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The stochastic organization of genomes and the doctrine of energy-information evolution based on bio-antenna arrays

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A B S T R A C T

The article is devoted to the possibilities of considering the evolution of biological systems in connection with the unique emergent properties of antenna arrays, that is, systems of mutually matched antennas widely used in technology. Materials are presented in favor of the proposition that the evolution of biosystems can be formally considered as the evolution of systems of bio-antenna arrays and their energy-information wave activity, which participates in biological computation and contributes to the unification of body parts into a coherent whole. The use of digital antenna arrays in technology is based on their tensor-matrix theory. The author discovers a structural analogy of this theory with the tensor-matrix features of genetic coding systems, as well as algebraic modeling of the universal rules for the stochastic DNA organization of the genomes of higher and lower organisms. This analogy is just one of the facts presented in the article in favor of the usefulness of borrowing knowledge from modern antenna technology to consider the evolution of biosystems. The described new approach may exist along with other known approaches in evolutionary biology.

1. Introduction

The development of evolutionary biology takes into account the progress in other scientific fields to use their achievements to better understand and model biological phenomena. In our time, special attention is paid to the possibilities of using in evolutionary biology the achievements of mathematical natural science and informatics, for example, from the fields of noise-immune coding and information transmission, physical fields theory, holography, quantum informatics, etc. One of the rapidly developing scientific and technical areas is the theory of digital antenna arrays, which has extensive applications: medical ultrasound scanning technology (on multichannel platforms with digital emitter arrays), sonar systems, seismographs, meteorological instruments, radio relay stations, avionics, radio astronomic devices, etc. The formation of these applications is accompanied by the intensive development of new computational methods. Let us clarify that in this article the term “antenna” is used in a broad sense to refer to devices that emit or receive physical waves, primarily of an electromagnetic and mechanical nature (hydroacoustic sonars are included in this interpretation of the term “antennas").

Antenna arrays coordinately combine many individual antennas into a single system - from a few antennas to many thousands of antennas (Fig. 1). The emergent properties of such systems provide their amazing functionality, which far exceeds the capabilities of individual antennas and causes humanity to saturate and envelop the Earth with millions of antenna arrays. The spatial configuration and dimensions of antenna arrays can be very different, but they all operate on a matched emission and reception of electromagnetic and other waves by separate antennas in their composition. The chemical and structural composition of antenna arrays can also be different and include, among other things, photonic crystals and liquid crystals, examples of which are abundant in living bodies. Modern science sees great prospects with nanoantennas, which are expected to lead to revolutionary changes in computer technology (photonics) and energy (efficient use of solar energy) [Krasnok et al., 2013; Slyusar, 2009; Zaitsev, 2011]. Nanoantennas are one of the elements needed to create quantum computers. Nanoantenna arrays make it possible to create wireless networks on a chip, including for systems on a chip as biological sensors that provide contactless remote data transmission [Slyusar, 2011]. The topic of nanoantennas and nanoantenna arrays seems to be especially important for biology due to the small size of genetic and cellular structures, communication between the parts of which takes place, including with the participation of electromagnetic waves (photons).

The theme of radiation and reception of electromagnetic and other waves by biological objects has long been of interest to science. One of the many examples is the study of mitogenetic radiation, discovered in

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Fig. 1. Examples of engineering antenna arrays (taken from https://commons.wikimedia.org/wiki/File:PAK_FA_AESA_maks2009.jpg and https://commons.wikimedia.org/wiki/File:Traqueur_acquisition.JPG, permission is granted to distribute these images under the terms of the GNU Free Documentation License).

1923 by A.G. Gurwitch [Beloussov et al., 2007; Popp, 1995; Voeikov, 2003; Volodyaev and Beloussov, 2015]. This radiation is associated with ultraviolet radiation [Frank, 1982]. It is characterized by a high orientation, discovered by Gurwitch himself and confirmed by additional experiments in [Inyushin and Chekurov, 1975].

Nanoantennas based on DNA are already used in scientific technologies: Canadian scientists have created glowing nanoantennas from DNA molecules to track the relationships within proteins. These nanoantennas are capable of fluorescence and can absorb radiation at one wavelength and emit light at a different frequency depending on the molecular environment [Harroun et al., 2022]. This antenna is 5 nm long and is the smallest antenna ever made. It can be assumed that humanity is entering the era of the technological use of biomolecular antennas.

The importance of antenna arrays in different technical fields has led to the intensive development of the mathematical theory of transmitting and receiving antenna arrays of various types, which is presented in many publications [Slyusar, 1999, 2021, etc.]. This developing mathematical theory provides, in particular, new, previously unknown approaches in the matrix-tensor analysis of complex systems not only for antenna arrays technology but also for mathematical natural science [Minochkin et al., 2011]. The mathematical description of the operation of engineering antenna arrays, operating to emit or receive waves, is almost the same. The concept of antenna arrays with its special computational methods is essential for the concept of biological computation since electromagnetic waves are capable of transmitting information in the course of biological computing, as noted in the works [Liberman, 1979, 2022; Minina and Shklovskiy-Kordi, 2022; Shklovskiy-Kordi and Igamberdiev, 2022].

This article aims to show the expediency of taking into account the factor of amazing emergent properties of antenna arrays in problems of evolutionary biology.

The article is based, in particular, on the results previously published by the author on the universal rules of stochastic organization of genomic DNAs, discovered through matrix analysis of nucleotide sequences in single-stranded DNAs of eukaryotic and prokaryotic genomes [Petoukhov, 2019, 2020a-c, 2021a,b]. The formalisms of algebra-matrix representations of these universal rules of genomes drew the author's attention to their analogy with the formalisms of the tensor-matrix theory of digital antenna arrays [Slyusar, 1999, 2021]. This particular analogy led to a general question about the possible existence of analogies between inherited physiological systems, which use photonic and other wave interrelations, and the amazing emergent properties of antenna arrays. It seems natural to assume that biological evolution has not passed by these emergent properties of antenna arrays, which have conquered the modern technology of remote interconnection and sense of the surrounding space. But in the scientific literature, it was not possible to find a single publication that would connect biological phenomena with the emergent properties of antenna arrays. Filling this gap, the author has studied and identified many heritable biological structures associated with the idea of bio-antenna arrays and their wave activity. The totality of these materials is the content of the "doctrine of energy-information evolution based on bio-antenna arrays", whose beginnings and arguments are outlined below.

2. Algebra-matrix modeling of universal rules of the stochastic organization of genomic DNAs

Genetics as a science began with Mendel's discovery of the stochastic rules of inheritance of traits in experiments on the crossing of organisms. Many processes in living bodies are stochastic. The well-known expressions "gene noise" or "cell noise" reflect the fact that even genetically identical cells within the same tissue exhibit different levels of protein expression, different sizes, and structures due to the stochastic nature of interactions of individual molecules in cells.

The stochastic nature of genetic processes in the "small" does not interfere with the inheritance of the traits determined in the "big". For example, fingerprints are different for all people, although fingers generally have a typical shape and composition (3 phalanges, nails, etc.). There are many inherited physiological phenomena, that existed in psychology, morphogenesis, metabolic processes, homeostasis, biomechanics of movements, and other physiological branches, in which stable holistic patterns are formed regardless of the variability of their constituent parts; such phenomena are united by a conditional term "Gestalt-biology" [Petoukhov, 2021c,b].

According to Mendel's law of independent inheritance of traits, information from the level of DNA molecules dictates the macrostructure of living bodies through many independent channels, despite strong noises. Thus, hair, eye, and skin colors are inherited independently of each other. Accordingly, each organism is a machine of multichannel noise-immunity encoding.

Protein systems of all physiological systems are genetically inherited by the next generations through their genetic coding. Therefore, one should look for the origins of inherited gestalt phenomena of physiology in DNA informatics, which is connected with Mendel's laws. The author discovered that already in the information system of DNAs of genomes of eukaryotes and prokaryotes, universal gestalt phenomena of their stochastic organization are embedded [Petoukhov, 2021a-c]. Let us remind this by using stochastic data of the single-stranded DNA sequence of human chromosome #1, which contains about 250 million nucleotides and is presented in the GenBank (https://www.ncbi.nlm.nih.gov/nuccore/NC_000001.11).

Any DNA sequence can be considered from the point of view of different DNA alphabets: the alphabet of 4 nucleotides - cytosine C, adenine A, thymine T, and guanine G; the alphabet of 16 duplets; the alphabet of 64 triplets; the alphabet of 256 tetraplets, etc. It allows representing any long DNA sequence in the form of multilayered texts, in which each nth layer is a sequence of n-plets (or oligomers of fixed length n); in other words, each nth layer is a separate DNA text written in its alphabet of 4^n n-plets. For example, in the sequence ACCTGTAACG …, the first layer is a text, which is based on the alphabet of 4 nucleotides (A-C-C-C-T-G- …), and the second layer is a text, which is based on the alphabet of 16 doublets (AC-CT-GT-AA-CG- …), the third is a text, which is based on the alphabet of 64 triplets (ACC-TGT-AAC- …), etc.

Calculating in the mentioned DNA the percentages of each member of the DNA alphabet of 4 nucleotides (%C,%A,%T, %G), we obtain a table of their probabilities (Fig. 2, the first row). Then we represent the same DNA as a text of two-letter words (such as CA-TT-GA-) based on the alphabet of 16 duplets and, calculating the percentage of each of the types of duplets, we get a table of percentages of 16 types of duplets (Fig. 2, the second row). Similarly, presenting the same DNA as a text of three-letter words based on the alphabet of 64 triplets, we obtain the table of percentages of 64 triplets in this text (Fig. 3). This procedure can be prolonged for higher values of n, but for this article, it is enough considering n = 1, 2, 3; a similar table for percentages of 256 tetraplets

	0	1
0	%C	%A
1	%T	%G

→ $P_1 =$

	0	1
0	0.208499	0.291001
1	0.291756	0.208744

	00	01	10	11
00	%CC	%CA	%AC	%AA
01	%CT	%CG	%AT	%AG
10	%TC	%TA	%GC	%GA
11	%TT	%TG	%GT	%GG

→ $P_2 =$

	00	01	10	11
00	0.054090	0.072739	0.050327	0.095037
01	0.071341	0.010305	0.074290	0.071368
10	0.060080	0.063123	0.044024	0.060083
11	0.095680	0.072859	0.050459	0.054195

Fig. 2. The left matrices contain percentage symbols of 4 monoplets and 16 duplets. The right matrices $\mathbf{P_1}$ and $\mathbf{P_2}$ show percentage values of all monoplets and duplets correspondingly in the 1-text and 2-text representations of the DNA nucleotide sequence of human chromosome N°1.

	000	001	010	011	100	101	110	111
000	%CCC	%CCA	%CAC	%CAA	%ACC	%ACA	%AAC	%AAA
001	%CCT	%CCG	%CAT	%CAG	%ACT	%ACG	%AAT	%AAG
010	%CTC	%CTA	%CGC	%CGA	%ATC	%ATA	%AGC	%AGA
011	%CTT	%CTG	%CGT	%CGG	%ATT	%ATG	%AGT	%AGG
100	%TCC	%TCA	%TAC	%TAA	%GCC	%GCA	%GAC	%GAA
101	%TCT	%TCG	%TAT	%TAG	%GCT	%GCG	%GAT	%GAG
110	%TTC	%TTA	%TGC	%TGA	%GTC	%GTA	%GGC	%GGA
111	%TTT	%TTG	%TGT	%TGG	%GTT	%GTG	%GGT	%GGG

→

$P_3 =$

	000	001	010	011	100	101	110	111
000	0.013845	0.018782	0.015236	0.018615	0.011825	0.019768	0.014466	0.036928
001	0.018532	0.002906	0.017889	0.021037	0.016224	0.002537	0.023753	0.019875
010	0.017584	0.012749	0.002508	0.002272	0.013175	0.019420	0.014406	0.022369
011	0.020088	0.020880	0.002591	0.002911	0.023881	0.017807	0.016136	0.018480
100	0.015877	0.019642	0.011031	0.019859	0.012545	0.014563	0.009615	0.019596
101	0.022258	0.002330	0.019392	0.012844	0.014374	0.002531	0.013271	0.017560
110	0.019724	0.019810	0.014573	0.019469	0.009561	0.011152	0.012560	0.015998
111	0.037246	0.018843	0.019881	0.018954	0.014452	0.015337	0.011855	0.013822

Fig. 3. The upper matrix contains percentage symbols of 64 triplets. The bottom matrix $\mathbf{P_3}$ shows percentage values of all triplets in the 3-text representation of the DNA nucleotide sequence of human chromosome N°1.

in this DNA as a text of four-letter words is shown in the preprint [Petoukhov, 2022].

One should say that a structure of the matrices, representing percentages of n-plets in Figs. 2 and 3, is built by a known principle of representation of DNA alphabets of 4 monoplets, 16 duplets, 64 triplets, etc, as members of the single tensor family of matrices $[C, A; T, G]^{(n)}$, where (n) refers to a tensor power [Petoukhov, 2008; Petoukhov, 2016; Petoukhov and He, 2010]. The columns and rows of these matrices of DNA alphabets are enumerated by binary numbers based on the following binary-oppositional molecular features of nucleotides: the columns are numbered due to binary indicators “pyrimidine-or-purine” (C = T = 0, A = G = 1), and the rows are numbered due to binary indicators “amino-or-keto” (C = A = 0, T = G = 1). For example, the triplet CAT belongs to column number 010 and row number 001, since its nucleotide sequence in terms of these indicators is: “pyrimidine-purine-pyrimidine” and “amino-amino-keto”. It should be emphasized that - by contrast to the matrices of DNA alphabets – the percentage matrices of n-plets in Figs. 2 and 3 are not members of a tensor family of percentage matrices $[\%C, \%A; \%T, \%G]^{(n)}$ at all. Comparative analysis of hidden algebraic interconnections of these phenomenological percentage matrices has led to revealing universal rules of stochastic organization of genomic DNAs [Petoukhov, 2021c,b].

At first glance, the sets of values in the percentage matrices (Figs. 2 and 3) are quite chaotic and the percentage matrices have no numeric interrelations. They have the following features regarding the percent of separate *n*-plets:

- The percentage of individual n-plets is not equal to the product of the percentages of their constituent nucleotides. For example, %CG = 0.0103 is not equal to %C*%G = 0.2085*0.2087 = 0.0435;
- Percent of *n*-plets significantly depends on the order of letters in them. For example, the percent of doublets CG and GC, having the same letter composition, differ several times: %CG = 0.0103, and % GC = 0.0440.

But in this seeming chaos, there are many universal rules for n-plet groupings that are valid for all genomes, which were studied by the author. For example, special n-plet groupings in percentages matrices of probabilities for different n-texts of the DNA are numerically interrelated (1): knowing the percentage of a nucleotide in genomic DNA, it is possible to predict with high accuracy the sums of the percentages of 4 duplets, 16 triplets, 64 tetraplets with this nucleotide at fixed positions in the duplet-, triplet- and tetraplet-representations of the genomic DNA sequence though the number of summands and their values are different in these sums [Petoukhov, 2021c,b]:

$$\%C \cdot \approx \cdot \sum \%CN \cdot \approx \cdot \sum \%NC \cdot \approx \cdot \sum \%CNN \cdot \approx \cdot \sum \%NCN \cdot \approx \cdot \sum \%NNC \cdot \approx \cdot$$

$$\sum \%CNNN \cdot \approx \cdot \sum \%NCNN \cdot \approx \cdot \sum \%NNCN \cdot \approx \cdot \sum \%NNNC \cdot \approx \cdot 0.2085;$$

$$\%G \cdot \approx \cdot \sum \%GN \cdot \approx \cdot \sum \%NG \cdot \approx \cdot \sum \%GNN \cdot \approx \cdot \sum \%NGN \cdot \approx \cdot \sum \%NNG \cdot \approx \cdot$$

$$\sum \%GNNN \cdot \approx \cdot \sum \%NGNN \cdot \approx \cdot \sum \%NNGN \cdot \approx \cdot \sum \%NNNG \cdot \approx \cdot 0.2087;$$

$$\%A \cdot \approx \cdot \sum \%AN \cdot \approx \cdot \sum \%NA \cdot \approx \cdot \sum \%ANN \cdot \approx \cdot \sum \%NAN \cdot \approx \cdot \sum \%NNA \cdot \approx \cdot$$

$$\sum \%ANNN \cdot \approx \cdot \sum \%NANN \cdot \approx \cdot \sum \%NNAN \cdot \approx \cdot \sum \%NNNA \cdot \approx \cdot 0.2910;$$

$$\%T \cdot \approx \cdot \sum \%TN \cdot \approx \cdot \sum \%NT \cdot \approx \cdot \sum \%TNN \cdot \approx \cdot \sum \%NTN \cdot \approx \cdot \sum \%NNT \cdot \approx \cdot$$

$$\sum \%TNNN \cdot \approx \cdot \sum \%NTNN \cdot \approx \cdot \sum \%NNTN \cdot \approx \cdot \sum \%NNNT \cdot \approx \cdot 0.2918; \quad (1)$$

In the expression (1), N symbolizes any of nucleotides C, A, T, G; Σ%CN = %CC+%CA+%CT+%CG, Σ%NC = %CC+%AC+%TC+%GC, etc.

This constancy of sums of probabilities of n-plets under conditions of different values and numbers of summands is one of the types of the revealed Gestalt rules of probabilities in genomic DNAs. Similar Gestalt rules of probabilities were revealed for all other eukaryotic and prokaryotic genomes, which were analyzed by the author till now, including the following: all 24 human chromosomes, which differ in their length, the number, and type of genes, etc.; all chromosomes of a fruit fly *Drosophila melanogaster*; all chromosomes of a house mouse *Mus musculus*; all chromosomes of a nematode *Caenorhabditis elegans*; all chromosomes of a plant *Arabidopsis thaliana*, and many other plants; 19 bacterial genomes of different groups both from Bacteria and Archaea.

But are there meaningful algebra-matrix relationships of a typical kind between the phenomenological probability matrices P_1, P_2, and P_3 (Figs. 2 and 3)? Yes, such relationships exist and their expressions use algebra-matrix operations, which are used in the theory of digital antenna arrays and quantum computing. Their revelation is one of the arguments in favor of structural connections of inherited physiological systems with emergent properties of antenna arrays and quantum computing. Let us explain this.

3. The Hadamard product of matrices and stochasticity of genomic DNAs

The author revealed that the desired expressions for the algebraic relationship between the probability matrices (Figs. 2 and 3) for genomic DNAs use the well-known operation of the Hadamard product of matrices. The Hadamard product (also known as the element-wise product, entrywise product, or Schur product [Horn and Johnson, 2012]) is a binary operation that takes two matrices of the same dimensions and produces another matrix of the same dimension as the operands, where each element *i, j* is the product of elements *i, j* of the original two matrices. In other words, for two matrices *A* and *B* of the same dimension $m \times n$, the Hadamard product *AOB* is a matrix of the same dimension as the operands, with elements given by $(AOB)_{ij} = (A)_{ij}(B)_{ij}$. The symbol O denotes the Hadamard product. The Hadamard product is a principal submatrix of the tensor (or Kronecker) product [Gunther and Klotz, 2012]. Fig. 4 shows an example of the Hadamard product for two matrices, one of which is a simple (2*2)-matrix and the second one is a block (4*4)-matrix, whose blocks are (2*2)-matrices, denoted by bold frames. This type of Hadamard product with block matrices is used below.

Such Hadamard product from Fig. 4 allows producing a general form of interconnection between any probability (2*2)-matrix for 4 monoplets and any probability (4*4)-matrix for 16 duplets (Fig. 5).

But phenomenological probability matrices of 4 monoplets and 16 duplets in genomic DNAs correspond to a very particular case of the general form in Fig. 5 since these probabilities obey the universal rules of stochastic organization of genomic DNAs including the following phenomenological equation (2), which are fulfilled with high accuracy:

$$\%C \cdot \approx \cdot \%CC + \%CA + \%CT + \%CG \rightarrow (\%CC + \%CA + \%CT + \%CG) \ / \ \%C \cdot \approx \cdot 1$$

$$\%A \cdot \approx \cdot \%AC + \%AA + \%AT + \%AG \rightarrow (\%AC + \%AA + \%AT + \%AG) \ / \ \%A \cdot \approx \cdot 1$$

$$\%T \cdot \approx \cdot \%TC + \%TA + \%TT + \%TG \rightarrow (\%TC + \%TA + \%TT + \%TG) \ / \ \%T \cdot \approx \cdot 1$$

$$\%G \cdot \approx \cdot \%GC + \%GA + \%GT + \%GG \rightarrow (\%GC + \%GA + \%GT + \%GG) \ / \ \%G \cdot \approx \cdot 1 \quad (2)$$

For each of the genomic DNAs, due to (2), each of the four (2*2)-blocks inside the (4*4)-matrix in the left part of the equation in Fig. 5 has a phenomenological feature: the sum of its 4 entries is equal to 1 with high accuracy (this feature holds for long single-stranded DNAs but it doesn't hold for relative short DNA sequences). These four (2*2)-blocks are called « tetra-multiplying matrices » since they provide the phenomenologic connections of each of the 4 monoplets with corresponding 4 duplets via their percentage values in line with (2). Briefly mention that the phenomenological feature of the unity sums allows an additional possibility to use formalisms of quantum informatics for modeling genomic stochasticity as it is shown in the preprint [Petoukhov, 2022].

Fig. 6 presents a transformation of the symbolic equality in Fig. 5 into the corresponding numeric equality for the case of the DNA of human chromosome #1 and its probability matrices P_1 and P_2 shown in Fig. 2. One can check that sum of entries of each of the 4 tetra-multiplying matrices in Fig. 6 is equal to 1 with high accuracy.

Let us now turn to an algebraic expression of the relationship between the percentage (4*4)-matrix P_2 of 16 duplets (Fig. 2) and the percentage (8*8)-matrix P_3 of 64 triplets (Fig. 3). Fig. 7 presents this

$$\begin{bmatrix} a_{00} & a_{01} \\ a_{10} & a_{11} \end{bmatrix} \circ \begin{bmatrix} b_{00} & b_{01} & c_{00} & c_{01} \\ b_{10} & b_{11} & c_{10} & c_{11} \\ d_{00} & d_{01} & e_{00} & e_{01} \\ d_{10} & d_{11} & e_{10} & e_{11} \end{bmatrix} = \begin{bmatrix} a_{00}b_{00} & a_{00}b_{01} & a_{01}c_{00} & a_{01}c_{01} \\ a_{00}b_{10} & a_{00}b_{11} & a_{01}c_{10} & a_{01}c_{11} \\ a_{10}d_{00} & a_{10}d_{01} & a_{11}e_{00} & a_{11}e_{01} \\ a_{10}d_{10} & a_{10}d_{11} & a_{11}e_{10} & a_{11}e_{11} \end{bmatrix}$$

Fig. 4. The Hadamard product for two matrices, one of which is a simple (2*2)-matrix and the second one is a block (4*4)-matrix, generates a (4*4)-matrix with combined entries.

%C	%A
%T	%G

∘

(%CC) / (%C)	(%CA) / (%C)	(%AC) / (%A)	(%AA) / (%A)
(%CT) / (%C)	(%CG) / (%C)	(%AT) / (%A)	(%AG) / (%A)
(%TC) / (%T)	(%TA) / (%T)	(%GC) / (%G)	(%GA) / (%G)
(%TT) / (%T)	(%TG) / (%T)	(%GT) / (%G)	(%GG) / (%G)

=

%CC	%CA	%AC	%AA
%CT	%CG	%AT	%AG
%TC	%TA	%GC	%GA
%TT	%TG	%GT	%GG

Fig. 5. A general form of interconnection between any probability (2*2)-matrix for 4 monoplets and any probability (4*4)-matrix for 16 duplets (Fig. 5).

0.208499	0.291001
0.291756	0.208744

∘

0.259426	0.34887	0.172944	0.326587
0.342165	0.04943	0.255291	0.245250
0.205925	0.216355	0.210899	0.287831
0.327945	0.249726	0.241727	0.259624

=

0.054090	0.072739	0.050327	0.095037
0.071341	0.010305	0.074290	0.071368
0.060080	0.063123	0.044024	0.060083
0.095680	0.072859	0.050459	0.054195

Fig. 6. The algebra-matrix interconnection between the probability (2*2)-matrix P_1 and the probability (4*4)-matrix P_2 (Fig. 2) in the case of DNA of human chromosome #1. All numbers are rounded to 6 decimal places.

%CC	%CA	%AC	%AA
%CT	%CG	%AC	%AG
%TC	%TA	%GC	%GA
%TT	%TG	%GT	%GG

∘

B_{CC}	B_{CA}	B_{AC}	B_{AA}
B_{CT}	B_{CG}	B_{AT}	B_{AG}
B_{TC}	B_{TA}	B_{GC}	B_{GA}
B_{TT}	B_{TG}	B_{GT}	B_{GG}

=

%CCC	%CCA	%CAC	%CAA	%ACC	%ACA	%AAC	%AAA
%CCT	%CCG	%CAT	%CAG	%ACT	%ACG	%AAT	%AAG
%CTC	%CTA	%CGC	%CGA	%ATC	%ATA	%AGC	%AGA
%CTT	%CTG	%CGT	%CGG	%ATT	%ATG	%AGT	%AGG
%TCC	%TCA	%TAC	%TAA	%GCC	%GCA	%GAC	%GAA
%TCT	%TCG	%TAT	%TAG	%GCT	%GCG	%GAT	%GAG
%TTC	%TTA	%TGC	%TGA	%GTC	%GTA	%GGC	%GGA
%TTT	%TTG	%TGT	%TGG	%GTT	%GTG	%GGT	%GGG

Fig. 7. Representation of the 64-triplet probability matrix (shown at bottom) via the Hadamard product of the 16-duplet probability (4*4)-matrix with the block (4*4)-matrix, whose 16 entries B_{CC}, B_{CA}, B_{CG}, B_{CG}, B_{AC}, B_{AA}, B_{AT}, B_{AG}, B_{CC}, B_{CA}, B_{CT}, B_{CG}, B_{GC}, B_{GA}, B_{GT}, B_{GG} are tetra-multiplicating (2*2)-matrices shown in Fig. 8.

desired expression, some components of which are shown below in Fig. 8; it uses the Hadamard product by analogy with the previous case in Figs. 5 and 6.

Fig. 8 shows - in a general symbolic form - 16 tetra-multiplicating (2*2)-matrices, which participate in the equality in Fig. 7. Their entries are equal to ratios of percentages of corresponding triplets and duplets.

In genomic DNAs, each of these 16 matrices (Fig. 7) obeys the same rule of unity sum of its 4 entries in line with the universal rules of genomic stochasticity (1). For a particular case of DNA of human chromosome #1, numeric expressions of these matrices one can see in the preprint [Petoukhov, 2022, Fig. 2.7]. Such chain of algebraic equalities - using the Hadamard product like in Figs. 5 and 7 - between the percentage (2^n*2^n)-matrices of n-plets and the percentage $(2^{n+1}*2^{n+1})$-matrices of (n+1)-plets can be continued by analogy for cases n = 4, 5, 6, …(but n should be much smaller the length of genomic DNA).

It should be additionally noted that the same matrix equalities based on the Hadamard product of matrices (like in Figs. 5 and 7) are appropriate for the stochastic organization of n-texts in so-called epi-chains of

$$B_{CC} = \begin{bmatrix} \%CCC/\%CC & \%CCA/\%CC \\ \%CCT/\%CC & \%CCG/\%CC \end{bmatrix} \; ; \; B_{CA} = \begin{bmatrix} \%CAC/\%CA & \%CAA/\%CA \\ \%CAT/\%CA & \%CAG/\%CA \end{bmatrix}$$

$$B_{AC} = \begin{bmatrix} \%ACC/\%AC & \%ACA/\%AC \\ \%ACT/\%AC & \%ACG/\%AC \end{bmatrix} \; ; \; B_{AA} = \begin{bmatrix} \%AAC/\%AA & \%AAA/\%AA \\ \%AAT/\%AA & \%AAG/\%AA \end{bmatrix}$$

$$B_{CT} = \begin{bmatrix} \%CTC/\%CT & \%CTA/\%CT \\ \%CTT/\%CT & \%CTG/\%CT \end{bmatrix} \; ; \; B_{CG} = \begin{bmatrix} \%CGC/\%CG & \%CGA/\%CG \\ \%CGT/\%CG & \%CGG/\%CG \end{bmatrix}$$

$$B_{AT} = \begin{bmatrix} \%ATC/\%AT & \%ATA/\%AT \\ \%ATT/\%AT & \%ATG/\%AT \end{bmatrix} \; ; \; B_{AG} = \begin{bmatrix} \%AGC/\%AG & \%AGA/\%AG \\ \%AGT/\%AG & \%AGG/\%AG \end{bmatrix}$$

$$B_{TC} = \begin{bmatrix} \%TCC/\%TC & \%TCA/\%TC \\ \%TCT/\%TC & \%TCG/\%TC \end{bmatrix} \; ; \; B_{TA} = \begin{bmatrix} \%TAC/\%TA & \%TAA/\%TA \\ \%TAT/\%TA & \%TAG/\%TA \end{bmatrix}$$

$$B_{GC} = \begin{bmatrix} \%GCC/\%GC & \%GCA/\%GC \\ \%GCT/\%GC & \%GCG/\%GC \end{bmatrix} \; ; \; B_{GA} = \begin{bmatrix} \%GAC/\%GA & \%GAA/\%GA \\ \%GAT/\%GA & \%GAG/\%GA \end{bmatrix}$$

$$B_{TT} = \begin{bmatrix} \%TTC/\%TT & \%TTA/\%TT \\ \%TTT/\%TT & \%TTG/\%TT \end{bmatrix} \; ; \; B_{TG} = \begin{bmatrix} \%TGC/\%TG & \%TGA/\%TG \\ \%TGT/\%TG & \%TGG/\%TG \end{bmatrix}$$

$$B_{GT} = \begin{bmatrix} \%GTC/\%GT & \%GTA/\%GT \\ \%GTT/\%GT & \%GTG/\%GT \end{bmatrix} \; ; \; B_{GG} = \begin{bmatrix} \%GGC/\%GG & \%GGA/\%GG \\ \%GGT/\%GG & \%GGG/\%GG \end{bmatrix}$$

Fig. 8. 16 symbolic tetra-multiplicating matrices participating in the desired equality in Fig. 7 whose entries are equal to ratios of percent of corresponding triplets and duplets.

genomic DNAs; the study of epi-chains gave pieces of evidence regarding the fractal-like stochastic organization of genomic DNAs [Petoukhov, 2019; 2021a]. By definition, in a nucleotide sequence N_1 of any DNA strand N_1 (Fig. 2.10a in [Petoukhov, 2022]) with sequentially numbered nucleotides 1, 2, 3, 4, …, epi-chains of different orders k are such sparse subsequences that contain only those nucleotides, whose numeration differ from each other by natural number $k = 1, 2, 3, 4, \ldots$

4. The doctrine of energy-information evolution based on bio-antenna arrays and their wave functioning

The method of revealing analogies is one of the basic methods of development of sciences, where it plays an important heuristic role, as it is known at least from the time of B.Bolzano. Max Planck wrote: «*We thus find that it is a characteristic of every new idea occurring in science that it combines in a certain original manner two distinct series of facts*» [Planck, 1936].

The author initially drew attention to the unexpected analogies in the effective matrix-tensor modeling of structures in two different areas, which had previously been developed in science completely independently of each other:

1) matrix genetics, long developed by the author, taking into account the formalisms of quantum mechanics and quantum informatics, which are fruitfully used to analyze systems of molecular genetics and their relationships with inherited physiological structures [Petoukhov, 2008, 2020c; Petoukhov et al., 2019; Fimmel and Petoukhov, 2020; Petoukhov, 2016]. In matrix genetics, it was recently revealed that universal rules of stochastic organization of genomic DNAs are connected with the Hadamard product of matrices, which are effectively used in the theory of digital antenna arrays [Petoukhov, 2022];
2) the tensor-matrix theory of digital antenna arrays, where essential using the Hadamard product for matrices provides a huge profit in calculations and synthesis of high-effective antenna arrays [Slyusar, 1999; Minochkin et al., 2011, p. 442].

These analogies led to the general author's hypothesis about biological evolution based on antenna arrays. The hypothesis seems to be useful for joint studying - from a single source platform - the features of the genetic system and physiological structures, inherited from generation to generation. The materials of the study, which support this hypothesis about using emergent properties of antenna arrays in inherited biostructures, are united by the author under the conditional name "doctrine of energy-information evolution based on bio-antenna arrays". From the point of view of this doctrine, DNA informatics uses molecular bio-antenna arrays, whose wave functioning is coordinated with other genetically inherited physiological bio-antenna arrays providing in living bodies many hereditary physiological structures and processes related to emission and absorption of wave energy and signals: compound faceted eyes in insects; inherited photonic-crystal arrays determining species patterns on butterfly wings and other animal bodies; the innate ability to echolocation and electrolocation in animals; and others. The author believes that these inherited functional abilities and macroscopic structures do not arise from scratch, but are, to a certain extent, a continuation of the emergent properties of molecular genetic systems. The study and modeling of these emergent properties is an important task.

In his book "What is Life?", Schrodinger made the auspicious proposal that the genetic material is an "aperiodic crystal" [Schrödinger, 1944; Ball, 2018]. The described author's doctrine of energy-informational evolution continues this line of thought but significantly supplements it with the provision of the key role of bio-antenna arrays and their wave functioning. The doctrine proposes to consider DNA and RNA as a germinal aperiodic crystal of bio-antenna arrays, which serves as a crystallization seed for the aperiodic crystallization of the entire developing organism as a huge growing set of bio-antenna arrays interrelated with each other. The processes of this aperiodic crystallization of the inherited body can be modified under the influence of the environment, nutritional conditions, stages of onto- and phylogenetic development, etc. The functioning of these developing bio-antenna arrays is accompanied by exchanges of wave energy and signals among physiological subsystems and external sources and also by related processes of biological self-organization with the participation of resonances mechanisms and principles of energy minimization. The doctrine considers bio-antenna arrays and their wave functioning as the possible key element of energy-information evolution, which deserve special attention and study.

To explain why the phenomena of digital antenna arrays can be useful in understanding biological evolution, let us recall the main emergent properties of antenna arrays as systems of coordinated individual antennas.

4.1. Emergent properties of digital antenna arrays

Emergent properties of systems of elements are called properties that the constituent elements do not have individually. Antenna arrays are used to provide such kinds of radiation patterns (or beamforming), which are unable for a single antenna element. Let's list some of them in line with the book [Voskresensky et al., 2006]:

- An array of N elements allows to increase approximately N times the directivity and, accordingly, the gain of the antenna compared to a single radiator, as well as to narrow the beam to improve the accuracy of determining the angular coordinates of the radiation source in navigation, radar, and other radio systems. With the help of antenna arrays, it is possible to raise the dielectric strength of the antenna and increase the level of radiated (or received) power;
- Antenna arrays are a unique tool for providing communication noise-immunity and extracting a weak signal from a strong noise. For this reason, they are used, for example, in satellite communications technology in navigation satellite systems GPS, GLONASS, and Galileo [Ryapolov and Fambulov, 2018]. This special property of antenna arrays is especially important for understanding the well-known phenomenal ability of organisms to work with weak information signals against a background of strong noise, providing communication noise immunity. The same property of antenna arrays allows us to rethink the amazing noise immunity of genetic coding, as well as the multichannel nature of genetic inheritance, expressed by Mendel's law of independent inheritance of traits mentioned above;
- An important advantage of antenna arrays is the ability to quickly (inertialess) survey space by swinging the beam or swinging the antenna by electrical methods (electrical scanning), as well as the possibility of parallel using many beams with their operating at different frequencies and other characteristics. The antenna system is a necessary link to ensure the noise immunity of the radio system, taking into account adaptation to the interference environment.

Given these unique emergent properties of antenna arrays, it can be expected that organisms be forced to use them in their life activity. The doctrine stated in this article confirms this expectation on a set of examples of the structure and functioning of inherited physiological systems based on antenna arrays and their energy wave. Let us continue the theme of features of antenna arrays.

An important class of antenna arrays is phased antenna arrays capable of operating with multi-beam radiation patterns (Fig. 9). A phased array usually means an electronically scanned and computer-controlled array of antennas, which creates a beam of radio waves that can be electronically steered to point in different directions without moving the antennas [Milligan, 2005; Stutzman and Thiele, 2012].

In simple antenna arrays, the radiofrequency current from the transmitter is fed to the individual antenna elements with a differential phase relationship so that the energy from the separate elements adds together to increase the far-field power in the desired direction and suppress radiation in undesired directions (due to wave interference). In other words, the specificity of a phased array antenna is that the amplitude-phase distribution among elements is not fixed, it can be adjusted (changed in a controlled manner) during operation. Thanks to this, it is possible to move the beams of the antenna array in certain sectors of space without mechanical rotations of the antenna. Since the size of an antenna array must extend many wavelengths to achieve high gain, phased arrays are mainly practical at the high-frequency end of the radio spectrum (usually between 300 MHz and 300 GHz). Phased arrays have spread to civilian applications such as 5G MIMO for cell phones.

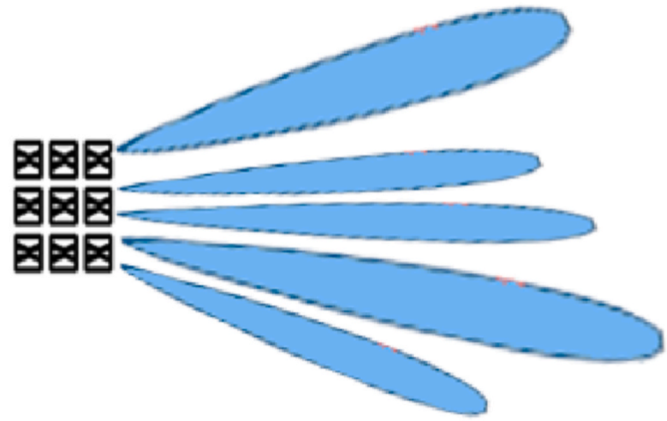


Fig. 9. A conditional radiation pattern of a multibeam digital antenna array.

The operation of antenna arrays is associated with the transmission and reception not only of information but also of energy. For example, there are rectennas (rectifying antenna [https://en.wikipedia.org/wiki/Rectenna]), which are non-linear antennas designed to convert the field energy of an electromagnetic wave incident on them into direct current energy. The simplest design option can be a half-wave vibrator, between the arms of which a semiconductor device (for example, a diode) is installed. To increase the gain, such engineering devices are combined into multi-element arrays. In engineering, rectennas are considered promising for energy transmission over long distances, for example, when transporting energy to Earth from solar power plants in space orbit. In living bodies, to pump the energy of electromagnetic waves through possible biological rectennas, semiconductors are needed, and they are present in them: "… *almost all types of living organisms are capable of biosynthesis of inorganic compounds, which by their nature are inorganic semiconductors and exhibit photochemical activity*" [Nikandrov, 2000].

The defining feature of the new generation of radio engineering systems is the implementation of their antenna devices using the technology of digital antenna arrays (phased and others), which are often called Smart Antenna or Intelligent Antenna [Minochkin, Rudakov, Slyusar, 2011; Slyusar, 1999]. These arrays additionally use analog-to-digital and digital-to-analog conversions to digitize the wave messages emitted or received by the antenna array to computer process these digital representations of antenna information with various mathematical algorithms to achieve certain goals. Such antenna arrays can operate in a multipath mode with several partial radiation patterns almost simultaneously existing. In particular, smart antennas are used in numerous systems of radio holography, which is an analog of optical holography and uses mathematical matrices for calculating and designing antenna arrays (see, for example [Pavelyev et al., 2004; Voskresensky et al., 2006; Sazonov, 2015],). In the active digital antenna arrays, the radar transmitter is distributed ("smeared") over the antenna array and is one of the most reliable elements: if several solid-state modules break down, there is no significant reduction in performance (previously for radars with a passive array, if the transmitter elements came out of the ensemble, the system is "blind").

It is in Smart Antennas that matrix methods are a key tool for the rational synthesis of antenna arrays, as well as the development of effective algorithms for computer processing of digital antenna information and digital beamforming with high noise immunity.

The problems arising here about Smart Antennas, sometimes containing hundreds and thousands of information processing channels, have led to the development of new tools for matrix analysis that have not previously been encountered in other areas of science and technology. First of all, we are talking about the tensor-matrix theory of antenna arrays by the Ukrainian scientist V. Slyusar, who proposed some new operations with matrices [Slyusar, 1999, 2021]. These new operations in the theory of digital antenna arrays (Smart Antennas) are closely related to the Hadamard product of matrices, which, as shown above, turned out to be adequate for describing the universal rules for the stochastic organization of genomic DNA (Figs. 5 and 7). In techniques, the apparatus of the tensor-matrix theory of antenna arrays makes it possible to simplify computational processes "*by replacing the inversion of the multidimensional matrix product (P*P)-1 with an identical procedure for more simply formed Hadamard products* …" [Minochkin et al., 2011, p. 441–442]. The huge savings in computational costs when using the Hadamard product for matrices in the theory of digital antenna arrays is illustrated by the following citation: «*Calculating the quadratic form by identity is reduced to the Hadamard product. As a result, for a 32x32 antenna array in each channel with 32 synthesized frequency filters in 32 distance intervals, we can decrease the amount of multiplication by 8004 times and the amount of summations by 8456 times with respect to the initial notation. In this case, the number of multiplication operations is decreased by more than 268.845 billion, as compared to a four-coordinate model based on a traditional matrix product*» [Slyusar, 1999, page10; Minochkin, Rudakov, Slyusar, page 442].

Similar matrix methods associated with the Hadamard product for matrices are used in artificial intelligence systems, machine learning, reducing the number of calculations when implementing the tensor sketch method to reduce the data dimension, etc.

4.2. Inherited physiological phenomena and bio-antenna arrays

The noted analogies between the tensor-matrix formalisms of matrix genetics and the theory of digital antenna arrays will now be supplemented by many impressive similarities between the inherited structural-functional organization of biosystems and digital antenna arrays. The abundance of these similarities and also a possibility of their understanding from the general non-trivial point of view testifies in favor of the presented doctrine of the evolutionary role of bio-antenna arrays and their wave functioning.

In this doctrine, one can talk primarily about electromagnetic radiation. But mechanical and electrical oscillations in living bodies are closely connected because many tissues are piezo-electrical (nucleic acids, actin, dentin, tendons, bone, etc.). The mathematics of mechanical and electrical oscillations is analogical (so-called "electro-mechanical analogies" are well-known). The article [Petoukhov, 2016] describes some aspects of this theme related to resonance phenomena. The functioning of antenna arrays is closely connected with resonance mechanisms. The concept of resonances has wide theoretical and engineering applications due to vibrational phenomena of a resonant synchronization of oscillatory processes, vibrational separation and structuring of multiphase systems, Vibro-transportation of substances, Vibro-transmission of energy within systems, etc. [Blekhman, 2000; Ganiev et al., 2015]. Virtually invisible vibrations can give rise to paradoxical phenomena that give the impression of violating the laws of mechanics (it's not for nothing that the article about these phenomena is figuratively called: "*Vibration "changes the laws of mechanics"*" [Blekhman, 2003]. These phenomena include, for example, the following: the upper position of the inverted pendulum becomes stable; a heavy metal ball "floats up" in a layer of sand; a rope takes a form of a vertical stem if a corresponding vibration acts on its base. Inside fluids, vibrating bodies can attract or repel each other (vibrating forces of Bjerknes) and pulsating gas bubbles may coalesce or divide. Such phenomena of Vibro-mechanics can explain many processes in living bodies, including complex processes under mitosis and meiosis of cells. In particular, contraction and expansion differentiation waves in developing cell ensembles are studied in epigenetic problems [Gordon and Gordon, 2019].

Let us describe some of the inherited physiological phenomena that are included in this doctrine as its natural components due to the following:

- these phenomena are associated with the mechanisms of generation and reception of multicomponent wave radiation, whose parameters are specific to different types of organisms and are inherited from generation to generation; each of these phenomena is associated with the joint work of separate antenna-like elements combined into a union biosystem, whose operation should be analyzed and modeled using the modern knowledge about emergent properties of antenna arrays;

- they can be explained naturally based on the idea of the energy-information functioning of bio-antenna arrays with their multi-beam radiation patterns.

One such example is a complex faceted eye of insects, crustaceans, and some other invertebrates (Fig. 10). These eyes serve as bio-antenna arrays to receive electromagnetic waves from the environment for solving many vital tasks of an intellectual nature (search for food, escape from predators, etc.). They are formed by the union of many special structural units – ommatidia, each of which is an analog of receiving antenna. The multi-component combined system of such separate receiving bio-antennas can possess emergent properties, which didn't analyze at all till now in biology from point of view of modern knowledge about essential emergent properties of antenna arrays. This article draws attention for the first time to the need for such analysis. Any image perceived by such eyes is "recalculated" from the numerous ommatidia. The eyes of various insect species consist of a large number of ommatidia: a worker bee has 5,000, butterflies have up to 17,000, and dragonflies have up to 30,000. Configurations of faceted eyes are reproduced by engineers in bionics to create antenna arrays with special properties [Solomatin, 2001].

Another example is the innate ability of many organisms to echolocation based on directed rays of a wave nature, which is important for their life and survival [https://en.wikipedia.org/wiki/Animal_echolocation]. Due to the mechanisms of echolocation, for example, dolphins and bats can recognize not only the distance to the target but also the dimensions and shape of the objects they track, by analogy with how active digital antenna arrays (Smart Antennas) make it possible in technology (Fig. 11). For example, the dolphin's receiving-radiating hydroacoustic system allows it to locate a pellet that has fallen into the water at a distance of 15 m; distinguish between the material and dimensions of objects of the same shape, differing by a few percent; to distinguish, like a tomograph, the details of the internal structure and shape of objects in water or a layer of silt; detect edible fish at a distance of 3 km and distinguishes it from those that do not go to food. There is evidence that dolphins can send images of objects to each other using their sonar systems [Prigg, 2015].

Sonar of dolphins uses the generation of ultrasonic vibrations by special membranes, which form a directed ultrasonic beam, the frequency and directivity pattern of which can change. It also uses many hydroacoustic receptors distributed at a high density on the front side and a lower density over the surface of the entire body.

These receptors "*form a multi-element broadband hydroacoustic receiving antenna with a circular pattern. This holographic reception subsystem provides illumination of the underwater environment, operating both in active and passive modes … Dolphin has several hydroacoustic information systems that partially overlap each other and work in parallel*» [Leo, 2015]. This citation uses the term "receiving antenna" though there exists a whole system of separate receiving antennas here; emergent properties of such biosystem should be taken into account and studied, but they were not analyzed till now from the point of view of modern knowledge about essential emergent properties of antenna arrays. Recall that mechanical and electromagnetic oscillations in organisms are interrelated since many biological tissues are piezoelectric.

In wildlife, electrolocation is also widespread with the generation

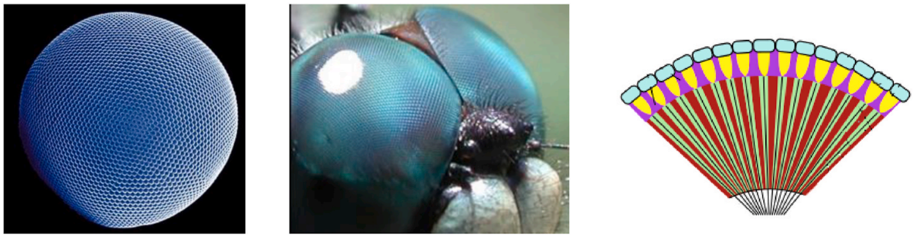


Fig. 10. Examples of complex faceted eyes. **At left**: compound eye of Antarctic krill as imaged by an electron microscope (from https://en.wikipedia.org/wiki/Compound_eye, photo by Gerd Alberti and Uwe Kils; permission is granted to copy and distribute this document under the terms of the GNU Free Documentation License). **In middle**: Dragonfly compound eyes (from https://en.wikipedia.org/wiki/File:Dragonfly_eye_3811.jpg, author David L. Green; permission is granted to copy and distribute under the Creative Commons Attribution-Share Alike 3.0 Unported license). **At right**: insect compound eye diagram (from https://tftwiki.ru/wiki/Arthropod_eye. Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.2, or any later version published by the Free Software Foundation).

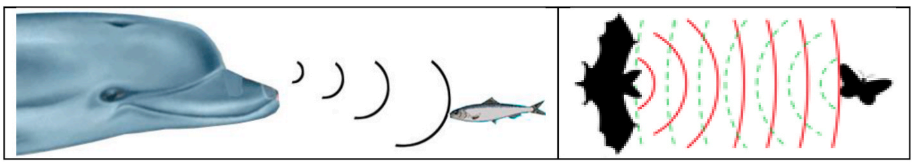


Fig. 11. Examples of biological echolocation: echolocation in dolphins (left) and bats (from https://commons.wikimedia.org/wiki/File:Chiroptera_echolocation.svg, the picture is available under the Creative Commons CC0 License).

and reception of electric fields for solving by organisms many vital tasks of a search, evaluation, and communication nature. In electrolocation, the animal senses its surrounding environment by generating electric fields and detecting distortions in these fields using electroreceptor organs [Albert et al., 2006]. This electric field may be modulated so that its frequency and waveform are unique to the species and sometimes, the individual. The perception of electric fields and their changes is usually carried out by many electroreceptors that are distributed throughout the body and form a coordinated antenna biosystem like a receiving antenna array. For example, the platypus possesses receiving bio-antenna arrays having almost 40,000 electroreceptors arranged in a series of stripes along with the bill. These same abilities of electrolocation are used by organisms for electrical communication with other organisms. For example, weakly electric fish can also communicate by modulating the electrical waveform they generate, an ability known as electrocommunication [Hopkins, 1999]. They may use this for mate attraction and territorial displays.

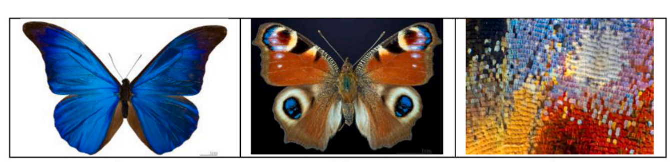
Detection of objects and their geometric characteristics based on biological echolocation and electrolocation is an act of intellectual activity. Therefore, the phenomenon of biological echolocation is one the evidence in favor of the fact that the innate ability for intellectual activity in living organisms is based on inherited systems of bio-antenna arrays with their wave activity (smart bio-antennas, by analogy with Smart Antennas in technology). According to the author, the development of this topic of "system-antenna intelligence" will lead in the future to the understanding that bio-antenna arrays with their wave energy and self-organization mechanisms are not just transmitting and receiving devices, but they are the key participants of intellectual activity in the living. One can mention that the tensor-matrix theory of digital antenna arrays allows the creation of new approaches to artificial intelligence systems [Slyusar, 2020].

4.3. Photonic crystals and liquid crystals in the theme of bio-antenna arrays

Modern engineering technologies actively use so-called photonic crystals to control the spatial distribution of photon beams [Joannopoulos et al., 2008; Hasan and Helleso Ol., 2021; Krasnok et al., 2013]. The technologies of antennas and antenna arrays based on photonic crystals are being intensively developed [Zaitsev, 2011]. A photonic crystal is a periodic optical nanostructure that affects the motion of photons. Photonic crystals contain regularly repeating regions of high and low dielectric constant. Photons (behaving as waves) either propagate through this structure or not, depending on their wavelength. This gives rise to distinct optical phenomena, such as inhibition of spontaneous emission, high-reflecting Omni-directional mirrors, and low-loss-waveguiding. The periodicity of the photonic crystal structure must be around half the wavelength of the electromagnetic waves to be diffracted. One should note that, as known, living bodies possess inherited opportunities to manage photonic beams using physical principles of photonic crystals with their properties of photon gratings, etc. Many inherited biological phenomena of structural coloration and animal reflectors are built on this, including the beautiful coloring of butterfly wings, peacock feathers, etc. (see details and lists of references in [https://en.wikipedia.org/wiki/Photonic_crystal, https://en.wikipedia.org/wiki/Animal_reflectors, https://en.wikipedia.

Fig. 12 shows some examples of inherited interrelated regular manifolds of biophotonic crystals forming biological analogies of technical antenna arrays. These examples give pieces of evidence that living bodies with their genetic system skillfully encode and inherit manifolds of bio-antenna arrays.

The amazing coloring of peacock feathers is due to the play of light on the photonic crystals in them [Blau, 2004]. The chameleon also changes the color of its body reversibly, using multiple photonic crystals on its surface and optical interference on them. This was recently established by studies by Swiss scientists who revealed the existence in



a) b) c)

Fig. 12. Photonic crystals form heritable species patterns on butterfly wings, which allow differentiation between different species of butterflies.
a) Rhetenor Blue Morpho (from https://commons.wikimedia.org/wiki/File:Morpho_rhetenor_rhetenor_MHNT_dos.jpg); b) European peacock (from https://commons.wikimedia.org/wiki/File:Paon-du-jour_MHNT_CUT_2013_3_14_Cahors_Dos.jpg; c) regular sets of photonic crystal scales on a wing of peacock butterfly (Aglais io) under the microscope (from Чешуекрылыеhttps://ru.wikipedia.org/wiki/Чешуекрылые). These images are available to share under the Creative Commons CC0 License).

the skin of chameleons of two layers of cells with highly ordered structures of small (~130 nm) photonic nanocrystals of the guanine, which serves as one of the nitrogenous bases in DNA [Teyssier et al., 2015]. Tension or relaxation in the system of these cells helps animals to quickly change color by changing the ability of the skin to reflect light. Many animals in nature such as fish or beetles employ responsive photonic crystals, which form matrix structures, in their intelligent-like activities for camouflage, signaling, or baiting their prey [Hui and Zh, 2013; https://en.wikipedia.org/wiki/Photonic_crystal_sensor].

It is natural to assume that the genetic transfer of inherited properties of photonic crystals in biological bodies is built on the that the molecular genetic structures themselves possess the properties of photonic crystals [Hu et al., 2018]. We believe that spatial characteristics of ensembles of genetic and other biological molecules, that form complex diffraction structures, play a managing role of photonic crystals in the problem of controlling photon beams that are generated and absorbed by these molecules (the range of photon frequencies in living bodies can be very wide, far beyond the optical range). In our opinion, the inherited morphogenetic processes in living bodies are also determined to a large extent by biological photon beams, the course of which is not accidental, but is strictly organized by ensembles of genetic and other biological molecules as photonic crystals. Of course, quantum-mechanic laws of resonances in molecular photonic interactions play an important role. Photonic crystals are related to the topic of nanoantenna arrays in two ways [Zaitsev, 2011; Herman, 1986; Shishkin and ShishkinaElectronics, 2009]:

1) They are used in optical nanoantenna and microwave technologies. Usually, a nanoantenna is understood as a miniature antenna, the dimensions of which do not exceed hundreds of microns, and one of the dimensions is 100 or fewer nanometers. Nanoantennas are also often referred to as nanodevices that allow the scattering of radiation in a given direction [Krasnok et al., 2013]. Photonic crystals and their lattices are such devices;
2) The location of many photonic crystals as a screen next to the nanoantenna can change its functional characteristics. In particular, the fluorescence of a single molecule that enters the nanoantenna gap can be increased by a factor of 10 [Krasnok et al., 2013].

In engineering techniques, photonic crystals are composed of a periodic dielectric, Metallo-dielectric, or even superconductor microstructures or nanostructures. As it is known, active biological systems have extraordinarily high dielectric properties [Fröhlich, 1988]. For this reason, just dielectric photonic crystals, which have wide application in techniques and are actively analyzed in the theory of photonic crystals and their applications in antenna arrays, are the most interesting for the theme of bio-antenna arrays.

One should add that the theme of nanoantennas, which are used in living nature for millions of years, is considered in modern science as very important: scientists believe that progress in technologies of corresponding nanoantenna production can lead to revolutions in computers (using photonics principles) and energetics (effective using of solar energy). The presented doctrine of the evolutionary role of bio-antenna arrays may be useful for understanding the mechanisms of photosynthesis in plant leaves.

The set of kinds of photonic crystals contains a subclass of liquid crystal photonic crystals. DNA and RNA are liquid crystal structures, like some other components of the living. Liquid crystal is a state of matter that has properties between those of conventional liquids and those of solid crystals [Sluckin et al., 2004; https://en.wikipedia.org/wiki/Liquid_crystal]. For instance, a liquid crystal may flow like a liquid, but its molecules may be oriented in a crystal-like way. There are many different types of liquid-crystal phases, which can be distinguished by their different optical properties. To date, tens of thousands of types of multicomponent liquid-crystal compounds have been synthesized for technical purposes around the world, for example, for liquid-crystal displays, etc.

Due to the anisotropy of their structure, liquid crystals can scatter electromagnetic waves incident on them in selected directions. If a liquid crystal object has dimensions characteristic of nanoantenna arrays, then due to this anisotropic ability, it can serve as a nanoantenna array. Emission at a photonic bandgap created by the periodic dielectric structure of the liquid crystal gives a low-threshold high-output device with stable monochromatic emission [Kopp et al., 1998; Dolgaleva et al., 2008].

Lyotropic liquid-crystalline phases are abundant in living systems, the study of which is referred to as lipid polymorphism. Accordingly, lyotropic liquid crystals attract particular attention in the field of biomimetic chemistry. In particular, biological membranes and cell membranes are a form of liquid crystals. Many other biological structures exhibit liquid-crystal behavior. For instance, the concentrated protein solution that is extruded by a spider to generate silk is, in fact, a liquid crystal phase. DNA and many polypeptides, including actively-driven cytoskeletal filaments can also form liquid crystal phases [Wensink et al., 2012]. The piezoelectric effect exists in liquid crystals; for this reason, interrelated electromagnetic and vibrational phenomena can coexist in them [Denisova and Scaldin, 2013].

As noted above, antenna arrays due to their emergent properties are capable of generating narrow and precision directional electromagnetic beams of multiply enhanced intensity. Getting in a targeted way on the piezoelectric areas in living tissues, such electromagnetic influences cause mechanical vibrations in the corresponding small (almost point) areas. Therefore the wave activity of bio-antenna arrays can lead to a very heterogeneous distribution of piezoelectric vibrations in cells and other tissue structures. These heterogeneous influences from one of the bio-antenna arrays on biological tissue can also lead to spatial-temporal reorganizing of other bio-antenna arrays in this tissue. Such interrelated wave influences of different bio-antenna arrays on each other, which reorganize their interconnected antenna systems, are participants of self-organization in living bodies.

Of particular interest for biological and applied research are liquid crystals called chiral phases or twisted nematics. For these crystals, the direction of the orientation of molecules in successive layers changes in a spiral. As a rule, chiral nematic crystals are obtained from compounds with pronounced anisotropy - the unequal properties in different directions. It is these properties that, as is known, DNA and RNA, which are naturally twisted into a double helix, possess. Abiotic ligation of DNA oligomers templated by their liquid crystal ordering is shown in [Fraccia et al., 2015].

Since their nitrogenous bases absorb ultraviolet, these chiral nematic crystals, when obtained in the laboratory, have a peculiar "color", which manifests itself in the form of an abnormally high optical activity (the ability to rotate the radiation polarization plane), which is tens and hundreds of times higher than the optical activity of single molecules [Yevdokimov et al., 2012]. This fact emphasizes the need to take into account the emergent properties of multi-element nanoantenna arrays and their wave activity, which are cardinally different from the properties of a single nanoantenna.

The chiral twisting that occurs in chiral liquid-crystal phases also makes the system respond differently from right- and left-handed circularly polarized light. These materials can thus be used as polarization filters [Fujikake et al., 1998]. The theme of circularly polarized light from biological chiral liquid crystals is connected with the fundamental problem of biomolecular asymmetry by L.Pasteur [Flack, 2009]. Sets of helical chiral biomolecules can serve as helical antenna arrays, which radiate and absorb electromagnetic waves of the corresponding circular polarization. This provides the opportunity for helical chiral biomolecules to exchange radio waves of the corresponding circular polarization selectively with helical biomolecules of the same kind of chirality. In radio transmission technologies, circular polarization is often used where the relative orientation of the transmitting and receiving antennas cannot be easily controlled, such as in animal tracking and spacecraft communications (that is, for example, a spacecraft rotation does not influence the communication). In other words, regarding these helical antenna arrays, the factor of chirality (left or right polarization) is very important for communication. We add that the directional properties of a helical axial radiation antenna can be determined by considering the spiral as a linear antenna array consisting of some turn emitters [Voskresensky et al., 2006, p. 287]. The author believes that the principle of the chiral stereochemical organization of biomolecules in living nature is deeply related to the informational principle of communication among biomolecules based on bio-antenna arrays working with electromagnetic waves of appropriate circular polarization. Helices are termed long ago as « *curves of life* » due to the multiple implementations of inherited helical structures and processes in living bodies on various lines and levels of biological evolution [Cook, 1914; Petoukhov et al., 2015]. For example in the human body, helical structures are genetically inherited from generation to generation in muscles, heart, vessels, bones, tendons, ligaments, nerves, organs of hearing (cochlea ear), etc.

An analog of a spiral antenna in a form of left-handed multi-turn helices was recently discovered by Swedish scientists in the tail of a spermatozoon. These authors speculate that these helical structures in particular can « *play a role in controlling the swimming direction of spermatozoa*», that is, play the role of antennas for communication with the environment [Zabeo et al., 2018]. But it was above-mentioned that a multi-turn helical antenna can be considered an antenna array consisting of turn emitters [Voskresensky et al., 2006, p. 287]. In other words, in the tail of a spermatozoon, there is an antenna array, whose emergent properties can provide amazing features in controlling the swimming direction of spermatozoa.

The structural properties of liquid crystals combine probabilistic and deterministic characteristics. The liquid crystal in the simplest case is a structure consisting of ordered molecular layers, which still retain some diffusion degrees of freedom characteristic of the behavior of molecules in a liquid solution. There is a well-known comparison of liquid crystals with a stream of logs floated down a river: in general, they are all lined up in the same direction, downstream, although each log floats on its own [Yevdokimov, 2005]. Thus, in the properties of liquid crystals, the "probability-determinism" dualism is represented at the molecular level, which is characteristic of biological phenomena of various levels and considered in Gestal genetics and Gestalt biology [Petoukhov, 2021c,b].

5. Regeneration phenomena, genetics, and antenna arrays

The cells of a multicellular organism must exchange information for their coordinated behavior. This implies the presence of a system of long-distance information links between many cells of the body. Modern data from some authors suggest that the bioelectrical connection between cells of other types that are not neurons is also used as a means of remote communication (see, for example, [Levin and Martyniuk, 2018]). The activity of bio-antenna arrays, which emit and receive electromagnetic waves and have significant communication advantages mentioned above, can be one of the types of long-range information links between cells and other structures of the body.

Many cell elements of a cell, such as its DNA, membranes, many polypeptides, and cytoskeleton, are liquid crystals. [Gupta et al., 2015; Schakenraad et al., 2020]. These crystals, as mentioned above, can serve as liquid crystal nanoantenna arrays. At the same time, they can participate in the intellectual activity at the cellular level. We note in passing that the cytoskeleton of neurons has long been considered by some authors as a computing environment when nerve cells perform their tasks [Liberman et al., 2008]. The activity of transceiver liquid crystal bio-antenna arrays can be considered a special chapter of bioelectric physiology.

It is natural to believe that the electromagnetic activity of bio-nanoantenna arrays is involved, in particular, in the distribution of rest electric potentials on cell membranes, which are liquid crystals. This factor of rest potentials is important for morphogenetic processes and regeneration as it was shown in impressive experimental works by M. Levin and his colleagues [https://ase.tufts.edu/biology/labs/levin/]. These works were carried out on flatworms - planarians, which have a head, a true brain, etc. Planarians are known champions in organ and tissue regeneration. The noted works studied the regeneration of amputation parts of the worm's body and showed that the determination of the correct position of the organ in the worm's body is controlled by the distribution of membrane potentials in not yet differentiated cells. Artificial changing by ionophores of the typical distribution of the membrane potentials on an amputated fragment of the worm's body leads to the formation of planarians with two heads (one should note, that such artificial influence on liquid crystal membranes can significantly change cell systems of liquid crystal bio-antenna arrays participating in morphogenetic processes).

It is especially remarkable that if both heads are cut off from the resulting two-headed worm, then a two-headed worm is again regenerated from the remaining middle fragment. And this procedure can be repeated many times, each time receiving the regeneration of a two-headed worm. According to Levin, this means that the memory of the correct structure of the body, which should be formed after regeneration, turns out to be radically changed, although the genome of this organism did not change and remained the same. Therefore, the memory that tells the worm about how many heads it should have is contained not in the genome at all! These experimental facts have led Levin to the idea that emergent properties of an ensemble of cells are key participants of morphological and some other processes. Multicellular ensembles can determine the type of morphological patterns formed, largely independently of the information in DNA, which is essential for the coding of proteins. This idea generated new experiments, in which Levin showed that the combination of cells from the skin of a frog into a single ensemble leads to the appearance of a tiny body of a completely new design. Such bodies, which are biological robots called "xenobots", can move, navigate a labyrinth, explore the environment, feed and heal themselves, and exhibit emergent group behavior, although they do not have a nervous system, do not have a brain, and they are simply collections of skin cells with unchanged DNAs. These results additionally concern the problem of the origins of biological intelligence [Yuste and Levin, 2021]. They allowed generating Levin's concept that «*the electrical blueprints orchestrate life*» [Levin, 2020].

Our doctrine of evolution based on bio-antenna arrays proposes another basis point of view. This doctrine states that just bio-antenna arrays with coordinated electromagnetic waves «orchestrate life». This doctrine draws attention to the following important factors of electromagnetic waves, which are absent in the concept of "*the electrical blueprints*":

1) Electromagnetic waves of bio-antenna arrays are involved in the operational transfer and redistribution of energy between the elements of the body;
2) For connections between parts of each bio-body, electromagnetic waves provide participation of magnetic and piezo-vibration components besides electrical potentials;
3) The types of polarization of electromagnetic waves of bio-antenna arrays are important for relationships between the elements of the bio-body since they are associated with the fundamental problem of biological dissymmetry and molecular chirality noted by L. Pasteur;
4) The unique ability of antenna arrays to provide noise-resistant multichannel operation with the extraction of weak signals against the background of strong noise allows us to rethink the phenomenal ability of organisms to work in many parallel channels with weak information signals against the background of strong noise with providing information noise immunity. (Remind that according to Mendel's law of independent inheritance of traits, information from the level of DNA molecules dictates the macrostructure of living bodies through many independent channels, despite strong noises);

5) Study of bio-antenna arrays and their wave-coordinated activity concerns and includes an important theme of inherited intellectual abilities, demonstrated by effective use by animals of echolocation, faceted eye vision, etc.

Concerning the role of bio-antenna arrays in energy flows in bio-bodies one can add that the idea of the organizing role of coordinated energy flows inside the body exists since ancient times. It is associated with Ancient Chinese ideas about a certain special energy "qi" (or "chi"), whose circulation defines human health and illnesses and which determines the existence of energy pathways called acupuncture meridians. By the impact of acupuncture needles on these meridians, these energy flows can be corrected. It cannot be ruled out that this mysterious energy "qi" is partially or completely precisely the energy of a multitude of coordinated electromagnetic and other wave rays from multi-level systems of bio-antenna arrays. As far as the author knows, in biology and biophysics, the possible biological significance of a self-organizing dynamic "web" (or openwork plexus) of narrowly directed rays of electromagnetic and other wave entities from bio-antenna array systems has never been considered; in this lace of beams and energy flows, there are interrelations and patterns associated with the principles of quantum mechanics and quantum informatics.

The described tensor-matrix analogies between structures of stochastic organization of genomes and Smart Antennas, and also the described connections of many inherited physiological phenomena with emergent properties of antenna arrays, allow supposing that the genetic code itself is one of the offspring of wave activity and self-organization of bio-antenna arrays and that this code is connected with other inherited physiological offsprings of bio-antenna arrays in the organism.

Some concluding remarks

The presented materials testify to the expediency of taking into account the emergent properties of bio-antenna arrays, which can define important features of energy-information interrelations among parts of biosystems and which never paid attention to in evolutionary biology. Living nature has not passed by the amazing emergent properties of antenna arrays and is actively using them in their creations. Unlike living nature, people have only relatively recently begun to use these properties in their technical creativity, rapidly saturating our world with millions of antenna arrays.

The described analogies between inherited physiological phenomena and emergent properties of digital antenna arrays additionally lead to new points of view. For example, stochastic organization of information sequences of genomic DNAs can be considered a special case of biological self-organization based on the wave activity of bio-antenna arrays, examples of which are presented at all levels of the body. In this case, the genetic code itself is one of the offspring of wave activity and self-organization of bio-antenna arrays, and this code is connected with other inherited physiological offsprings of bio-antenna arrays in the organism. Correspondingly, the secret of the structural organization and origin of the genetic code, as well as the origin of organisms, must be sought not in the random combination of the molecular elements of the genetic code, but the emergent properties of self-organizing systems of bio-antenna arrays with their wave energy activity.

Accordingly, it is not genes that are the dictators of all life activity, since they are built into the information-energy coherences of bio-antenna arrays and are produced by them. Dialects of the genetic codes arise in the course of the evolution of bio-bodies, when new living conditions appear and, if necessary, the dynamic systems of bio-antenna arrays associated with quantum mechanics are corrected. The genomes themselves and the genetic system are an integral part of the wave activity of ensembles of bio-antenna arrays and can be considered biological smart-antennas.

Previously, the author liked the well-known short definition of life: "*Life is a partnership between genes and mathematics*" [Stewart, 1999]. But in the light of the above facts, the author proposes a new short definition for a discussion: "Life is a partnership of organisms with bio-antenna arrays and their wave energy". Of course, the role of mathematics in revealing the content of this definition, which is implicitly related to the algebraic theories of Smart antennas and resonances, quantum mechanics, and quantum informatics, is exceptionally great. The presented doctrine includes connections of bio-antenna arrays and genomic DNA sequences with formalisms of quantum informatics [Petoukhov, 2022].

Accounting for emergent properties of bio-antenna arrays provides new opportunities for the analysis and discussion of several problems of biological evolution. For example, they concern with a nomothetical concept of evolution [Berg, 1969; Lyubishchev, 1982; Meyen, 1992], which was recently considered in the light of modern achievements in [Sharov and Igamberdiev, 2014]. These emergent properties of interrelated systems of bio-antenna arrays also concern the theme of different biological codes, which are emerged under the evolutionary complexification of organisms [Barbieri, 2015; Igamberdiev, 2021].

They also touch on the subject of cyclical processes in the body, which are often associated with the concept of biological time [Igamberdiev, 2014]. This touching is based on the above-mentioned property of phased antenna arrays to change the direction and intensity of rays of produced and received wave radiation due to a change in the phase relationships in the operation of their antennas (without moving the antennas themselves): the coordinated changes in the wave phases of the elements of bio-antenna arrays make it possible to rebuild the spatial-temporal characteristics of wave energy rays, cyclically redirecting and redistributing energy flows in space and time to provide cyclic activations and deactivations of biological components.

People have long discussed the relationship between innate knowledge and knowledge acquired in the course of life. The extreme point of view is formulated in Plato's famous statement that to know means to remember, awakening, as it were, from sleep. Close to this is the widespread opinion that our body already carries in hidden forms the fullness of knowledge, whose parts come into our consciousness when they are insistently requested. But our body grows from a single fertilized cell. Can this original cell contains all the named completeness of knowledge? Or additional knowledge comes into our body from outside in the course of ontogeny from cosmic and planetary wave energy-information influences through bio-antenna arrays? These questions are open for further study.

Declaration of competing interest

I have no conflict of interests regarding my submitted article:

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