2015).

**Biorobotics** is a subfield of robotics—making robots that emulate or simulate living biological organisms. Since ‘robot’ may mean quite wide variety of semi-autonomous devices, there is certainly an overlap with biomimetics.

**Nanobiotechnology**, or biologically informed nanotechnology converges with nanoscale biomimetics.

**Bio-inspired design** (also ‘biologically inspired engineering’) is again another name for biomimetics, however often with an emphasis of broader aspects of design [20, 62].

**Biohybrid and the biomorphic systems approach** describe a design or relationship that is even closer than mimicking by sharing the principles of living systems and their behavior. As Sarpeshkar [56: 252] mentions, “the field of biomorphic design suggests that we can mine the intellectual resources of nature to create devices useful to humans, just as we have mined her physical resources in the past. Such mining will require us to combine inspiration with perspiration and to understand how nature works with insight.”

**Biomaterials science** or biomaterials engineering focuses on studies on function and design of biomaterials (for instance, bioceramics), and on how materials interact with living organisms.[14]

**Physionics** is a term combined from ‘physiology’ and ‘electronics’ (while ‘bionics’ from ‘biology’ and ‘electronics’). As Giordan [19] argues, while bionics has paid attention mainly to morphological and anatomical aspects, physionics focuses on physiological and regulatory aspect of living systems.

**Semionics** is an important but a fairly seldom used term that is not about the materials or devices, but is about the building of signs. Thus this is, in some analogy with bionics, a theory of sign formation [13: 99], a study of the creation of new signs, or a technology of making signs (cf. [24]) on the basis of models used by living systems.

What we can learn from the diversity of these terms and approaches is that there has been a recurrent fascination with the construction of living systems that has resulted in a whole movements with specific aims, emphasis and ideology. The long-term parallel existence of these movements is interesting and is the overriding focus of biomimetics.

## 2 How Organisms Acquire and Preserve Their Materials, Structures, and Mechanisms

Key questions are: why are biological materials and processes as they are, and why are they different from the materials and processes outside of living realm? And, what kind of role does life play in the establishing these body-materials?

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[14] On the contemporary material biomimetics, see [59].

The materials and processes that are technologically mimicked are of course not in themselves life. These are materials and structures that both enable life and are products of life. These are structures that allow life to proceed and are the scaffolding (channeling, limiting, restricting and constraining) of the life processes.

While biomimetics turns attention to the aspect of transferring the findings of living systems into a technology, the role of biosemiotics includes explanations of the innovative capacity of life, description of the ways life is doing its discoveries and polishing them, and also working out typologies and possible measures of the functional value of organic qualities. Biosemiotics is focused on the study of life itself.

When using various structures or mechanisms of living systems as paragons and as examples to follow and mimic, it is important to understand the ways and limits of perfection of biosystems themselves, yet before or without any cultural design. This is because the ways by which certain forms or structures have been achieved or constructed is usually life-dependent. Likewise, their chemical composition is also life-dependent.

A Russian biogeochemist Vladimir Vernadsky paid attention to the fact that living matter, i.e. the material the organisms are built of, is in several ways different from the matter that is produced without the assistance of life. For instance, there exists a wide diversity of organic substances and materials created by organisms. Analogically, when making a distinction between the biosphere and the human noosphere, Vernadsky pointed out chemical substances and materials that required only the human symbolic mind in order to be produced, such as free aluminium or molybdenium which did not occur in native form before our anthropocene.

Organisms' capacity to catalyse and construct is based on their acquired features. These features work as constraints that channel behaviour of organelles, cells and organisms. These learnt constraints persist via inheritance and can be interpreted as knowledge in a broad sense. One way biologists have spoken about the knowledge of organisms is via the concept of adaptation. In this sense, everything meaningful that organisms do or make or build is adaptational. However, one needs to be careful with this term because as it is used by almost all schools of thought in biology, the concepts behind this term may have very different definitions.

The neo-darwinian explanation of the origins of adaptations claims that adaptations are exclusively worked out by natural selection, that is by the differential replication of randomly occurring differentiation of forms. However, do the changes that occur as a result of natural selection create some knowing for the organism itself? Since the number of replicas is not a feature of a single replica (i.e., behaviour of a particular system does not depend on the number of copies of this system in the world), the differential reproduction of organisms cannot by itself change the information the organisms possess.

Nevertheless, the mechanism of natural selection (defined as the differential reproduction of genotypes) has been seen as a certain primitive optimization mechanism. Random mutations provide new genomes, replication reproduces and thus amplify some of the genomes (that are called "fit"); their persistence (stability) can be different. Also, due to the limitedness of resources there appears feedback that "compares" the efficiency of variants.

This mechanism, however, optimizes poorly. First, evolution is just so extraordinarily slow—the number of variants of genomes that has ever been created and thus tested throughout the whole history of life (roughly equal to the number of individuals lived during three billion years) is utterly small in comparison with the number of possible combinations of a gene. Second, even if an optimum is found, there is no reason to stay on it due to ever changing context or conditions (which are also changing under the influence of organisms themselves), including the ever changing other parts of the genome, and because many of the less efficient solutions can also survive.

Thus we can say that biological evolution does not have optimality as its general aim. An "arms race" is quite exceptional in most communities and species. The main drive in the world of life is the fulfilling of needs, while there is no general reason or tendency to go up to the limits. Furthermore, there are seemingly no simple general invariants or universals of biological perfection or progression.

It is obviously not enough to explain the innovation, or abduction (inference on the basis of hypothesis), via the amplification of random change, as the explanation via the mechanism of natural selection would assume and suggest. What can then be said about the mechanism which may lead to knowledge?

Nevertheless, in addition to natural selection, there exists another mechanism that works for finding solutions—direct choices made by organisms. These are the choices between options that are available simultaneously—of food, of directions, of construction, of signals, etc. This mechanism has been studied much less, mainly because it requires knowledge about the umwelt of the organism, about the distinctions organism can make, and especially about its intrinsic time. The nature of this mechanism is to solve the incongruences, to remove the logical conflicts, and thus to move towards logically more consistent processes. This is a fast mechanism. This is the field of epigenetic processes. Adaptive epigenetic processes can be called learning. However, there is no direct way from a solution found in behavior to the inheritance of that solution.[15]

Knowing can be defined as something that results from learning. Adaptations, in the biological sense, are such. This means that adaptations are carrying certain knowledge. Knowing, including its primary and primitive forms, expresses itself also as modelling. In this general sense, artefacts also carry meaning, i.e. knowing. All these are directly semiotic aspects of life.[16]

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[15] On the mechanisms of how the behavioural decisions can be conveyed via epigenetic and ecological inheritance and further fixed through genetic drift, see, e.g., [35, 65].

[16] It should be emphasized that semiotics is dealing not only with sign processes or life processes, but also with what is built or constructed by life processes, like it is the case with artefacts in technology and structures of organism's body.

We can distinguish between three main stages in the process of learning:

(1) Incompatibility, or the situation of a problem. What can induce a functional change, is an incongruence of functional relations (i.e., of sign relations), a semiotic (logical) conflict or untranslatability, a confusion, a controversy, or a problem.[17]
(2) Innovation: if several options (potentialities) are available simultaneously, then choices have to be made and certain new links are established. This is problem-solving or decision-making. Here, the earlier experience in the form of constraints, or habits or scaffolding,[18] play a big role in channelling or directing the decision-making and creating innovation.
(3) Habituation: this is how the new connections or links may become stabilised, and sometimes, (partially) inherited.

In a general sense, functional relations are worked out or established to solve incompatibilities or problems. If a new functional relation is established, this can be called 'learning'. Learning, in this sense, is a broad concept; learning can occur as widely as semiosis.[19] Acquiring a functional relation can be of several types—recognition of something new, or association of something to something else, or imitation of some movement, making a new link, etc. As a functional relation, it is *for* something, i.e. for a certain use, aim, or purpose.

Establishing new links is, broadly speaking, the fundamental basis for building an artefact.[20] An organism, in this sense, is a network of functional links established by the life processes themselves. Thus, an organism's body is an artefact that has resulted from earlier learning. Everything in life, all its diversity of forms and processes, is a result of a continuous search with dialogues and negotiations during millions of years. Commonly, this is a permanent practice or usage of materials or structures (analogous to organs) for a very long time that involve many cycles of rebuilding and allow the structures and materials to stay stable.

Most of the functional changes take place in evolution in the form of exaptation, defined as the change in function of earlier existing structures. This is possible due to potential multifunctionality or polysemy of organic forms. Some changes have been inherited. For this to happen there must be scaffolds that delimit functioning considerably. This being the case, it is possible that despite of potentially wide range of usages, the structures are used mostly in the same way for so long time that the scaffolds could be fixed due to random drift in genome.[21]

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[17] As we have argued, it is also where the organism's phenomenal world stems from and the phenomenal present appears. This is because conflict (as well as choice) presupposes options, but options assume simultaneity, which implies that if an organism makes choices, it should have a phenomenal present. See [38].

[18] See [37].

[19] Semiosis or sign process is also ordering—the process in which indeterminacy turns into a relation, and further into a habit or rule. Cf. [29: 132].

[20] Spelled also as 'artifact'.

[21] A more detailed description of this mechanism, see [35].

What makes an artefact a non-living semiotic structure are the bonds that make and hold this structure.[22] These bonds (which are built into artefacts and represent their embedded code[23]) are both dynamic and static. Dynamic bonds are generally of the *if … then* logical type as a perception–action relation. Static bonds are glue-type bonds that are both replicable and non-replicable, one-time and unique bonds which hold together the pieces of built patterns. Artefacts cannot be constructed only on the basis of self-assembly, since their construction requires work.

Thus, life is intelligent because of its capacity to be illogical—incompatible and conflicting. This paradoxical formulation points to the situation on which knowledge-making stands: the situation of choice that is a situation of incompatibility of rules, a situation of confusion and a challenge to problem-solving. This is where abduction takes its origin and where invention becomes possible.

The materials, structures and mechanisms of living systems are smart because they store the results of the choices that have been made. Knowledge can be defined as traces of choices. Knowledge acquisition is based on short-term processes—decision making in situations of incompatibility and making choices if there are options. As a result, the systems are rebuilding and redesigning themselves. This can mean that innovations are quick, but also that fine-tuning takes a long time.

Natural selection (i.e., differential reproduction) has certainly played a role in filtering out the solutions and life's findings. However, the findings, innovations, inventions themselves require additional semiotic description of interpretations or of choices or decision-making. Thus the biosemiotic view in biomimetics would add the understanding as to why the solutions found in living systems can be useful and should be evaluated, and also how organisms create value by creating the systems that persistently work.

## 3 Perfection for Sustainability: Changing Without Trace (Some Ecosemiotic Aspects of Biomimetic Work)

With technology and with artefact-building we embed some knowledge into a matter. The embedded knowledge is a product of earlier choices and decisions. It works as scaffolding and constraints for the next situations of choice. With this, we influence the decision-making in the future. Some needs can be fulfilled easier, some with a bigger effort. With this, we either facilitate or render difficulty to subsequent ideologies.

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[22] On the relationship between signs and tools, cf. [46].

[23] Code as (a rule, based on) a mediated correspondence is commonly a carrier of knowledge. However, it may not be the case for all codes. Namely, if a code is a result of (originates from) a purely random processes, i.e. if it is not a result of choices, then it may not by itself carry any knowledge. For instance, genetic code as the correspondence between nucleotide triplets and amino acids is a code, while seemingly without any knowledge to carry on (because it is not a product of choices).

Biomimetics is frequently assumed to be a means for sustainable or green technology. The ecological approach and the idea of sustainability have obviously enhanced the searches in this area. However, life-inspired technology is only a half of solution towards a sustainable life. Sustainable economy, in an ecological sense, requires the zero balance in all element cycles, i.e., the thermodynamically closed but not isolated system. In an ecosystem, it is largely assured by biodiversity. Thus, diversity is an additional aspect that should be taken into account in development of biomimetics. Such an approach can be called *systems biomimetics*.

Technology that mimics living nature may be assumed to be environment friendly (or green) by itself [45: 5; 20, 32, 33]. However, biomimicking may not be sufficient criteria for sustainability. As, for instance, John Barry [3] has suggested, “the explicit examination of what constitutes ‘progress’ is central to the task of rethinking green politics”. One way to approach this is to make a clear distinction between progress and perfection, from which only the latter meets the criteria of sustainability.[24]

A large-scale application of biomimetics is an aspect of what is sometimes called posthumanities (e.g., [55: 94; 42]). This is where a fusion between technology and living body takes place, where artefactual constructions and ecological network turn into a swarm intelligence [49].

Heinz von Foerster [16] has described bio-logic as coalition-making. In the context of ecological technology, we can interpret it as making coalition with the ecological network of an ecosystem in which the particular culture is a part, facilitating the functions of sustainability. In this case, we already take the ecosystemic processes as a certain metamodel for the technological design, and this would mean that we could even define the ecological approach as biomimetic in large.

A paradoxical aspect of life is that it is not only a problem-solver, but also the single problem-creator. Repeated decisions lead to habits, or rules of behaviour and action that organize the processes of an ecosystem. Since these acquired rules are not universal, they can be mutually incompatible and thus lead to various kinds of unpredictable conflicts. These conflicts provide new problems for organisms to solve, and the more complex the living (eco)system becomes, the more numerous and diverse the problems become. An ecological approach would attempt to find the type of solutions that would avoid catastrophic or unsolvable situations. For instance, Allen Newell [43] has written: “since we want machines to help us solve problems, the more intelligent we are able to make it, the more unobtrusive it

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[24] This discussion can make a reference to the final (eleventh) thesis in Karl Marx’ “Theses on Feuerbach” (1845), which sounds: “Philosophers have hitherto only *interpreted* the world in various ways; the point is to *change* it” (translation by Cyril Smith 2002). While the emphasis of Marx was just on practice, the thesis has been used as a call for an overwhelming and unlimited technical progress, a call to remake our environment on the basis of technical and industrial innovations. This principle, however, is not an implication from a model of sustainable ecosystem. Since the understanding of ecology of the biosphere, however, the major challenge of science became to be “how *not to change* the world”.

should be in providing this help. Contemplating the more extreme forms of this vision, there is little to describe about the machine except that it gives a great deal of help quickly and with very little pain." Thus the biomimetic technology is both helping to solve ecological problems as well as create unpredictable new ones. An *ecosemiotic* view could be usable in order to understand these aspects of our activity [34, 41].

Living systems, except humans, do not define the aim of their construction or behaviour. They just solve or remove the inconsistencies by using some earlier experience in the form of habits or memories if they are available. The buildings this living process (semiosis) results are often amazing.

In a balanced ecosystem, everything what is produced is consumable to somebody in the same ecosystem—and it will be consumed. This illustrates an important and simple guideline for sustainability: the reversibility[25] or reusability of materials from the same ecosystem, together with low energy-use. In more semiotic terms, the features like non-universality, locality, communicative restrictedness, and context-dependence appear to be relevant in the building of scaffoldings for the sake of smarter choices.[26] Inspired by and in tune with one's own local ecosystem this may have an effect on improving health.[27]

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[25] On certain irreversibility of growth of knowledge, however, see [47].

[26] On some other semiotic qualities of biomimetic product design, see, e.g., [9, 15].

[27] Cf. [27].