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DISCUSSIONS

Biophysics of Evolution of Intellectual Systems

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Abstract—The first work on noogenesis as evolution of intellect was published 150 years ago. However, it was not until the 21st century that quantitation became possible for certain parameters that contribute to the understanding of the evolution of intellectual systems in natural sciences, the progress being due to basic achievements in physics, biology, medicine, and interdisciplinary fields. Analyses of the parameters of intellectual systems, patterns of their emergence and evolution, distinctive features, and the constants and limits of their structures and functions made it possible to measure and compare the capacity of communications (~100 to 300 million m/s), to quantify the number of components in intellectual systems (10–100 billion components), and to calculate the number of successful links responsible for cooperation (from 150 to 1 trillion links). Prognostic models can be developed by studying the phenomenon of the origin and evolution of the brain as a population of neurons within the biological evolution of *Homo sapiens* and the advent of cognition; by studying the brain of an individual throughout individual anatomic and physiological development, including the development of creativity, thinking, consciousness, idea, insight, intuition, and eureka; and by studying and "noo" in the context of the hypothesis of the morphological and functional evolution of the human population.

Keywords: biophysics of development and evolution, neuroinformatics, psychophysics, neurophysics, parameters of intellectual systems, noogenesis

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INTRODUCTION

In 1871, MD Doherty [1] was the first to coin the term "noogenesis" in the chapter Noogenesis of his book *Organic Phylosophy*: "The growth of the mind in the human race keeps pace with the gradual evolution of the sciences, and is easily traced in history, while the origin of mental faculties and their gradual evolution in the individual mind is a vexed question of psychology... We cannot trace the formation of an experimental mind in utero, as we can trace the formation of the body, but biological unity involves the mental as well as physical faculties in the newborn child... The experiential faculties of mind are more or less exercised in all the sciences, as the organs of the body in all physical vocation; but, like these organs, they must be formed in utero before they can be developed in adult life. Instictual vocations are limited to experience and work on the surface of the globe, while the mind investigates all the depths of nature in the universe, bounded only by infinity... What is the fixed cycle of sociogenetic evolution for the collective organism of humanity, compared with that of individual embryogenesis?"

The concept of noogenesis emerged 150 years ago simultaneously with the concept of "abiogenesis", which is understood as a natural process whereby life originates from inanimate matter [2]. Knowledge of abiogenesis intensely developed in the 20th century: hypotheses were advanced, experiments performed, theories grounded, and many works published. In contrast, prolonged pauses occurred in the development of the noogenesis concept on the evidence of relevant published works, and intense studies were resumed approximately 70 years later.

In 1955, the anthropologist Teilhard de Chardin [3] mentioned noogenesis several times in his book *The Phenomenon of Man*, but without providing its exact definition. The term was interpreted mostly as the origin and evolution of intelligence in several more recent thesauruses. It should be noted that the emergence of intelligence is one of the five main new phenomena in evolution. These phenomena include: (1) the origin of life; (2) the origin of nucleus-possessing protozoans; (3) the origin of forms with sexual reproduction; (4) the origin of animals with a nervous system; and (5) the origin of thinking animals, that is, humans.

In 2005, the current definition was proposed. Noogenesis is understood as a process whereby intellectual systems develop in time and space. Noogenesis is a set of structural and functional rearrangements that are regular and interrelated, follow a definite temporal order, and affect the total hierarchy and the total set of relatively elementary structures and processes, which interact with each other. This definition was proposed in a book on noogenesis [4]. Concepts of intellectual systems, information logistics, intellectual energy, acceleration, strength, and potential were proposed in that work and combined to form a theory of intelligence. As a result, the concept of noogenesis was introduced in science as the concept of evolution of intellectual systems [5]. The biophysical parameters of the energetics of intelligence were introduced, including the volume of information and the quantitative acceleration (frequency, speed) and distance of its transmission [6]. An analogy was drawn between the human brain, which consists of a huge number of neurons working in parallel, and a human society, which consists of individual humans [7]. However, estimates of the number of neurons in the brain differed by three orders of magnitude, from 10^9 to 10^{12}, at the time of publication. It was not until the 2020s that more exact quantification of a number of parameters made it possible to start constructing and studying models that simulate the development of structures and functions of real intellectual systems in order to explain the respective phenomena, make predictions for natural intelligence, and develop bionics for artificial intelligence.

The study objective was formulated as follows. Using biophysical tools and the current data on particular parameters, experiments were to be carried out to simulate the development of complex intellectual systems:

—evolution and the advent of intelligence in *Homo sapien*s (phylogeny),

—development of intelligence during individual development (ontogeny), and

—evaluation of the hypothesis that the human population tends to merge into a global intellectual system.

SEVERAL PARAMETERS OF INTELLECTUAL SYSTEMS, THEIR QUANTIFICATION, AND DEVELOPMENT OVER TIME

Etiology and semantics of terms. Noogenesis (derived from the ancient Greek νόος for intelligence and γένεσις for origin, emergence) is the origin and evolution of intelligence. It should be noted that Russian ноо-, English noo-, and Chinese 智慧 are the earliest known derivatives of the ancient Greek νόος and, based on the dictionary meaning, combine the phenomena of mind, sense, intelligence, thought, insight, and wisdom into a single phenomenon.

Evolution of the speed is detectable in transmission and exchange of material objects and physical signals that carry information. An analysis shows an increasing speed for adaptation, reflexes, movement, and exchange of substances and information. The speed increases at every new level of evolution and organization of biological systems, and the fitness of an organism (a population) improves with increasing speed of response to environmental changes (including the speed of communication between intellectual components). In a unicellular organism, the speed is 10^{-10} m/s for ion movement across the membrane, ~10^{-6} m/s for water movement across the membrane, and ~2×10^{-5} for intracellular (cytoplasmic) trafficking, while a speed of ~0.05 m/s is observed for blood movement through vessels in a multicellular organism. In 1849, Helmholtz [8] was the first to measure the speed of signal propagation through a nerve fiber (24.6–38.4 m/s). Current measurements estimate the nervous pulse velocity at 0.5–120 m/s. The speeds of sound and light were determined earlier, in the 17th century. It became clear by the 21st century that the speeds of light and sound mostly determine the speeds of physical signals that carry information: ~300 m/s for sound (voice or an audio signal) and ~3×10^8 m/s for quantum electronic devices (the speeds of radio electromagnetic waves; electric current; light and optical flows; and telecommunication, including television, telephony, the now widespread Internet, and numerous portable communication devices). A compact graphic model was constructed for the evolution of speed (Fig. 1).

Evolution of the number of components. Intellectual systems may form when certain critical amounts are reached by their intellectual components and communications between them. When the number of intellectual components reaches $n \geq 1$ billion, the phenomenon of noorevolution may be observed; i.e., the quantitative development of an information system is transformed to yield a qualitatively new autonomous intellectual system. An intellectual system is a set of relatively elementary structures and processes that interact with each other and are united into a single entity by performing an intellectual function that cannot be reduced to the functions of individual components. Features of intellectual systems are as follows: an intellectual system acts as a single entity when interacting with the environment and other systems and consists of hierarchic subsystems of lower levels [4].

In the case of individual development (ontogeny) of the human brain, noogenesis starts from one or two primary embryonic cells, which increase in number via cleavage and division at the morula–blastula–gastrula stages to ensure the formation of a respective primitive tissue layer and its differentiation. A nervous system forms in the embryo. The brain volume reaches 375 cm^3 in a human fetus by the time of birth and

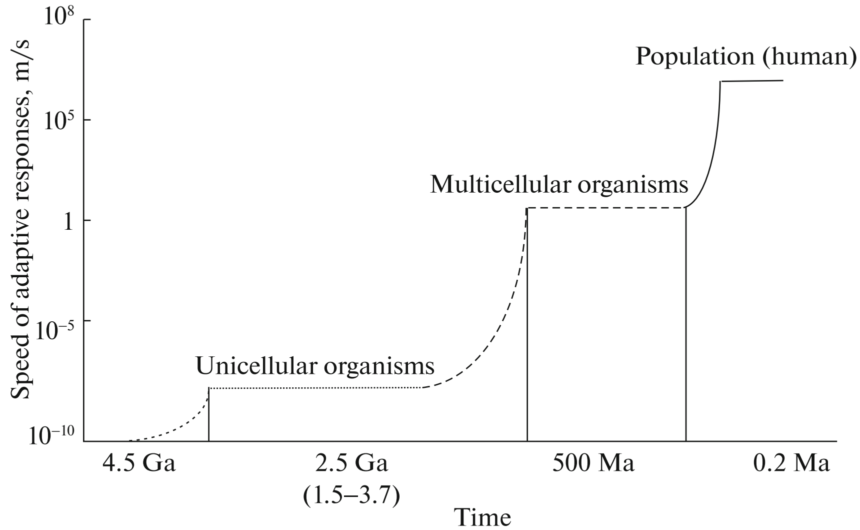

Fig. 1. Evolution of the speed of material objects and physical signals that carry information.

1300 cm^3 by 10 years of age according to some data. Morphological and functional maturation of brain structures is completed by 13 years of age, and definitive morphological and functional maturity corresponds to 16–17 years of age.

In 1889, Ramón y Cajal [9] discovered neurons, and the neuron doctrine was developed more recently as the concept that the nervous system is made up of discrete individual cells. The number of neurons in the brain was estimated in the 21st century: there are 86 billion neurons in the adult *H. sapiens* brain as a result of phylogeny and ontogeny [10]. This makes it possible to construct compact graphic models of comparative evolution of the component number in intellectual systems (Fig. 2).

It should be noted for comparison that the human population increased in evolution from two protohumans to ~79 million people in the 20th century BC, ~300 million people by the beginning of the Christian Era, ~1 billion people by the 1930s, and 6 billion people by the end of the 20th century and is predicted to reach 12.5–14.0 billion people in the 21st and 22nd centuries according to mathematical models [11].

Evolution of the number of connections. Methods to study communications and cooperation. The importance of studies in the field is evident from modern comprehensive investigations of cooperation, information and genetic connections [12], and structural connections in the brain at the neuronal level [13] and is supported by the role that cooperation plays in the development of the human population. An analysis was therefore performed using the available data on the number of connections involved in cooperation in intellectual systems and the information society [14]. It is possible to think that connections and contacts between biological objects emerged with the advent of multicellular organisms ~3.0–3.5 Ga ago [15]. The nervous system, which is a system of high-speed connections between specialized cells that utilize electric signals to transmit information, evolved only in a single large evolutionary lineage, that is, multicellular organisms (Metazoa) in the Ediacaran Period (approximately 635–542 Ma ago) [16].

In 1897, Sherrington [17] coined the term “synapse” based on the Greek συνάψις, which means “a junction” and originates from the Greek συν (together) and άπτειν (to clasp). The number of connections between neurons increased from one to

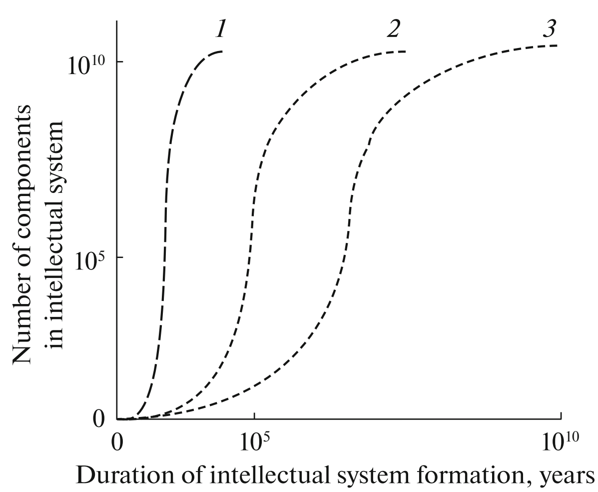

Fig. 2. Evolution of the number of components in intellectual systems: *1*, the number of neurons during individual development (ontogeny) of the brain; *2*, the number of individuals in the human population; and *3*, the number of neurons during the evolutionary development (phylogeny) of the nervous system in organisms.

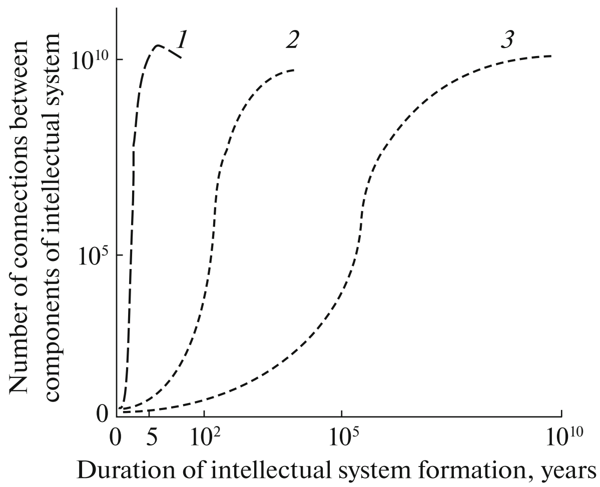

Fig. 3. Evolution of the number of connections in intellectual systems: *1*, the number of synapses between neurons during the individual development (ontogeny) of the human brain; *2*, the number of connections between people during the growth of the human population; and *3*, the number of synapses between neurons during the evolutionary development (phylogeny) of the animal nervous system up to the human brain.

~7000 synaptic connections per neuron with other neurons in the human brain during evolution. Modern physical imaging methods (functional magnetic resonance imaging) made it possible to detect the intense growth of the brain connectome in the human fetus from the 22nd to 37th week of gestation [18]. There are approximately 10^{15} (1 quadrillion) synapses in the brain of a three-year-old child, and this number decreases with age to ~10^{14} in the course of individual development (ontogeny) [19]. According to other estimates, the calculated number of neocortical synapses in the male or female brain decreases from ~1.4×10^{14} to ~1.2×10^{14} during life [20].

Although the number of connections maintained by an individual is difficult to count, Dunbar's number is used in science to describe a suggested cognitive limit to the number of people with whom one can maintain stable social relationships, being ~150 connections of an individual with other people [21]. The range is 100–290 according to other researchers. Structures responsible for social interactions were identified in the brain [22]. Starting from the origin of *H. sapien*s ~50–300 thousand years ago, the importance of cooperation in the human population quantitatively increased during evolution. The human population on Earth was ~0.1 billion people 2000 years ago. ~1 billion people 100 years ago, ~3 billion people in the mid-20th century, and is 8 billion people now. Thus, the total number of stable connections between people, that is, social relationships within the population, is possible to estimate at $150 \times 8 \times 10^9 = {\sim}10^{12}$ (Fig. 3).

Quantitative analogies are possible to infer from Figs. 1–3. Evolution of the intellectual system of the total human population repeats particular features of brain evolution (phylogeny) in the short term and certain characteristics of human brain ontogeny (individual development) in the long term. The repeated features include the growth in the number of components, the number of connections between them, the speed of information exchange, etc. It is possible to consider potential intellectual iterations (from the Latin iteratio, meaning "repetition"), including repetitive actions, such as the formation of the intellectual function in a material series that is uniform in size (human minds), and repetitive events, such as the emergence of intellectual systems in a size series that is higher in the material hierarchy [4].

PROSPECTS OF DETERMINING THE PARAMETERS OF A NATURAL INTELLECTUAL SYSTEM IN BIOPHYSICS

*Homo sapien*s is the only intellectual (sentient) system commonly known from *Systema Natura*e (1735) [23].

A search for parameters of intellectual systems has been carried out from that time to allow a more comprehensive biophysical description and is necessary for further study. It should be noted that the regularities of the origin and parameters of the features have been considered for the human intellectual system in many studies: a working memory span of 7 ± 2 [24], the ability to predict [25], a multilevel (six layers of neurons) hierarchy in systemic selection of valuable information [26], consciousness, memory, the concept of strokes of insight or intuition [27], limits of certain physical parameters of human intelligence [28], etc.

The field is developing intensely, especially with works on several megaprojects (Blue Brain Project, Allen Brain Atlas, Human Connectome Project, and Google Brain), in an attempt to better understand the brain functions and to develop human cognitive functions in the future with the use of artificial intelligence and information, communication, and cognitive technologies [29]. The International Brain Initiative currently combines the national brain initiatives (Brain Initiative, United States: Human Brain Project, European Union; China Brain Project; Japan Brain/MINDS; Canadian Brain Research Strategy; Australian Brain Alliance; and Korea Brain Initiative). The aims are to maintain cooperation between countries and to ensure synergistic interaction with interdisciplinary approaches that originate from recent studies in neurobiology and brain-inspired artificial intelligence [30]. Still many issues are unresolved in neurophysics, including neural coding, the phenomenon of information fusion, the level of simplification in describing the information processing in the brain, calculations by cortical

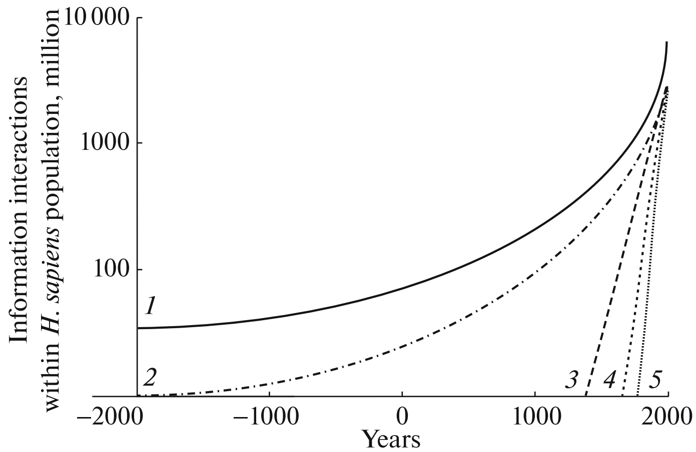

Fig. 4. Development of connections and informational interactions within the *H. sapien*s population: *1*, total global population; *2*, literate global population; *3*, total book readers (with the emergence of book printing); *4*, total radio and TV sets; *5*, total phones, computers, and Internet users.

columns, the exact timing of action potentials to process information in the neocortex, quantitative assessment of long-term memory, etc.

EFFORTS TO EVALUATE THE HYPOTHESIS THAT THE HUMAN POPULATION TENDS TO A GLOBAL BIOTECHNICAL INTELLECTUAL SYSTEM

The hypothesis of tending to a noosphere (following V.I. Vernadsky), global brain, world mind, global intelligence, superintelligence, etc., is not new, but was first mentioned in the early 20th century. However, a commonly accepted theory has not been formed. Several aspects can now beconsidered on the basis of verifiable quantitative parameters and qualitative phenomena. The experiment is rather difficult according to Gödel's concept that the description of a system from within the system can be either discrepant or incomplete.

Qualitative measurements. Initial attempts to estimate the structural and functional parameters can be based on the available data that there are 6 billion TV sets, 6 billion phones, 2 billion computers, 4 billion Internet users (We Are Social, HootSuite, 2018), and 3.2 billion users registered in social media (GlobalWebIndex, 2017) to 7.5 billion people. Evolution of biotechnological connections in the population is shown in Fig. 4.

The annual information production in the human population reached 18×10^{18} bytes (18 exabytes) by the start of the 21st century. Parameters and volumes of information produced by the human population and stored in various media were estimated; the volumes increased annually by 30% over the globe [31] and reached 2.5×10^8 bytes per day (IBM, 2017).

Assessment of the emergence of new qualitative phenomena. Autonomy is characteristic of cognitive systems [32] and consists of the ability to make decisions independently. It is possible to determine the human acts that result from the joint, global, highly intellectual activity of people or characterize the population as a united autonomous system capable of effective rational decisions.

Examples of the global decisions and acts that occurred in the second half of the 20th century and were of global importance include the organization of the UN and its specialized agencies, smallpox eradication via vaccination, peaceful use of nuclear energy, the ban on nuclear and bacteriological weapon tests, space exploration with low Earth orbit flights and flights to the Moon, the Internet, and satellite television [4].

As for the phenomenon of Wikipedia, which was founded in 2001, it should be noted that as early as 1938 the futurist and evolutionary biologist Wells [33] published his essay *World Brain* and described his views of a new free, synthetic, credible, continuously updated, global encyclopedia, which would help global citizens to best use universal information resources. Wikipedia currently has ~300 language versions and includes more than 40 million articles, there are >4 million editors in enWiki only, and the global number of users has reached 6.3 billion. Wikipedia facilitates the spread of new research work and helps researchers that have limited access to scientific journals. Apart from reflecting the current state of sciences, Wikipedia also partly affects further scientific development [34].

Features of the 21st century include responses to global warming; a contract-based balancing of hydrocarbon extraction; resolution of economic recessions;

joint megaprojects aimed at investigating space, the nanoscale world, the atom, and the brain; and the creation of universal artificial intelligence as delineated in national and international strategies [35, 36]. As the COVID-19 pandemics presented a new challenge, the problem was formulated as a choice between "infopandemics or noogenesis" in the hyper-information community and a growth of global collective intelligence [37].

It should be noted in this assessment that eradication of wars, which is an attribute of the noosphere according to V.I. Vernadsky, has not yet been achieved [38]. To be fair, mental disorders and strokes are characteristic of natural intellectual systems.

To summarize the analysis of new qualitative phenomena, humankind currently displays certain signs of rationality, but cannot still be identified as a strictly intellectual system, or "body," from the biophysical viewpoint, rather it is approaching the state of a biotechnical colony or population.

Value and significance of predicting further evolution of intellectual systems. The ability to predict is one of the most valuable features of intelligence [25, 39]. Risks of quantitative and qualitative ups and downs of species are known from biological evolution [40] and are supported by involution and degradation of thousands of extinct species from sponges to dinosaurs.

Many processes are not predetermined in evolution. Progressive variants and bifurcations are therefore possible to predict:

—a prevalent trend of evolution of egoistic individual intelligence with a struggle for survival,

—a prevalent trend of evolution of altruistic collective intelligence of a community, a society, and the total human population with cooperation between their components, and

—joint balanced development of individual-collective intelligence.

*Evolution of individual intelligenc*e may involve not only biological and genetic mechanisms acting to improve brain morphology and functions, bioinformatics, psychotechnology, and noopharmacology. An additional possible way can be described as a briefcase with extra brains, which are understood as tools (organs: widgets and gadgets) that serve to increase the speed of information production and transmission; improve the search for actual knowledge; and ensure efficient coding, compression, and reliable storage of information in necessary volumes.

Evolution of collective biotechnical intellectual systems of a society or humankind. Much depends here on the formation of motivations (instincts and intentions) in people, which form a multicomponent population. The aims of humankind will be clarified and joint efforts will become more efficient when individuals come to understand that joining into a single intellectual system is necessary for counteracting cosmic, planetary, and climatic disasters; taking advantageof collective access resources; controlling the aggressive changes in the atmosphere, lithosphere, and hydrosphere; and preventing lethal challenges imposed by microorganisms of the biosphere.

Further progress at the national level can be expected by achieving the maximal possible population size, providing objective conditions to improve the intelligence of community members, working to maximally supply the population with various high-speed communication systems through the region to ensure the intellectual acceleration of social interactions, developing the connectome among individuals and intellectual energetics, increasing the efficiency of community intelligence, accumulating and using intellectual heritage, taking measures to accumulate and store memory on physical storage media for the long term, improving relevant laws in a highly motivated manner, forming activity-based approaches and engineering tools that are necessary and sufficient for efficiently responding to environmental, microcosm, and macrocosm challenges.

Biophysical interdisciplinary studies could facilitate the understanding of the regularities of mind. Gaining knowledge in the field is similar to understanding quantum physics, the development of the Universe, the origin of life, and biological evolution. The search is mandatory to continue because the results can provide the basis for confidence that intellectual systems will cope with the most unexpected and sometimes dangerous problems that may arise in their development.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The author declares that he has no conflicts of interest.

Statement on the welfare of humans or animals. This work does not contain any studies involving animals or human subjects performed by the author.

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