About Physical Informatics

Igor Gurevich
The Institute of Informatics Problems of the Russian Academy of Sciences,
Hetnet Consulting Corp., Moscow, Russia,
iggurevich@gmail.com

***Abstract*— Physical informatics is information background of physics: informatics laws have general, universal character, operate in all possible universes with different physical laws. Informatics laws precede physical laws. Definitions and estimates are given for information characteristics of physical systems (fundamental and elementary particles, atoms, molecules..., star objects, galaxies,…, the Universe as a whole). Information restrictions on interaction of physical systems are received. Physical Informatics is Science of modern Information in Physical and Chemical Systems, including Quantum Informatics, and is the basis of Informatics of the Living Systems. The informatics laws together with the physical laws will allow to open all secrets of nature, in particular, to construct the theory of quantum gravitation.**

keywords*— *physics; informatics; physical informatics

I. INTRODUCTION

Ursul A.D. predicted in 1968 in his book [1] "The Nature of the information: "By methods of information theory the properties of space and time will be studied while before they were mainly studied by physical theory (eg, special and general theories of relativity, Einstein). So, physics and information theory interpenetrate each other, that, in general, leads to the creation of two major synthetic disciplines - the special application of information theory (and most likely, a number of its branches - a thermodynamic and quantum) physics and information". The interpenetration of physics and information theory in the development of informatics has formed a synthetic discipline "Physical informatics" [2, 3].

II. SOME HISTORY

Many eminent scholars have noted the importance of information [1, 4-6]. J. Wheeler, "My life in physics seems to me to split into three periods. The first of them, stretching from the beginning of my career and the beginning of the 1950s, I was captured by the idea that "Everything - a particle." I was looking for ways to build all the basic elements of matter (neutrons, protons, mesons, etc.) of the lightest, most fundamental particles - electrons and photons. The second time I call the "All - this field". Now I have caught a new idea: "Everything - it's information" (1962); E. Steen (2000) "... identify some of the laws that are similar to the laws of conservation of energy and momentum, but used in relation to the information and determine the most quantum mechanics "; B.B. Kadomtsev (1999): "In going to study increasingly complex systems is the structural and information aspects of their behavior and development of the foreground and the dynamics of creating a framework for Information Development. In view of quantum processes in the microcosm of the world picture becomes even more complex and richer in terms of information behavior. " For the first time an analysis of physical processes using the concepts of information has been made by A. Einstein (1905). L. Szilard (1929), analyzing the thought experiment, "Maxwell's demon", has shown that the entropy lost by the gas, is exactly equal to the information received, "Maxwell's demon." I. Von Neumann (1932) introduced the notion of quantum entropy. Neumann entropy of a pure state, by definition, is zero, but physicists tend to describe and study quantum systems using this entropy. Shannon (1948) introduced the concept of information entropy. Information defined by the Shannon entropy in bits (nats) is a universal measure of uncertainty (information) of the classical and the quantum systems. The systematic application of information theory to the analysis of physical phenomena and processes was apparently first performed by Brillouin (1960). "We now introduce a distinction between two kinds of information: 1) free information, occurs when possible cases are treated as abstract and have no particular physical significance, and 2) the associated information (bound information), occurs when the possible cases can be presented as a microstate of a physical system. " L. Brillouin (1959) showed that a binary unit of information equal to the energy of Boltzmann constant multiplied by temperature and estimated the volume of information contained in the physical law. Penrose (1989), Hawking (2005) and others have used information-based approach to the process of black holes formation.. "Can information disappear during the formation of a black hole? Where can it go? The black hole swallow distorts information, but do not destroy it completely. During evaporation of the black hole information comes out of her embrace. " A. Zeilinger (1999) put forward the following principle as the foundation of all possible quantum theory, presenting two of his statements: 1) an elementary system represents the true value of a proposition, and 2) an elementary system carries one bit of information. S. Lloyd (2001) postulated: 1) the theorem Margolis-Levitin, and 2) the total number of bits available for processing in the system is limited by the entropy of the system. 3) The rate of flow of information is limited by the speed of light. These three limits are applied to assess the ability to process information universe. In particular, the total number of bits available in the universe to compute, and the number of elementary logical operations that can be performed on these bits during the lifetime of the universe is estimated by Lloyd. The total number of bits of matter (the result of the author, 1989). Gurevich I.M. (1989-present) organizes knowledge in complex systems, information practices on the basis of their research informatics laws and

conducts studies of complex systems based on these laws. The main results of the author are: the assertion of the existence of natural laws more general than the physical ones - the laws of informatics, defining, limiting physical phenomena and processes [5, 6], and prior to physical laws, the wording of the laws of science; estimate the volume of information in the universe. The number of scientists who use the information approach and information methods in physics research, is increasing rapidly. At the beginning of 2010 there were many interesting works, including works by Erik Verlinde. Lee Smolin. N Jarmo Makela. Rong-Gen Caia, Li-Ming Caob, and Nobuyoshi Ohta. Lorenzo Maccone [5-6].

III. Definition of the Information

Along with matter and energy the Universe contains, includes information. Information is an integral part of the Universe. The fundamental principle of quantum mechanics postulates that the elementary physical system carries one bit of information. "Information is heterogeneity, stable for some definite time" [4]. Regardless of the nature of heterogeneity, would be it letters, words, phrases or - elementary particles, atoms, molecules, or - people, groups, societies, etc. "By information we mean a stable for some time heterogeneity, arbitrary physical nature. Thus, the character in the book, atom, molecule, an elementary particle, the star, drawing, painting, plowed fields, woods and other heterogeneities contain and carry information. " Heterogeneities classes are: physical, chemical, biological, geological, technical, social, economic [4-6]. The measure of the degree of heterogeneity or information is Shannon's information entropy (entropy, by Neumann's definition, can not be used as a measure of heterogeneity, since it is zero for a pure state which has a structure) and other information characteristics (information divergence, joint entropy, mutual information). This leads to the use of information research methods, such as information itself, and its related matter and energy. This approach provides a new and sometimes more general results with respect to the results obtained on the basis of only physical laws. Ursul A.D. in 1968 in his book "The Nature of the information. Philosophical essay" [1] gave a general definition of information:" ... first of all, the information related to diversity, difference, and secondly, with reflection. Accordingly, it can be determined in the general case, as reflected by the diversity. Information - this variety, which contains one object for another object (in their interaction)... But information can be viewed as diversity as a result of reflection as to the object itself, that is self-reflection.

Information is a property of matter, which is universal ... The concept of information reflecting both objectively real, independent of the subject property is inanimate and animate nature, society, and the properties of knowledge and thinking ... Information in this way, is inherent in both material and ideal . It is also applicable to the characterization of matter, and the characterization of consciousness. If the objective information can be considered property of matter, the ideal, subjective information is a reflection of the objective, material information" "V.M. Glushkov characterizes information as a measure of heterogeneity in the distribution of energy (or matter) in space and time ... there is information to the extent that there are material bodies, and therefore he created heterogeneity". Interestingly, in his book Ursul A.D. noted that "heterogeneity - is another expression of the form diversity." Information - is stable for some time diversity (heterogeneity) of any physical nature (animate and inanimate matter, society, mind), described and studied by all applied sciences, which has a number of properties, primarily a reflection. Informatics – is the science of information. The subject area of informatics: Natural systems (living and nonliving), a system created by civilization, including the social and economic systems. The study of information laws (in specific subject areas and general). There is not a single definition of information, which would not be a special case of this definition. This definition can not affect, limit anyone's research interests, can not cancel, deny any known or future directions of research" [5].

IV. Physical Informatics. Main Results

Physical Informatics is the science that studies physical systems by information methods. This discipline is created, mainly in the works of Gurevich I.M. [3-6]. It is shown that information together with physical laws can be an effective tool for understanding natural systems and the Universe as a whole. The relationship between physical and information characteristics of physical systems - mass, energy, entropy and information makes it possible to use information research methods assessing physical characteristics of systems. Information laws (the laws of informatics) are universal, operate in all possible universes. The main characteristics of heterogeneities (information) of physical systems are: uncertainty (information) [7] and information divergence [8] observed (observable in quantum mechanics, called by any physical quantity that can be measured, and the results of the experiment must be real numbers) and states (the state of a physical system defined by the vector in a Hilbert space), which characterize the volume of information (information capacity) of the heterogeneity; joint information entropy [7], which characterizes the unitary transformation; mutual information [7], which characterizes the interaction of physical systems; differential information capacity of matter [5, 6]. Physical systems, objects, the observable are described by information characteristic - uncertainty (information). A measure of uncertainty (information) is Shannon's information entropy, defined as functional on wave function or amplitudes of probability. C. Shannon [7] has entered the concept of information entropy. Entropy of a discrete random variable: $H=-\sum p_i \log_2 p_i$ [bit] ($H=-\sum p_i \ln p_i$ [nat]), Entropy H of a continuous random variable $H(x) = -\int p(x) \log_2 p(x) dx$ *[bit]*, ($H(x) = -\int p(x) \ln p(x)\, dx$ [nat]). *Heterogeneity of physical system is described by information characteristic of - divergence, defined as functional on wave function or amplitudes of probability*.

Presence and properties of the heterogeneity set by distribution P, we will estimate information divergence $D(P/R)$ [8] distributions P concerning uniform distribution R $D(P/R) = -\int P(x) \cdot \log_2 (P(x)/R(x) \cdot dx$, where $P(x)$ - the distribution corresponding to heterogeneity, and $R(x)$ - uniform distribution to interval $0 \le x \le a$

$$R(x) = \begin{Bmatrix} 0 \text{ if } -\infty < x \le 0 \\ 1 \\ - \text{ if } \ 0 < x \le a \\ a \\ 0 \text{ if } \ a < x \le \infty \end{Bmatrix}.$$

If $P(x)$ is defined on interval $0 \le x \le a$ information divergence is equal to

$$D = -\log_2 a - \int_0^a P(x) \cdot \log_2 P(x) dx = N - \log_2 a .$$

Information divergence concerning uniform distribution differs from uncertainty (information entropy) on $-\log_2 a$.

Unitary transformations are described by the information characteristic - joint entropy [7].

Let's define for the unitary operator (transformation), unitary matrix $U = \left\| u_{ij} \right\|$ Shannon matrix

$$SH(U) = \left\| u_{sh\,ij} \right\| = \left\| u_{ij} \ / \sqrt{n} \right\|, \quad i, j = 1, ..., n$$

which elements are elements of a unitary matrix, divided by $\sqrt{n}$.

Let's define on Shannon matrix final probability space: set Ω of elementary events (outcomes) is made by steams of basic vectors y_i, x_j bases y and x; their probability measure is set by squares of modules of Shannon's matrixes elements $p_{ij}(SH(U)) = \left| u_{ij} \right|^2 / n$ (probability of joint realization of states y_i and x_j at measurement of states y in basis x).

$$\sum_{i,j=1}^{n} p_{ij}(SH(U)) = \sum_{i,j=1}^{n} \left| u_{ij} \ / \sqrt{n} \right|^2 = \frac{1}{n} \sum_{i,j=1}^{n} \left| u_{ij} \right|^2 = 1 .$$

At such definition of final probability space for considered unitary matrix $U = \left\| u_{ij} \right\|$ at measurement of states y in basis x the probability of realization y_i and x_j is equal to

$$p_{ij}(SH(U)) = (1/n) \left| u_{ij} \right|^2$$

$$\sum_{i=1}^{n} p_{ij}(SH(U)) = \sum_{i=1}^{n} (1/n) \left| u_{ij} \right|^2 = 1/n$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}(SH(U)) = \sum_{i=1}^{n} \sum_{j=1}^{n})1/n) \left| u_{ij} \right|^2 = 1 .$$

Thus, the matrix of joint probabilities

$$P(SH(U)) = \left\| \left| u_{sh\,ij}(U) \right|^2 \right\| = \left\| \left| u_{ij} \right|^2 / n \right\|$$

is defined on Shannon's matrix to a matrix unequivocally. Using a matrix of joint probabilities, we will define the joint entropy corresponding to unitary matrix $U = \left\| u_{ij} \right\|$.

$$H(U) = H(P(SH(U))) = -\sum_{i=1}^{n} \sum_{j=1}^{n} \left| u_{sh\,ij}(U) \right|^2 \log_2 \left| u_{sh\,ij}(U) \right|^2 =$$

$$-\sum_{i=1}^{n} \sum_{j=1}^{n} (\left| u_{ij} \right|^2 / n) \log_2 (\left| u_{ij} \right|^2 / n).$$

Interaction of physical systems, objects is described by the information characteristic - the manual information.

The manual information I_{xy} of random variables x and y is equal to [7]. $I_{xy} = N_x + N_y - N_{xy}$, where N_x, N_y - uncertainty (information entropy) random variables x and y; N_{xy} - joint uncertainty (information entropy) random variables (x, y). The communication information can be considered as a measure of entanglement of physical systems.

Differential information capacity of matter [4, 5].

There are some types of matter with different dependence of volume of the information (information capacity) on mass, including: - Linear for usual substance $I \propto M$, - Square-law for black holes $I \propto M^2$, Linearly-logarithmic for neutron stars and white dwarfs) $I \propto M \log_2 M$. Generally, mass dependence of information volume in substance looks like $I = f(M)$. Variation of information volume in matter dI at variation of its mass dM is defined by differential of function $I = f(M)$ $dI = (df(M) / dM) dM = f'(M) dM$. The derivative of information volume on mas

$$(dI / dM) = (df / dM) = f'(M) \quad \left[bits / kg \right]$$

is characterized by differential information capacity matter - to change the mass of matter per unit ($dM = 1$) changes the volume of information in the matter to the extent equal to the differential information capacity $dI = f'(M)$.

The informatics laws of nature are [4-6]: the law of simplicity of complex systems, the law of uncertainty (information) conservation, the law of finiteness of complex systems characteristics, the law of necessary variety by Ashby W. (1956), and the theorem of Gödel K. (1931). The main principle of quantum mechanics by Zeilinger (1999) is: elemental physical systems contain (carry) one bit of information. The law of finiteness of complex systems characteristics and the principle of necessary variety by Ashby impose restrictions on the topology and symmetry of the universe. The main results obtained earlier by the author, were published in [5-6, 9-10]. Further, and the report [11] presents new results of the author.

1) Fundamental limits on information capacity storage devices and on productivity of informational systems. Estimates of the amount of information in atoms, amino acids, nitrogenous

grounds, differential information capacity of a substance determine fundamental limits on information capacity storage devices. Differential information capacity of storage devices, built on the basis of atoms does not exceed $\approx 10^{-28}$ bits/kg, and the information capacity of the storage mass 1kg $\leq 10^{28}$ bits, and it can be increased by no more than 10^{14} times. The last limitation is the most powerful fundamental limit on the nature of the information capacity of natural and artificial systems.

The difference between the energies of the basis states of hydrogen atom, considered as a qubit, impose fundamental limitations on the speed of computing devices. The number of operations is satisfied by a hydrogen atom, a q-bit, limited $k_{op/s} = 2\Delta E / \hbar \approx 1,5 \cdot 10^{12}$ operations per second. The productivity of the computer built from atoms of hydrogen, which mass is one kg, not more than 10^{39} op/sec. Restrictions 10^{28} bit/kg, 10^{39} (op / sec)/kg you can add a number of fundamental natural limits, including the speed of light, the elementary charge, Planck's time, ...

2)The program Estimations of Information Characteristics of Molecules (EICM) is designed to calculate the informational characteristics of molecules (the volume of information in the structure of a molecule, the volume of information in a molecule), a description which is stored in An Information Portal to Biological Macromolecular Structures (Protein Data Bank): http://www.rcsb.org/pdb/home/home.do. The method and algorithm for calculation of volume of information in the structure of molecules, is developed by
I.M. Gurevich and M.P. Evstigneev. The program is designed by M.A. Puchkov.

Gurevich I.M. and American, Canadian, European, Chinese ... scientists confirm the primacy of information laws.

• Information laws (the laws of informatics) define and limit the laws of physics.

• Use of information laws (laws of informatics) in conjunction with physical laws to reveal all the secrets of nature, in particular, to construct a theory of quantum gravity.

V. Current Problems of Physical Informatics

Taking into account the received results we list the current problems of physical informatics.

1. Development of information research methods of physical systems - physical informatics.
2. Evaluation of information characteristics (information entropy, information divergence, a joint information entropy, mutual information and differential information capacity) of physical, chemical and biological systems.
3. Estimates of the amount of information in physical, chemical and biological systems.
4. Derivation of physical laws from the laws of informatics.
5. Joint application of energy conservation law and uncertainty (information) conservation law for calculating characteristics of physical systems and processes.
6. The study of information interaction of physical systems.
7. Formation of information restrictions on the formation, development, interconversion of physical, chemical and biological systems.
8. The study of information characteristics of quantum computers and quantum computing.
9. Formation of fundamental constraints on characteristics of information systems.
10. Estimation of the volume of information that defines the appearance and development of the universe. Estimation of mass heterogeneities containing this information.
11. Study of the universe's expansion as the causes and sources of forming information in the universe.
12. Formation of constraints on the control of the universe.
13. Formation of restrictions on the cognition of the universe.
14. The study of methods of forming classical (memorized, copied) information in the universe.
15. Analysis of information characteristics of extraterrestrial civilizations.
16. Determination of the minimal cognition subject.
17. Study on a compact representation of knowledge and conservation of the accumulated knowledge of civilization.
18. Development of information bases of the theory of quantum gravity, "Theory of Everything."

References

[1] Ursul A.D. The nature of the information. Philosophical essay. Politizdat. M. 1968. – 288 p.

[2] Kolin K.K. The evolution of informatics. Information Technologies, № 1, 2005. Pp. 2-16.

[3] Gurevich I.M. Introduction to physical informatics. The Scientific Session of IPI RAN. M. 2005.

[4] Gurevich I.M. Law of informatics-a basis of researches and designing of complex communication and management systems. (In Russian) «Ecos». Moscow (1989) 60 p.

[5] Gurevich I.M. Ursul A.D. Information - the general property of matter. The characteristics. The estimations. The restrictions. The consequences. URSS. LIBROKOM. 2011. 312 p.

[6] Gurevich Igor. Physical Informatics. LAMBERT Academic Publishing GmbH & Co. KG. 2012. 288 p.

[7] Shannon C. A. Mathematical Theory of Communication // Bell System Technical Journal. T. 27. 1948. pp. 379-423, 623–656.

[8] Kulbak S. Information theory and statistics. Moscow. Science. 1967. 408 p.

[9] Gurevich Igor. Physical Informatics – Information Methods of Natural Systems Research. tripleC - Cognition, Communication, Co-operation, Vol 9, No 2 (2011) Pp. 385-395. http://triple-c.se/

[10] Gurevich I.M. Information methods of research of laws and properties of the nature. The Third International Conference "Problems of Cybernetics and Informatics", 2010, Baku, Azerbaijan. Section #3 "Modeling and Identification". Pp. 55-58.

[11] Gurevich I.M. Informatics laws restrict and define Physical laws. The Fourth International Conference "Problems of Cybernetics and Informatics". Baku (2012).