From Archebiosis to Evolution of Organisms and Informational Systems

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Abstract. Laws of evolution seem to be relevant not only for biological domains, but for informational systems as well. The paper provides a rough sketch of comparing two systems – that of homeostatic stability, and that of verbal language evolution. We argue that the patterns of evolution of functions are hierarchically organized and can be described according to 4 main levels: I – primary level: ‘a cell’ in biology, ‘a phoneme’ in natural language; II – functional units: ‘a nephron’, ‘a morpheme’; III – organs: ‘a kidney’ (a lung, a heart, etc.), ‘a word’; IV – a system: ‘water-salt balance’, ‘a sentence or a phrase’. We are aware of a set of restrictions presented by each domain: the linguistic changes under discussion have not occurred in all languages, in many cases the changes are still underway, there are ‘old’ and ‘young’ languages, etc. Data proves that such comparisons appear to be relevant and shows that same patterns can be applied to objects as far removed as these. This allows us to speak of certain evolutionary universals that were foreseen by L.A. Orbeli - one of the founders of research aiming to understand the basic features of evolution.

Keywords: laws of physiological evolution, history of evolitional physiology in Russia, origins of life, language evolution, anticipation

1 Introduction: A Glimpse of History

Problems of evolution initially drew the attention of investigators who studied the emergence and development of life on Earth. History, general questions and principles of evolutionary physiology – covering physico-chemical factors in the evolution of functions, the development of organisms’ integrity, the origin of physiological adaptation, the development of interconnection of physiological systems, etc. – are observed and discussed in [1,2].

The term evolution derives from Latin evolvere, denoting unwinding or unfolding. This word in its modern sense was probably first used by the Swiss naturalist C. Bonnet in 1762. In the 18th and 19th centuries, students of evolution established the foundations of evolutionary morphology. One obstacle in developing such work in physiology must have been the ideas of the comparative anatomist and palaeontologist Cuvier (1769-1832) and other anatomists. Dwelling on the data on the substantial differences in the functions of homologous organs, they came to a conviction that functional research is of little value in solving problems of systematics. But interest in investigating physiological processes increased rapidly: Walter in 1807, Wilbrandt in 1833, and Müller in the 1830-ies suggested the development of comparative physiological studies. Darwin in his "Origin of Species" drew attention to the problem of the evolution of structure and function in the organs of animals [3]. From 1860's through 1880's, interest in comparative physiological studies greatly increased. Hackel wrote in 1864 that the objective of future physiogeny will be an equally exhaustive and successful elaboration of the history of the development of functions as had already long been accomplished in morphogeny with respect to the development of form.

Darwin and physiologists of the second half of the 19th century gave primary importance to the interaction of the organism with its environment, to the influence of environmental conditions, and to the selection of organisms best adapted to external environmental factors. It is worthwhile to recall the work of Bernard [4], who insisted that two proper milieus exist for animals: one, the milieu exterieur, in which an animal resides, and the other, the milieu interieur, in which its tissues live. This is what makes homeostasis stable.

Attempts were made to clarify not only the morphological, but also the functional principles of the evolution of organisms. Evolutionists pointed out that the development of the evolutionary doctrine was not yet adequately reflected in physiology, in contrast to anatomy. The publication of Lucas [5] on the evolution of functions became an
important landmark in the history of evolutionary physiology. The term "evolutionary physiology" was suggested by Severtsov [6], who thought that research on the history of physiological functions seemed to present the most difficult aspect of phylogenetic physiological investigation. The establishment of evolutionary physiology in Russia was begun by a number of research groups in the 1920’s, and it is especially associated with the name of Leon Abgarovich Orbeli.

On November 16, 1920, Pavlov addressed the Physico-Mathematical Department of the Russian Academy of Sciences, stating that "during the last decades, physiological exploration has gradually spread over the whole animal kingdom…. Physiology virtually becomes general or comparative physiology". In 1933, Orbeli stressed that the developmental approach is fruitful for both physiological and morphological studies. In 1939 in Koltushi, near Leningrad, Orbeli founded the I.P. Pavlov Institute of Evolutionary Physiology and Pathology of Higher Nervous Activity, and intensive development of evolutionary physiology was underway in Moscow and Leningrad [7,8,9].

On March 7, 1956, at the First Meeting on Evolutionary Physiology held in Leningrad, Orbeli proposed a new definition of the methods and goals of this discipline. The I.M. Sechenov Institute of Evolutionary Physiology of the USSR Academy of Sciences, founded in the same year (1956), became the centre of Soviet research in this area. The first issue of the Journal of Evolutionary Biochemistry and Physiology appeared in 1965, and its translation to English was soon undertaken by Plenum Press. Beginning in 1956, conferences on evolutionary physiology were held regularly.

It’s important to stress that Leon Orbeli, being a student of Ivan Pavlov, was thinking within a more complex paradigm, which is currently seen as more adequate to the state-of-the-art of this century than the strict reflex paradigm going back to Descartes. One should also remember that the classical works of A. Ukhtomsky and N. Bernstein had developed similar accounts, so Orbeli was in a relevant context.

Anticipation is an important feature of nature: life itself could not evolve and be stable if organisms were unable to make probabilistic predictions concerning possible events on the basis of previous repeated experience. Even protosystems were to have stability against external perturbations – it was one of the instruments of evolution.

Being an outstanding scholar and thinker, Orbeli could not avoid such an exceptionally difficult topic as language origins and its evolution from communication signals of other species. Biological foundations and prerequisites of human speech made Orbeli consider it from an evolutionary perspective. As he wrote, it’s hard to imagine that Pavlov’s principle of the “second signalling system” – which distinguishes verbal conditioning, or language acquisition in man from the conditioning of the “first signalling system” in man and animals – could suddenly appear in a certain species deus ex machina and thus form contemporary humans. It’s evident – he argued – that there should be some preliminary stages of development that have gradually led to the evolution of human language. It’s interesting that during the famous session of the Academy of Sciences, which caused a dark period in Orbeli’s life, one of the ‘shortcomings’ that was incriminated to him was an idiosyncratic platform of psychophysical parallelism. His great teacher Pavlov wrote already in 1914 that he totally excludes even a hint of mentioning subjective states in his studies of brain activity. Pavlov was sceptical of Bergson’s philosophy, insisting that all subjective (or phenomenal as we call it now) states are just stories and have nothing to do with science. In fact Pavlov’s aim was to substitute ‘vague and fuzzy’ psychological descriptions of mental states by objective registration of physiological reactions. He could never agree that there is a complex internal world, a 1st person experience, qualia that are either not reflected in physiological activity, or we do not yet know how to juxtapose it.

Still later at ‘Pavlov’s Wednesdays’ he again and again discussed specifics of psychic events, did not deny animal reasoning and formulated a very strict question – one of the most challenging for physiology: ‘How can brain create subjective states?’ Pavlov was sure that merging psychic and physiological, subjective and objective – is the most important question for future science. Who knows – probably Orbeli’s ideas were influencing him in their turn. In 1945 Orbeli wrote that the level of scientific expertise has reached the stage when separate study of objective and subjective worlds is irrelevant, and physiologists have to include the latter to their paradigms; he insisted that only parallel study of the both could give us adequate picture of human higher nervous activity. To say nothing of his outstanding ideas to use ontogenetic, phylogenetic and pathological data (including recapitulation) to reveal evolutionary features.

Amazingly, these battles are still active: compare nativists’ views vs. those of functionalists on language origins and its specific features and never ending discussions on phenomenal mind and qualia [10-21]. Orbeli’s anticipation of the future trends in cognitive science is impressive – we are still there in spite of all the mighty methods and technologies. Inborn preference of young infants to perceive human faces and speech sounds, their need for communication and contextual type of information processing are similar to ecologically based inborn preferences in other species. It is important to stress that such capacities are to be tuned by the external world as genetic mechanisms
only subserve potential abilities: e.g. universal grammar in humans that later gets its parameters formed by a specific language surrounding. Anticipatory character of phylogenetic development was also well demonstrated. In Orbeli’s work, it gets a broad meaning as an attempt to consider the leading and primary role of individual ontogenesis in evolution, and to see the unfolding of more stable and long-term patterns (reflexes) also as a product of individual associations in learning.

It is important to stress that evolutionary ideas in the domain of cognitive research are extremely influential and promising: we should name the most profound and brilliant works of Terrence Deacon – summed up and developed in his ‘Incomplete Nature. How Mind Emerged from Matter’ [14]. Deacon argues that human language is a spontaneously evolved emergent adaptation, not just a formal computational system. Its structure is the result of self-organization and selection and its features emerge from the interactions among semiotic constraints, neural processing limitations and social transmission dynamics. In this view, the biological basis of this unprecedented adaptation is not located in some unique neurological structure nor the result of any single mutation (as Chomsky insists), but is a result of the interaction of numerous coevolved neurological biases and social dynamics.

The ideas of Orbeli and his followers continue to be the basis for formulating general principles of evolution not only in biological but also in symbolic informational systems [22]. Some examples of this will follow. Moreover, testifying to an amazing anticipation of future scientific trends, Orbeli also foresaw the development of a convergent science, aiming to merge not only different domains, but science and arts per se [23-25].

2 Methods of Evolutionary Physiology

Orbeli and his predecessors considered it essential to study phylogenetic aspects of evolution of functions by the methods of comparative physiology, and to elucidate the establishment of functions in the course of individual development both in pre- and postnatal ontogenesis. In Orbeli's opinion, clinical studies are important, since certain disease symptoms may reflect what occurred at earlier stages of development. Thus functions in pathology can be considered as a kind of a return to earlier developmental stages of functions. Another method of evolutionary physiology draws on comparisons of possibilities of adaptation of animals and man at different stages of individual development in a wide variety of environments. The study of functions under extreme environmental conditions or in the presence of unusual factors in the milieu exterieur can reveal functional reserves and range of evolutionary plasticity. Finally, substantial information on evolutionary physiology may be obtained by pharmacological [26] and toxicological [27] studies, as the differential sensitivity to the effects of toxic substances seen in different classes of animals can be found also in the early stages of postnatal ontogenesis, particularly in birds and mammals. This makes it possible to analyse such phenomena as resistance, functional states of cellular metabolic systems, and their plasticity. All of these approaches of evolutionary physiology necessarily involve physiological, biochemical, biophysical, molecular biological, and morphological methods, as well as the methods of mathematical modelling and genetics.

3 Language Evolution

In the past decades there has been increasing progress in the development of the multidisciplinary domain of language origins and evolution. This progress has resulted from paradigms and data being shared between researchers who study such disparate subjects as historical linguistics and archeology on the one hand, and primatology, anthropology, anatomy and neurosciences on the other [cf. 28-30]. There is a wealth of findings indicating that not only cross-disciplinary borrowing of data provides further knowledge, but that theoretical implications and analogies are no less valuable and productive.

The contribution of paleoanthropological research to the problem of language evolution is well-acknowledged. Most relevant for the purposes of this paper are studies that further support the possibility of establishing a relationship between linguistic typology or differentiation and evolutionary affinities (cf. [31-39]). Demonstrating the congruence of genetic and linguistic evolution, Cavalli-Storza et al. conclude that linguistic and genetic evolution are closely related and that associations between linguistic families and the genetic history of humans is far from random. Reformulating Darwin’s prediction (ch. 14 in ‘Origin of Species’, 1872 [3]) that information on the genealogical arrangement of man would enable to classify languages currently spoken, they indicate that when general principles of correlation between the genetic tree and linguistic families and super-families are established, predictions
could be made on the timecourse – and even locations – of the origins of linguistic families. It is evident that the ‘realization’ of human language is achieved through articulation, audition, and mental processing [40-41]. Therefore evolution is seen in peripheral–articulatory, auditory, and integrative systems of the brain. The latter, however, are a subject of constant controversy compared to the former two. While behaviorists and some artificial intelligence researchers treat the brain as a general purpose processor, Chomsky’s followers describe it as a bundle of highly specialized ‘instincts’ (‘universal grammar’ among them) designed by evolution to learn certain things [39-42]. Discussions over this dichotomy never end.

What about linguistic evolution as compared to the biological one? Does it reveal the same principles? Of course, its rate is much faster than that of biological changes. Nevertheless, at least some traits seem to be comparable.

The regularities of the evolutionary process go far beyond the province of biological evolution and appear to have a general nature. In the present paper, concerned with supporting the above view, two different subjects of study have been chosen: natural language and a physiological system. The physiological system chosen is the one that maintains the constancy of the physico-chemical parameters of the internal milieu in the body, preserving conditions for the effective function of the brain and sensory organs, but depending itself on the brain’s coordinating activity. Natural language, as a product of a long period of evolution as a communication system, is examined.

4 Homeostatic Systems and Principles of Evolution

Brain-controlled homeostatic systems do their best to provide a high degree of constancy of the internal milieu in the face of wide fluctuations in the external milieu. Almost six decades after Bernard, Barcroft wrote that over the ages, the constancy of the internal medium has become increasingly accurately regulated until, in the long run, it reached a degree of sophistication which enabled the development of human capabilities – thus, man could come to cognize the world around him in terms of abstract knowledge. Barcroft gave a graphic answer to the question why the physico-chemical parameters of the internal milieu are required to have the highest degree of stability. He wrote that the chemical and physiological processes associated with mental activity are so delicate by nature that in comparison, changes measured with a ‘thermometer’ or a ‘hydrogen electrode’ look enormous, catastrophic. To presume high intellectual maturity in conditions of unstable internal milieu properties is like seeking music in the crackling of an ill-tuned broadcast, or a ripple left by a boat on the surface of stormy Atlantic.

Thus, it can be inferred that progressive development of higher cortical functions, including informational systems, needs an internal milieu which is as stable as possible. This idea was expressed aphoristically by C. Bernard: “La fixité du milieu intérieur est la condition de la vie libre”.

Finally, we need to explain the necessity of a thorough analysis of the principles of kidney evolution. The kidney plays a key role in the maintenance of the physico-chemical constants of the internal medium in humans and animals [3,40]. The more advanced an organism is in its evolutionary history, the more stable the volume of its extracellular fluids, their chemical composition, osmolality, and pH. So, the purpose of this paper is to compare some features of the evolution of homeostatic and informational systems in order to reveal these systems’ evolutionary principles. Darwin [3] and his various followers, including Haeckel [41], Lucas [5], and Orbeli [9], discussed problems pertaining to the origin and evolution of functions. Towards the end of the 19th century and in the first decades of the 20th, some basic principles were advanced on the evolution of functions in a number of organs. Between 1875-86, the principles of functional change in the evolution of organs and the principle of organs’ substitution were formulated. At the same time, Severtsov [6] showed that the intensification of functions and the multifunctional nature of organs represent principles of evolution of functions.

The above concepts were built largely on morphological grounds, but from the physiological point of view it is obvious that each organ can perform its functions only as part of whole functional systems. For this reason it was thought that the principles of evolution of functions in physiological systems should be regarded on the different levels of their organization [1]. In case of a homeostatic system, particularly that of water-salt homeostasis, we deal with the evolution of functions on a primary level – in specialized renal cells (I). The next level corresponds to the evolution of functions in the nephron (II), which is a functional unit of an organ (the kidney); the third level is the evolution of an organ (III), that is, the kidney itself. The yet higher level involves the evolution of a physiological system (IV). Regulation of water-salt balance includes specific receptors (osmoreceptors, volume receptors, ion receptors), central nervous system integrative centres, efferent nerve outputs, as well as humoral regulatory factors and effector organs (kidneys, salt glands, gills, etc.) that realize the decisions of the nervous system.
5  Language and Principles of Evolution

A similar four-level approach may be applied to natural languages. In the present paper, an attempt is made to consider the principles of evolution of function in all objects of analysis on the basis of the hierarchy of their functional organization. As distinct from biology, evolutionary ideas in linguistics are not well recognized.

Nevertheless, in the 19th century, when language first came under the scrutiny of systematic science, a few successful attempts were made to apply evolutionary ideas from biology to the description of language [44]. Although these attempts were made by such prominent linguists as Sapir [45] and Jespersen [46], they were not taken seriously until recently. This is because in the 20th century, through the influence of Saussure [47], Jakobson [48], and others up to Chomsky, language came to be viewed as a static system with a set of rules for the combination and substitution of elements, regardless of how it may have evolved from protolanguages to modern languages. Thus the central idea in the study of language from an evolutionary perspective – that human languages evolve and become more effective – is quite paradoxical within linguistics, although it is generally accepted in biology.

Nevertheless, since the beginning of comparative linguistics and throughout its subsequent extensive development in the 20th century, there has been much discussion on the issue of language typology – comparing both related and widely separated languages – and also on the question of what features may be shared by all languages. Studies on the reconstruction of protolanguages are progressing rapidly, especially in recent years [49]. General features of language evolution can be seen in the family of Indo-European languages, because they are best studied for the longest period of time (6-7 thousand years). Regularities revealed in studies of Indo-European languages have turned out to be applicable to the evolution of other language groups as well: Hamito-Semitic, Altaic, Uralic, and others. Thus there appear to be regularities of evolution which are widely shared among different languages, and which can be traced at different levels, from that of phonology (I) up to the sentence level (IV).

It is important to bear in mind that these regularities will be expressed differently, according to the type of language being considered. For example, in tone languages changes can take place only in tones, the segmental sounds remaining the same. In languages of other phonological types changes may occur in the segmental sounds or phonemes. Furthermore, linguistic features are “scattered” over different languages and are not necessarily present in each of them.

Despite all of the aforesaid, the evolution of language – characterizing comparable, though differently expressed phenomena – is quite evident, in much the same way as basic features of evolution can be traced in the changes of different groups of organisms. For an interdisciplinary analysis of evolutionary principles it seems promising to compare the data of historical linguistics, on the one hand, and ontogenetic data on first language acquisition, on the other.

Work on the fossil anthropoid sound-producing apparatus’ simulation and on the synthesis of sounds that could be articulated by this apparatus is of considerable importance. It is also significant to compare these data both with the cognitive level of hominids and the anthropological evidence on the development of particular cerebral areas. Valuable information on this topic is to be found in neurolinguistics – in the studies of linguistic functions as related to cerebral mechanisms [16,20,25,28,50-54].

In recent years, attempts have been made to discuss language development in terms of processes recognized in biological evolution, such as paedomorphism, neoteny, recapitulation, language hybridization, mono- and polygenesis, etc. Substantial contributions to this have been made by Bichakjian [52]. In our paper, only data on the evolution of the best-studied Indo-European languages will be briefly considered. Further on, the principles of functional evolution inherent to all four levels will be considered separately for each of the two systems analysed.

6  Principles of Evolution of Functions

6.1  ‘Primary Element’ (I)

6.1.1  Evolution of Physiological Functions at the Cellular Level

To realize homeostatic activity in a system it is necessary to develop specialized subsystems for the excretion and secretion of substances. Excretory organs in the Metazoa may consist of different parts that reabsorb filtered substances from blood and return them to blood, and synthesize new compounds necessary for more effective removal
of substances from the organism. The kidney participates in performing many additional functions including the incretory and endocrine ones. For these functions to be realized, directional transport of substances (reabsorption or secretion) from the cell into the blood or urine are required. The primary event in the origin of the excretory organ was the specialization of initial (‘ancestral’) forms, resulting from the emergence of an asymmetric cell capable of directly transporting substances. This process involved the functional biochemical differentiation of the opposite sides of the cell – the apical and basal plasma membranes, with the allocation of ion channels principally to the former, while allocating ion pumps, hormone and transmitter receptors to the latter side, as well as the redistribution of mitochondria throughout the cell. Thus the evolution of the excretory organ cell has its origin in the formation of an asymmetrical cell through cellular specialization.

The basis for the evolution of kidney function in vertebrates lies in increasing energy metabolism and energy consumption – especially in warm-blooded animals, in contrast to cold-blooded ones. This process is reflected in the intensification of trans-cellular transport of substances, increase in oxygen consumption and numbers of mitochondria, and increase in oxidative enzyme activities. All of these events represent another important principle of evolution – the principle of intensification of cellular function.

The comparison of cells from homologous parts of nephrons in representatives of various classes of vertebrates (from hagfish to mammals) that took hundreds of million years to evolve reveals an increase in the number of cell types that differ morphologically and functionally from each other. In other words, the evolution of function is related to the differentiation of nephron cells. This may be the result of a simplification or complication of certain cellular functions, or only an increase (or loss) of distinct forms of initial cellular activity.

The evolution of cellular function is accompanied by an increase in cell’s ability to perceive and respond to outside stimuli, and to more accurately fulfil its functions in the whole organism. This is reflected in an increasing number of specific receptors of various kinds for different hormones and transmitters, and in the realization of cellular responses together with different intracellular signalling systems. The increasing efficacy of cellular function – and the evolution of functional systems – depends not only on the effects of distant regulators (hormones, transmitters), but also on the intercellular interactions accompanied by the specialization of cell-to-cell junctional complexes.

6.1.2 Evolution of Phoneme Function

In this part of the paper we try to analyse linguistic data to show similarities and differences in the evolution of phonemes as compared to the evolution of the first level of the physiological system – the cell.

The phoneme is the minimal sound unit of language, enabling us to distinguish the meanings of different words and morphemes. The sound system of protolanguage most probably comprised very few vowels. The most frequent one was the sound /e/, less frequent was /a/, still less frequent were /i/ and /u/. There existed laryngeal h-like sounds which later dropped out (an example of a decrease in the number of similar units – sound regression, phoneme regression). Language development led to an increase in the number of vowels /i/, /e/, /a/, /o/, and /u/ (grouped in two subclasses) long and short vowels (increase in quantity and change of quality). Different articulation variants of the same cardinal (basic) set of vowels, as they are generally called, subsequently arise with a tendency toward increasing differentiation: nasal, mid-, front-, etc.

The same trend is evident in the neglect of “complex”, “mixed” sounds, the tendency towards the formation of “simple” more clearly articulated sounds, and the elimination of co-articulations. This can be readily illustrated by the example of consonants which evolved from complex mixed sounds to a “variety of separate” sounds covering the full range of possible articulations, from stops to fricatives.

Undoubtedly, these events reflect an increase in the intensification of phoneme function, a specialization of contact types, and an increase in the number of modes of functioning. This is expressed in the possibility of combining certain sounds, while other combinations are impossible, as most clearly seen in comparing different languages. Vowel changes have resulted in changes in the quality of adjacent consonants, e.g., in making them voiced or voiceless. The process of such changes can be exemplified by the merging of the Indo-European sounds /e/, /o/, /a/ of different timbres into the Sanskrit /a/.

Regression shows itself in the disappearance of glottalization and in the degradation or substitution of aspiration in other sounds, e.g., fricatives. aspiration. Noteworthy is the division of the “double” sound into two different classes, e.g., labio-velar sounds disappear in the course of evolution, being substituted by labials and velars.

The same type of new sounds can have different origins, e.g., voiceless aspirate consonants in Sanskrit can stem from either voiceless non-aspirate sounds plus “h”, or from voiced aspirate consonants. The long vowel in Sanskrit
6.2 Functional Units of an “Organ” (II)

6.2.1 Evolution of Nephron Function

Nephron is the main morpho-functional unit of the kidney. Each human kidney has about 1 million nephrons. This, however, does not imply that all of them are uniform. In mammalian kidneys there are up to eight distinct nephron populations (superficial, intra-cortical, juxtamedullary). The increase of nephron heterogeneity may be regarded as one of the features of evolution in functional units. The kidneys of lower vertebrates do not have such a variety of nephrons, and lack a number of functions that originated later in the kidneys of mammals and birds.

Increased differentiation of nephrons is a characteristic of mammals and birds compared to lower vertebrates. Kidney efficiency is characterized by the degree of constancy in the composition and volume of bodily fluids.

Another feature in the evolution of nephron functions is the intensification of reabsorption and secretion in warm-blooded vertebrates as compared to coldblooded ones. This is due to the intensification of cellular activity and the reorganization of cell-to-cell functional complexes in different parts of the nephron, both of which form preconditions for the reabsorption of greater amounts of various organic and inorganic substances and water.

In kidney evolution, the formation of new morpho-functional complexes takes place and the complex (medulla) includes the vasa recta and the loops of Henle in warm-blooded vertebrates. In the former case, it’s a prerequisite for the appearance of a structure that analyses information on tubule content. In the latter case, these elements make up a system that contributes to the formation of a new kidney function related to osmotic urine concentration.

The increase of nephron heterogeneity and differentiation, the intensification of basic nephron functions, the formation of complexes with tubule vessels and interstitial cells with intercellular matter – all these factors raise the regulation of renal functions to a quantitatively higher level, and thereby ensure more efficient maintenance of the physico-chemical constancy of the internal milieu. Thereby mammals, as compared to lower vertebrates, obtain new homeostatic possibilities due to their enhanced ability of regulating kidney functional activity.

6.2.2 Evolution of Morpheme Function

In linguistics, the minimal meaningful segment is a morpheme. There are several types of morphemes: root, affixal, suffixal, derivational (word-formative), etc. Language structure has undergone a number of successive changes in its development from protolanguage to its modern forms [51]. This pertains both to changes in grammatical features and how they are marked.

Increased differentiation appears in the progressive separation of elements’ roles: i.e., inflexions become particles with specific fragmentary meanings. A narrowing of functions also occurs, as morphemes previously incorporated into words become separate units – words with distinct grammatical functions; and as the ancestral absolute (indefinite) case splits up into different cases.

A reduction or complete regression of functions is observed in, e.g., the decreasing number of categories (for numbers and genders – from 3 to 2); a complete elimination of cases is possible; and a trend of abandoning declension is observed.

These processes are compensated by intensification (increase), the development of preposition roles, the appearance of articles, and a shift towards a more economical algorithm – from synthetic to more analytical forms. This is achieved by strengthening regulation, particularly by the introduction of a syntactically relevant order of elements, their stricter agreement in a system. As a result, the formation of ‘morpho-functional complexes’ (analogous to those described above for biological objects) takes place, which provide for new functions by merging two or more forms with different meanings.

We can see an increase in the number of same-class units, each of them with a different meaning (e.g., prepositions), and the emergence of a new class (articles); these are required to provide a new function – analyticity, leading to more flexible syntax. A change of morpheme functions becomes apparent in the emergence of new qualities in already existing units, with possible regression of earlier ones: the future tense and the subjunctive mood originated from three archaic aspeclual forms (aspects), which took place after the common Indo-European protolanguage split.
This can be exemplified by the conversion of asaspectual and modal forms into temporal ones: the three asaspectual forms (Present, Aorist, Perfect) of Indo-European language become two tenses (Present, Preterit) and two moods (imperative and indicative) in Anatolic languages. The Perfect aspect turns into a temporal form, and the Objective Future Tense is formed from the subjective modality.

In general, there is a narrowing in element’s role from a poly-functional one towards more specialized ones, with vector to fragmentary, independent expression of one or another function. As an example, a tendency can be traced of shifting from the “heavy” synthetic forms, peculiar to Russian syntax, to the “light” analytical constructions of the English type. We can also observe increasing heterogeneity when an element’s polysemy may result from its position in the whole structure.

6.3 An ‘Organ’ (III)

6.3.1 Evolution of Kidney Function

Obviously, there is no need to develop an argument for the interrelationship between structure and function, particularly when this concerns the principles of evolution of organ functions. At the same time, some of these principles reflect to a greater extent the evolution of organ structure, while others, on the contrary, account better for the evolution of organ functions (e.g., increase in the number of functions). It is worthwhile to bring together the principles of morpho-functional evolution because they provide a deeper insight into the principles of development of both structure and function of the physiological systems being investigated.

Increased multi-functionality can be seen as a characteristic feature of organ evolution. The kidneys of lower vertebrates provide fluid volume and ion regulation. In the lamprey, the possibility of adapting to fresh water depend on the appearance of a new kidney function – hyperosmotic regulation. In vertebrates, the kidneys, in addition to excretion, produce a number of hormones and autacoids that participate in the regulation of mineral metabolism, arterial pressure, and perform some other functions.

Glomerular filtration rate and reabsorption of substances are 10-100 times greater in mammals than in lower vertebrates, as calculated per 1 g of kidney weight. This points to the intensification of processes responsible for kidney functions as one of the main lines in the evolution of renal function, as relative kidney weight in relation to body surface does not increase during vertebrate evolution.

A qualitatively new factor in the evolution of renal function in birds and mammals was the appearance of the ability to regulate osmotic homeostasis under conditions of water deficiency, and to survive for a long time in the desert without any water. Development of this new function was determined by the formation of two layers in the kidney-cortex and medulla. The principle of “superstructures” may be regarded as one of the fundamental principles of the evolution of organ functions, including that of kidney.

A change of functions is another essential principle in the evolution of functions. For example, the kidneys of teleosts have functions (i.e., blood cell production) that in higher vertebrates are lost– although higher vertebrate kidneys still participate in the regulation of blood cell production.

The principle of substitution of an organ or its functions can be illustrated for kidneys by several examples. In bony fishes, ion excretion occurs not only in kidneys but also in gills. Salt glands bear the main burden of hyposmotic regulation in many species, and kidneys become the main organ of osmoregulation only in mammals.

Decrease in the number of similar organs and increase in the number of functional units are significant factors for the growing role of the kidney as a principal homeostatic organ. The numerous, metamerically arranged metanephridia in earthworms give way to paired excretory organs in molluscs, crustacea, and vertebrates. In the paired organs, e.g. in the kidneys, there are numerous functional units: nephrons (about 1mln in each kidney in man).

The principles of evolution of functions characterizing progressive kidney evolution, such as multi-functionality, intensification of functions, etc., have been dealt with above. However, development may be accompanied also by regression of at least some functions. This may be illustrated by the loss of the ability to produce hyposmotic urine in marine bony fishes, as compared with their ancestors the fresh-water fishes, and by a reduction of the number of glomeruli and glomerular filtration rate, which decrease water loss in kidneys.

The regression of renal function may be illustrated on the water vole (water rat), who lost both the ability to osmotically concentrate urine and, therefore, osmoregulation capacity in conditions of water deficiency. The second migration of bony fishes from river to sea water hundreds of millions of years ago led to irreversible changes in a number of systems, including the kidney, which resulted eventually in the loss of hyperosmotic regulation – the
ability to excrete hypo-osmotic urine, excrete osmotic free water, and to live in fresh water. In anadromic migration of monocyclic salmon, soon after the fish enter the river from the sea, they are unable to return to the sea due to a functional switching in the osmo-regulatory system and an irreversible loss of the physiological mechanisms of hyposmotic regulation – of ‘producing’ fresh water in the sea to keep water balance. Only some fishes could adapt to living both in fresh and marine water.

6.3.2 Evolution of Word Function

Language development shows an increase in the number of morphemes in a word, resulting in a decrease in the number of words. Earlier existing morphemes are used for coining new words in modern language. These are: archi-, anti-, poly-, etc. Word groups are formed according the principle of supra-structure: coordinative – “bread and butter”, subordinative – “fresh milk”, constructions – “I saw him coming”.

In Indo-European protolanguage, words in the sentence did not subordinate but adjoin each other as if they were on their own. Later on, they began to be united into groups, with the form of one word beginning to affect the form of the other [52]; however, this was not yet a sentence. Change of function reveals itself in that pronouns start playing the role of conjunctions. Combining cognitively dissimilar phenomena into a new single linguistic unit takes place.

Differentiation of word function is apparent in that particular meanings evolve from more amorphous ones; differentiation of the cognitive and grammatical roles takes place – separation of subject and object, agent and patient etc. The tendency towards regulation, fixed word order in the sentence, and constructions is a significant feature of the evolution of this linguistic level. On the other hand, increase of multi-functionality manifests in the appearance of dissimilar, sometimes very different meanings in the same word.

Regression of functions, including irreversibles ones, can be seen in the disappearance, dropping out of the words or some of their meanings (archaisms). One is justified in speaking about valences, i.e., the ability of words to combine with each other, as both strongly varying in different languages and also being their universal characteristics.

6.4 ‘System’ (IV)

6.4.1 Evolution of the Water-Salt Balance System

The system of water-salt metabolism governs the stability of physico-chemical parameters in animals and humans, including fluid volume in the body, osmolality, pH, ions and concentration of blood plasma, extracellular fluids. The investigation of organisms belonging to different types of Proto- and Deuterostomia, and different classes of vertebrates at different stages of postnatal development points to the following principles as most significant in the evolution of system functions: (1) increase in the number of regulatory factors (2) increase in the number of regulated parameters, and (3) increase in the precision of homeostatic control.

In most marine invertebrates and hagfish, the regulated parameters of the internal milieu include pH and concentration of certain ions. Lamprey, fish, and other higher vertebrates have systems to stabilize blood and body fluid osmolality (osmotic pressure). This opened up new avenues for these animals to occupy sea-water, fresh water, and terrestrial areas. A comparison of the functional organisation of systems regulating water-salt balance in animals at different levels of development indicates that a number of humoral regulatory factors change. Thus, for each of the ions of particular significance for cellular activity, there are not one but two and even more hormones and other regulatory factors. In the present paper, where special attention is focused on informational systems, it is important to point out that both regulatory peptides, various hormones, and autacoids may be considered as “words” of the biological language of homeostatic systems.

An increase in the number and role of regulatory factors is not the only mechanism employed in evolution to attain higher quality of regulation. Our studies on the impact of the nervous system on muscles show that while the stimulation of one group of nerves may have a triggering effect, the stimulation of another one exerts adaptive control by adjusting the muscle to its immediate demands. With specific hormones, particularly vasopressin, two types of effects are established. One of them, produced when V2 receptors are stimulated by vasopressin, induces an increased water permeability in the epithelium of some osmoregulatory organs; the other one depends on the stimulation of V1 receptors in the same cell. In the latter event, the release of other second messengers and the modulation of permeability level take place, thereby changing the intensity of water transport. As a result, greater precision is
attained in the regulation of blood osmolality, which is of prime importance for cellular activity in many systems – especially the nervous one, including higher cortical functions and the state of cognitive functioning. Cell volume fluctuations depend on changes in extracellular fluid osmolality. This parameter must be maintained with utmost precision for cellular functions to be efficiently performed. During vertebrate evolution, there is an increase in the homeostatic ability of kidneys with respect to various physico-chemical parameters of the internal milieu, as well as with respect to other effector organs and systems.

6.4.2 Evolution of Sentence Functions

Inasmuch as sentences are formed of words according to certain rules – which are both universal, reflecting general cognitive characteristics of humans, and specific, inherent to particular languages – one cannot but touch upon the evolution of such rules themselves (i.e., syntax) when considering this level. In this respect, a number of general trends should be emphasized.

First of all, linguists analyse the following tendencies in the evolution of syntax: cognitive aspects, such as role definition – action, agent, object of action, etc. – on the one hand, and proper linguistic aspects on the other: appearance of such sentence parts as the subject, predicate, and object, not necessarily coinciding with cognitive roles. This divergence indicates an increase in functional specialization.

We can also see a reorganization of sentence structure aimed at increasing its functional adequacy – the ability to express complex systems of notions and relations. The structural hierarchy reveals itself in the emergence of subordination – first, in word groups within a simple sentence, and then in the formation of specialized subordinate clauses.

In syntax, we can note an increase in the degrees of syntactical freedom – a shift to more mobile rules applied to both separate sentence parts and separate sentences within complex sentences, the substitution of the declension system for syntactical functions (which represents a more economical algorithm), and, accordingly, the introduction of syntactically more relevant word order.

The trend of syntax evolution can be tentatively presented as follows: from groups of equivalent words to correlated ones, and from the combination of two simple equivalent sentences – patterned as to correlate the origin of the subordination within the sentences – to the origin of complex sentences. Development proceeds towards the emergence of complex sentences with subordination and co-ordination at different levels (e.g., one inside the other). Various participial and other constructions can be included here, too. The concept of syntax depth (i.e., of co-ordination and subordination levels) has been developed to describe these extremely complicated constructions. Language historians point to the interesting phenomenon of “reversion” of grammatical structure in the process of language evolution: from the “object-action” type to the “action-object” type, and from the “left-branching” structure to the “right-branching” one.

7 Discussion

Evolution is revealed already in nonorganic nature, but manifests itself especially vividly in versatile living forms. Developments in genetics and molecular and systems biology have led to intense progress in evolutionary biology. The evolution of life has progressed in continuous interaction with the environment, between inorganic and organic domains. There is no doubt that the fundamental features of inorganic chemical elements predetermined their role in forming the foundations and conditions for the basic organic components of life and living beings. We presume that the genesis of proto-cells created the first whole functional structure adaptable to the milieu exterieur, and able to prevail in the natural selection of the most adapted species in a changing environment. Life and development in a changing world gains enormous advantages from the use of information. This indicates that development has been subserved by a constant interaction between living systems of different levels of complexity and relevant informational systems.

The key point here is answering the question about the first stage of a living object [55]. As its a cell, and not its elements, that gives adaptable progeny, we assume that a proto-cell was a first-stage living being that: had to be self-sufficient, independent, and protected by a membrane. In the huge diversity of living cells K ions dominate intracellularly, while the extracellular fluid is dominated by Na ions. Therefore, theoretically it does not seem possible to create the first K-rich cell in a Na world (ocean): a Na pump is needed. Protein synthesis requires the
predominance of K ions [56]. After the emergence of plasmatic membrane, adaptation to various external circumstances becomes possible. This leads us to argue that archebiosis did not begin in a sea rich in sodium (as was accepted earlier), but in lakes where K ions are predominant [57]. This is supported by geochemical data [58, 59]. Another idea is developed of archebiosis in geothermal fields [60]. The listed environments provide conditions for effective protein synthesis and the formation of a minimal set of components necessary for functioning in cells that were already surrounded by plasmatic membrane, ensuring their independence and adaptability.

The following two steps were of extreme importance: the emergence of multi-cellular organization and differentiation of functions (circulation, digestion, breathing, and excretion) [61], as well as the informational system subserving both intra- and extracellular signaling and interaction [62]. Difference in the size of Na and K ions is very small, while the concentration of K ions within a cell is ten times higher. Our research allows to understand the physicochemical nature of this [63, 64].

There is a growing interest in bio-evolutionary perspectives on the mechanisms that underlie the complexity of human behaviour and language evolution [cf. 65-69]. The main features outlined are those graduality, structural differentiation, and adaptivity. Mayr stresses that ‘the evolutionary changes that result from adaptive shifts...are followed secondarily by a change in structure’ [70], and that ‘during a succession of functions a structure always passes through a stage when it can simultaneously perform both jobs’ [71]. Givón formulates six general principles that in his view control both language and biological evolution [72]: graduality of change; adaptive-selection motivation; functional change and ambiguity before structural change and specialization; terminal addition of new structures to older ones; local causation with global consequences, and uni-directionality of change.

Conclusion

Anticipation can also be discussed in a historical perspective as a scientific foundation and grounds for Nature’s choice, i.e. physical and chemical limitations being the basis of a realized trend in life development. If we assume that one of the purposes of the Universe development was Life - then creating a living cell in an inorganic world on one of the planets was an anticipation at one of the stages of evolution. Then a crucial question arises – what is it that distinguishes the living and inorganic nature? One should not get attached to trivial topics like carbon, genes and proteins but better think what concrete elements of inorganic nature become constitutive and integral components of the living? Those are the same in a proto-cell as well as in the ocean and in a geological mineral, and in any cell of a now living creatures – from amoeba and infusoria to monkeys and humans.

At the same time in all the diversity of living forms and their cells – be it a neuron or a nephron - K-ions dominate in a cytoplasm while Na-ions - in a extracellular fluid. This can be seen as the main anticipation of Nature at the start of Life that remained intact through innumerable generations. As it was discussed earlier these cations have no difference in electric charge, and their sizes differ insignificantly. However, the difference between the ions concentration in the cytoplasm and the pericellular liquid is 10 times or more. Concentration gradient between a cell and a extracellular fluid provides for electro-genesis as the basis for information transfer. Was such an anticipation foreseen and provided?.. The reason, rather, was that K ions are specifically good for protein synthesis that made them be successfully used in the proto-cells and the living systems, while electro-genesis that at the beginning was just a side-effect was later used as a precious advantage.

The discovery of such an anticipatory choice of Nature can be seen as a kind of intuitive insight per se. It was a sudden understanding that the hypothesis of archebiosis from a sodium ocean medium is irrelevant, as it is impossible to create a K-cytoplasm there [73], so another idea appeared based on initial K water basins [57], that was confirmed by geochemical data [58 ] and in a special experiment [63]. A proto-cell could then accommodate to salt and fresh water, evolve to higher forms of life reaching conscious mind, intuition and different forms of anticipation.

The paper has attempted to substantiate the applicability of some principles of evolution of functions to phenomena as different as those of natural language and a physiological system. L.A. Orbeli was one of the founders of research aiming to understand the basic features of physiological evolution, and our current knowledge allows us to apply this approach to the analysis of both physiological and informational systems in all their complexity, and to formulate principles of their evolution. As we have shown earlier, both linguistic and biological data provide evidence for an increase in the number of regulatory factors and regulated parameters, and this increase contributes to effective conveying of information.

The paper should be taken as an attempt to analyse the principles of evolution of these systems from a novel, unconventional point of view. It has been shown above that close analogies can be drawn between the processes of
evolution in physiological systems and those in natural language. It is the more surprising as the mechanisms of evolution of homeostatic systems and languages differ sharply. The analogies observed suggest that there exist general regularities of functional systems’ evolution. In physics, the parallels between mechanical, acoustic, and electrical phenomena have long been known and productively employed. It is conceivable that the same uniformity exists in the evolutionary processes of different systems.

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References

71. Mayr E. This is Biology. Cambridge, MA: Harvard University Press (1997)