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THE PRINCIPLE OF OPTIMAL DESIGN AS A LEGITIMACY OF BIONICS

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The living world is an exciting and inexhaustible source of high performance solutions to the multitude of biological problems, which were attained as a result of a natural selection, during the millions and millions years evolution of life on Earth. This work presents and comments some examples of high performances of living beings, in the light of the universal principle governing the realm of living matter: Optimal Design Principle. It is this principle that legitimate Bionics. The transfer of these optimal solutions, from living matter to the technologies, as the main objective of Bionics, is also discussed.

Key words: Biomaterials; Bionics; Optimal design; Optimal solutions; Natural selection; Neural networks; Struggle for survival.

1. INTRODUCTION

The astonishing high performances of biological systems (hereafter, called also, biosystems) have constituted, during the history of mankind, a permanent and fascinating challenge and nowadays still continues to provoke the curiosity and imagination of scientists [1]

It is sufficient to quote, be it at random, some of these performances to convince everyone that living Nature made wonders: the high sensitivity of the electrosensitive marine animals [2] to detect predator and/or prey using extremely weak electric fields (e.g. 5 *nV/cm*!) due to current leakage from aquatic organisms, the impressively high quantum yield (99.6 %) of the firefly bioluminescence, [3] the outstanding mechanical properties of the spider web fibres [4-7], etc.

How have these beings succeeded to attain such extraordinary performances? Are these performances a hazard or are they the result of very profound natural laws and principles? Is it important to invite, once more, the engineers to imitate these performances, by applying them to artificial devices, in order to improve them? This work is an attempt to answer these legitimate questions.

2. OPTIMAL DESIGN PRINCIPLE

Both the structural organization and perfect operation of biological systems, are the result of the specific objective laws and principles, guiding the structuring and functioning of living matter.

One of the universal principles, acting upon living matter, was called [8] *Optimal Design Principle (ODP).* As any principle, *ODP* cannot be demonstrated or proved directly, but it is considered to be valid because, till now, its *consequences were verified on a very large scale and at different levels of living matter organization*, from molecular till the population one.

In fact, *ODP* is a methodological consequence of two tightly connected biological concepts in Darwinian evolution theory: *struggle for survival*, and *natural selection*. It is known that, if inside a relative homogeneous species, *mutations* are taking place, then the *mutants* and the *wild type individuals* will be engaged in a continuous struggle for survival (in fact, a competition for resources and vital space). Finally, these new mutants will replace, sooner or later, the other individuals. It results that these new mutants are

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superior to the other individuals, taking into account some *specific criteria*. As one of the criteria for the fitter individuals, in many cases, is taken the *energetic cost* for maintenance, operation and propagation.

3. BIOLOGICAL PERFORMANCES: EXAMPLES

The *ODP* was invoked at different levels of living matter organization, beginning with the *molecular* and ending with the *population* one.

3.1. Molecular Level

Some biomolecules have attained, during evolution, such a contribution to *structural and functional inclusive fitness*, that their features, are universally used in an *optimal operation*, irrespective of the species involved. These molecules are also the result of a common descent and thus "unity" principle in biology.

Thus, the *photoreceptive cells of vertebrates, mollusca and arthropods*, although morphologically distinct, and with an independent evolution, utilise the same visual pigment as chromophor: the *retinal 11-cis*.

Another interesting example is offered by the *cytochromes*, present in bacteria, *protozoa, yeasts* and *eukaryotic organisms*. The ubiquity of the cytochromes could be considered as a proof that their *chemical design* is well adequate to their function. Indeed, most of them are involved in energy conversion during *respiration* and *photosynthesis*. It is somehow strange that the structural formulae of *chlorophylls*, involved in photosynthesis, and *haem*, involved in respiration, possess similar features. But, because both of these molecules are involved in analogue tasks (i.e. *electronic charge transfer* along complex reaction chains), their structural similarity is clear.

3.2. Cellular Level

Cells generally obtain the energy necessary to drive all their metabolic processes by means of mitochondria, considered to be the power plants of the cells.

The energy recovery yield in mitochondria is about 43 %, a quite high value if we realise that the mitochondria machinery is operating in *isothermal, isobaric and isovolumic conditions*, performance impossible to be attained by any artificial system devised by man.

Indeed, at this small scale, the biochemical system of a living cell is far from resembling a macroscopic unstirred chemical reactor. It should be viewed as a *network* formed by a *population of active macromolecules* that is characterised by a given high degree of *"communication"* between the members [9].

The time required to complete the synthesis of any single protein is only a few seconds. In contrast, the synthesis of a protein in a laboratory is requiring the work of highly skilled team of chemists, many and expensive reagents, hundreds of separate operations, complex automated equipment, and months of time of preparation and execution. The optimisation of energetic processes, occurring in mitochondria is possible due to the existence of their *optimal structural design*. Indeed, mitochondria are endowed with a specific topology consisting an extensive compartmentalisation of their inner space by membranes, which are permitting efficient couplings between different biochemical reactions.

One could say that, in order to use nonequilibrium thermodynamics, Nature has devised and assembled mitochondria, the true energetic subcellular reactors, endowed with an *optimal membrane system* allowing directed (i.e. one way) *biochemical reactions*, both by a favourable energetic coupling and by an adequate spatial separation of the intermediate compounds of the biochemical reactions [10].

A last, but also remarkable example, is the way in which some unicellular organisms are moving. It is known that man has been proud of his discovery of the wheel, and indeed, at a macroscopic level the wheel is not found in living beings. However, at a microscopic level, the *wheel was designed and assembled* in the case of many micro-organisms (e.g. *Escherichia coli* and *Salmonella typhimurium*) [11] operating with a high versatility and reliability. In this case, the *driving force* is no longer the actin-myosin interaction supplied by *ATP*, but a *proton gradient across the membrane* of the unicellular organisms [11, 12] which is assured by the activity of the *proton pumps*. These organisms are endowed with flagella like a corkscrew, inserted in the bacterial wall, which can rotate with high speed (100 *rotations/second*), behaving like a miniature propeller, while the protons are diffusing into the cell.

3.3. Organ Level

The minimal energy, able to induce a visual sensation, represents the *absolute visual threshold*. It was established that a *rod* of the human retina is *activated by a single photon*. In this way, the rod has attained the *ultimate physical limit of sensitivity* for light detection. A visual sensation, however, is only provoked by the absorption of at least two spatio-temporal correlated photons.

It is interesting that the photon is absorbed by a single *rhodopsin-retinal complex*, provoking only a slight *conformation transition* of retinal *11-cis isomer* to *11-trans* one. This very minute structural modification constitutes the *trigger of a cascade of biochemical reactions* (involving also, transducin) with a 10^5 amplification factor [11], that leads to a *nervous influx* at the level of ganglionar cells.

The mobilised metabolic energy, by a single nervous influx, is 10^6 times greater than that of the absorbed photon, hc/λ (where λ = 510 *nm*, *h* is the constant of Planck and *c* is the light velocity in the vacuum). Thus, the visual system is acting, in virtue of its *optimal design*, as a very efficient *light amplifier*, operating also at constant temperature, volume, pressure, and *pH*. It is also interesting that the human eye, which is no the best performing one, is sensitive over *11 order of illumination magnitude* (from 10^{-5} *lx*, in darkness, till 10^{+6} *lx*, in strong light).

4. BIONICS APPLICATIONS

The last question, raised in the introductory part, was whether the optimal solutions found in the living nature, deserve to be imitated and applied in technology, in order to improve both the performances and the costs of the existing devices and equipment.

The answer is affirmative and, already many of these marvelous findings were transferred to technology. I mention that this task to explore the features of plants and animals with optimal solutions and suggestions to be transplanted to technology, is the object of a multidisciplinary science, called *bionics* [13].

Bionics is systematically exploring the biosystems in order to reveal their structural and functional laws and to transfer them to technology, with the aim to conceive and *create artificial systems with an optimal and performance operation* [14] being at the same time economical and nonpollutant. Therefore, bionics is proposing a "technological transfer" from biosystems to the artificial systems, as was suggestively pointed out by the *"motto"* of the first Bionics Symposium [15]: *" The Living Prototypes - A Key to New Technology"*.

By infusion of these new ideas into technology, it is to be expected that bionics will contribute elegant solutions, to present day pressing problems: the discovery of new gentle, efficient and nonpollutant biotechnologies for obtaining energy, food, medicines and materials [16]. I shall comment on some of these transfers, without pretending to be exhaustive.

Artificial models of vehicles. Many of the aerial vehicles and maritime ships are imitating the *aerodynamic and hydrodynamic shapes* of birds and marine beings, respectively. In this respect, I shall mention only the artificial model of performance *race navy NACA 67-021* which imitates the characteristics form of tuna-fish (*Thunnus thynnus*) [17].

Laminflow. Starting from the findings of Kramer [18], concerning the particular *morphology of the dolphins skin*, an artificial material was devised (from a rubber like material and silicon) called *laminflow*, with this covering the hydrodynamic resistance of the aquatic racing navies, could dramatically be reduced.

Synthetic enzymes. The design and synthesis of molecules that might mimic the natural catalysts (enzyme) or hormones were recently attracting the attention of the organic chemists and biochemists. Quite recently a *cyclic trimer of Zn porphyrin* was synthesised so that is able to bind two adequate substrates, in such a way, that the reaction between them is enhanced. In this case, the process is more energy efficient and more specific in terms of the products formed than the existing processes (McPartlin *et al*., 1994, quoted by [19]).

Biomaterials. In general, biomaterials are substances used in *prosthesis, therapy and diagnosis*, which are in direct contact with tissue and biological fluids. The biomaterials have to possess many biocompatibility qualities. So, they *must not be: toxic, carcinogenic, allergenic, immunogenic, and thrombogenic*. Of course, only the body's own biological products possess such qualities. Therefore, it is absolutely necessary to graft biomolecules on these synthetic artificial substrate [20] used as biomaterials.

Neural networks and neurocomputers. One of the most dynamic and challenging field of *neurobionics* consists in natural and artificial neural networks (*ANN*) approach. Natural

neural network (*NNN*) are involved in various physiological processes, from *simpler behaviour acts* and to very *intricate higher activities of the human brain*.

The potential future application of the artificial neural networks (*ANN*) are directed to [21, 22]: a) *design of the decision systems* (associative memories, classifiers, data compressor and optimizers), b) *pattern recognition*, c) *models for signal processing* (system identification, deconvolution, automatic control and noise cancellation), d) *detection of chaotic from noisy signals* [23] e) *creation of future new type of versatile reliable and performing computers*.

The efforts of a *technological transfer*, from the *modalities of human brain organization and operation* for the creation of a *new generation of computers* (with a substantial increased flexibility, reliability and a very high speed of operation) is the main *objective of neurobionics* [14], a promising branch of bionics.

5. CONCLUSIONS AND PERSPECTIVES

The high performances elicited by biosystems are the legitimate result of the *ODP*, a universal principle governing living matter, itself a consequence of natural selection. Due to this principle, *living Nature is an inestimable and inexhaustible reservoir of optimal solutions* that could be imitated or transferred, in a creative manner, to the coming future biotechnologies.

The search of living matter performances, as consequences of *ODP*, will be a permanent challenge for scientists, both for a philosophic and aesthetic point of view, but especially, for a bionic pragmatic goal: their imitation and transfer to technology, in order to improve and optimise a great part of the existing equipment. In all the cases, the endeavour of the researchers and engineers will certainly be fully rewarded.

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