Dear Readers,

We offer You the first number of our quarterly *Bulletin of the Polish Academy of Sciences — Technical Sciences*. Among scientists representing technical sciences there is a lot of individuals wishing to impart their scientific results and experience to others. *Bulletin of the Polish Academy of Sciences — Technical Sciences*, a continuation of the quarterly edited in 1953–2003 by the Centre for the Advancement of Science with the same title but in the different graphical shape, has come into being to meet these needs.

At present the *Bulletin of the Polish Academy of Sciences* is connected with Division IV, Technical Sciences of Polish Academy of Sciences, taking this into account it should represent publications of specialists of all science disciplines covering areas of research pursued by Division IV.

The Editorial Board has to deal with a difficult problem to satisfy both requirements: editing articles with important scientific results of technical sciences and presenting new research problems and new strategy aims of science.

We hope to satisfy our ambitions of editing a journal at the highest scientific level, evoking an interest of Polish and foreign scientists, which will be cited on ISI Master Journal List — Philadelphia List (up to 1981 the bulletin was cited on that list). I am convinced the quarterly will be important and necessary for our scientific circle and because of that the scientists of great distinction are invited to the Editorial Advisory Board of our bulletin to support it.

To make the quarterly more interesting articles of similar disciplines are grouped in “blocks” and published in the respective number of the bulletin.

The first block includes articles on: informatics, nanotechnology and optoelectronics. One of the next number of bulletin will be devoted to the machine construction, micro-mechanics, functional materials, robotics and automatics.

Important information from the Division IV such as awarded scientists, conferences and sessions will be presented here too.

I would also like to encourage readers to send us interesting and ambitious articles as well as comments and suggestions about our bulletin’s form and content. I hope that it will make an essential contribution to the popularisation of it.

Professor WŁADYSŁAW WŁOSIŃSKI
The Chairman of the IV Division of PASs

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Nano and quantum systems of informatics

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Abstract. The fundamental concepts of nano and quantum systems of informatics have been presented. The nanotechnological processes taking place in biological systems of informatics have been discussed in terms of informatics. Presented analysis shows that the application of nanotechnologies in the technical informatic systems enables realization of processes for formation of products and objects with self-replication feature, similarly to the processes existing in biological informatic systems. It seems also that the quantum technologies enable further miniaturization of the technical systems of informatics as well as make the execution time of some computing processes like, e.g. Shor's and Grover's algorithms, shorter.

Keywords: nanosystems of informatics, nanotechnologies, quantum algorithms, quantum technologies.

1. Introduction

Informatics is a discipline of science dealing with the movement, processing and transfer of information.

Systems of informatics are responsible for executing actions of information movement, processing and transfer.

Important features to note about the systems of informatics are:

1. A goal and tasks which are to be fulfilled by the system.
2. A method of coding data as well as programs for their automatic execution in the system.
3. Logic and physical structure of that part of a system, which processes the data.

Nowadays, the two best known and discussed systems include:

1. Systems of informatics that have been created for the last 60 years as a result of human activity. They provide facilities to support people in data gathering and storage as well as in implementation and completion of computational processes. These systems utilize electronic computers and their peripherals. Almost each area of human activity somehow uses or is related to those systems. We will call them technical systems of informatics.
2. Systems of informatics that have existed and developed for billions years inside of biological organisms. They provide facilities for existence, development and reproduction of those organisms. We call them biological systems of informatics.

At present, there are nano and quantum systems of informatics during numerous trials and experimental research. In particular, the essential research focuses on molecular nanotechnology and quantum technology to address issues of data gathering and processing.

A goal of this paper is to characterize biological and nanotechnical systems of informatics with a special focus on molecular and quantum systems of informatics.

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2. Technologies

Generally speaking, a technology determines a set of simple, base elements (building blocks) and, next, defines a set of operations, which have to be performed, to get the solution of a given problem including e.g. manufacturing of products, appliances or objects.

2.1. Nanotechnologies. If basic, constituent elements applied in a given technology are the elements with dimensions denominated in nanometers (prefix nano means 10^{-9}), then the technology is called nanotechnology.

2.2. Molecular nanotechnologies. Molecular nanotechnologies we call the nanotechnologies which use single atoms or molecules as basic building blocks [1–3].

Molecular nanotechnologies need systems capable of arranging an arbitrary molecule or atom in a specific order in the created structure with an accuracy of 0.1 nanometer, which is equal to the amplitude of thermal vibrations of a molecule.

The following motto is a good expression of the essence of molecular technology: "*Let's form the world atom by atom and molecule by molecule*". One of the implementations of this slogan is shown in Fig. 1.

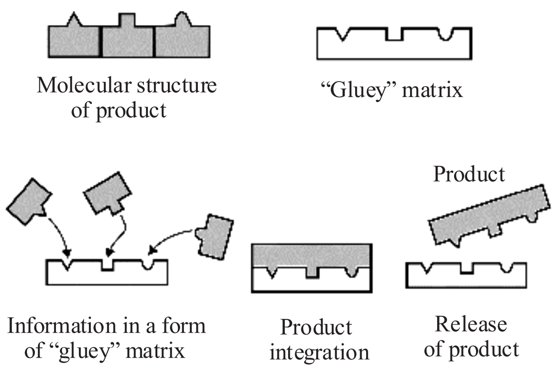


Fig. 1. An idea of nanotechnological molecular synthesis of the products

When molecular structure of a needed product is known (see Fig. 1), a nanotechnological process of synthesis may be executed in the following way: coded information about its molecular structure in a form of so called "gluey matrix" is an input into the environment of suitable, freely moving molecules. This matrix triggers a concentration process of proper molecules and, subsequently, fixes the integration of them on the surface of matrix forming the needed product.

2.3. Quantum technologies. The main idea of quantum technology is to exploit parameters of quantum mechanics in order to record and convert encoded information. A use of a multi-atom molecule as a quantum register as a one of potential implementation of that idea is shown in Fig. 2.

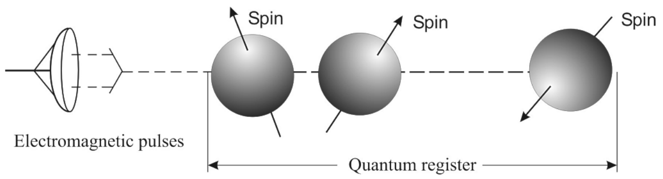


Fig. 2. Illustration of the idea of quantum technology. Implementation of molecule and its atoms as a quantum register with spins of these atoms expressed as qubit's symbols or elementary units of information

A state of this register is determined by the states of spins of atoms closed in that molecule. The spins are treated as symbols of elementary units of information called qubits, and are controlled by the external, electromagnetic pulses with properly matched frequencies.

The program execution on this quantum register is triggered by the suitable matching sequence of electromagnetic pulses forcing the spins changes in particular atoms, starting from the initial state until the final state representing result of the computation following the last pulse.

3. Nanosystems of informatics

We talk about nanosytems of informatics when the terminal symbols of used programming languages are single molecules, and the molecular technologies are technologies applied in their hardware parts.

Biological nanosystems of informatics, which can be found in biological organisms, are one of the examples of such nanosystems of informatics [4–8].

Letter symbols appearing in programs of biological nanosystems of informatics are the molecules of thymine (T), cytosine (C), adenine (A) and guanine (G) appearing in nucleotides (Fig. 3a), and texts of programs recorded in chains of DNA have a shape of double strands of the molecules as shown in Fig. 3b. Information in both strands is the same, the only difference is a formal exchange of the symbols:

$A \leftrightarrow T$

$G \leftrightarrow C.$

This double recording of a program, is later on exploited in a self-replication of the program.

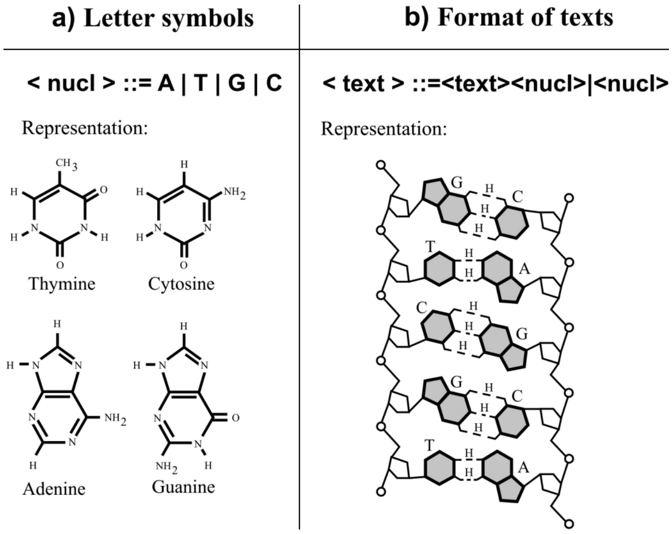


Fig. 3. Coding format of informatic programs in biological systems of informatics: a) the letter symbols of a biological programming language (nucleotides), b) a format of the informatic programs' texts in DNA

In biological nanosystems of informatics, the DNA chain, which is usually in a cell nucleus, performs a function of the secondary or external basic storage which parts of basic programs can be extracted and next sent from the cell nucleus into cytoplasm, where the process of technological operation for the manufacturing of the needed product takes place (see Fig. 4).

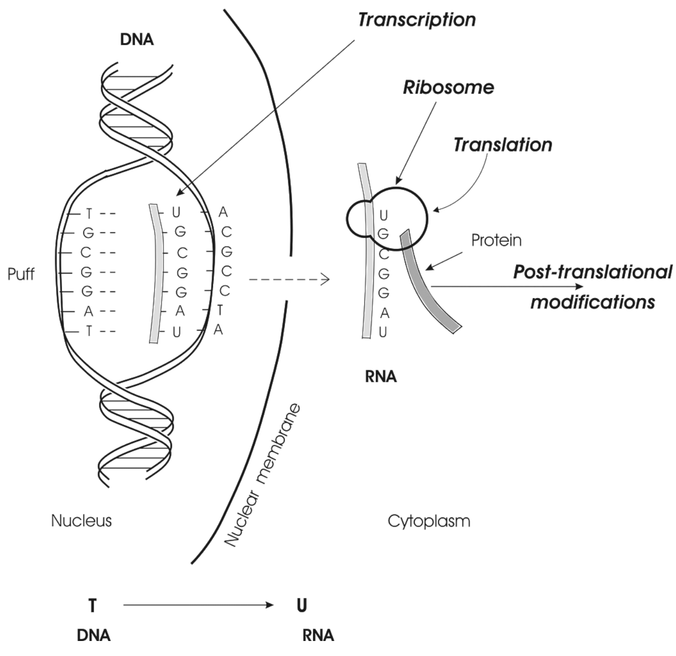


Fig. 4. Illustration of appliance structure in biological systems of informatics realizing a process of synthesis of the desirable product

Foregoing the transfer of a given fragment of DNA program from cell nucleus to the cytoplasm, the text of that piece is rewritten in a so-called RNA text. This is a single text in which the molecules T (thymine) have been interchanged to the molecules U (uracil) such as presented in Fig. 5.

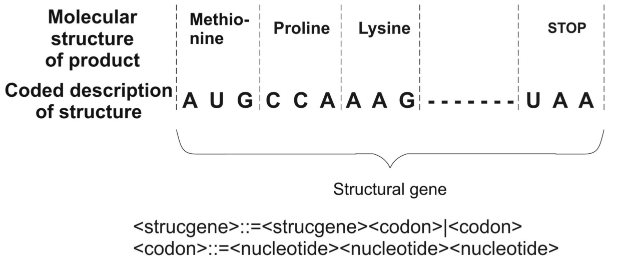


Fig. 5. Code description of a product structure in RNA matrix

In this notation, triplets of following letters representing the triplets of consecutive nucleotides or codons exist, so we may write:

$\langle$codon$\rangle$::=$\langle$nucleotide$\rangle\langle$nucleotide$\rangle\langle$nucleotide$\rangle$

$\langle$nucleotide$\rangle$::=A|U|G|C

Table 1 shows the correspondence between codons and proper molecules of amino acids forming the proteins needed in organism.

A sequence of codons in RNA is the same, as a sequence of amino acids in the protein under construction.

Table 1
Amino acid codons in RNA

Amino Acid	Codons					
Alanine	GCA	GCC	GCG	GCU		
Arginine	AGA	AGG	CGA	CGC	CGG	CGU
Asparagine	AAC	AAU	U			
Aspartic acid	GAC	GAU				
Cysteine	UGC	UGU				
Glutamic acid	GAA	GAG				
Glutamine	CAA	CAG				
Glycine	GGA	GGC	GGG	GGU		
Histidyne	CAC	CAU				
Isoleucine	AUA	AUC	AUU			
Leucine	UUA	UUG	CUA	CUC	CUG	CUU
Lysine	AAA	AAG				
Methionine	AUG		(initiation codon)			
Phenyloalanine	UUC	UUU				
Proline	CCA	CCC	CCG	CCU		
Serine	AGC	AUG	UCA	UCC	UCG	UCU
Threonine	ACA	ACC	ACG	ACU		
Thryptophan	UGG					
Tyrosine	UAC	UAU				
Valine	GUA	GUC	GUG	GUU		
STOP codon	UAA	UAG	UGA			

A coded text defining alignment of amino acids in protein to be formed is called a structural gene. In DNA, the number of different genes, which are coding the proteins, is smaller than the number of the types of proteins existing in biological organisms. This is due to the fact, that the protein with the linearly ordered amino acids sequence according to the code contained in DNA, is not a final product. That protein is an intermediate product, which has to undergo different modification processes [9–12] as determined by the particular needs of organism. These modifications define so-called post-translational modifications (Fig. 4).

An illustration of informatic synthesis process for the hypothetical molecule of protein is presented in Fig. 6 through Fig. 8. A linear structure of the protein contains of six linearly bonded amino acids: methionine, arginine, glycine, proline, glycine and alanine. Consequently in DNA, the molecular, linear structure of this product according to the relations presented in Table 1, is coded in the following form:

Template strand of DNA

– TACGCACCAGGACCACGA –

Coding strand of DNA

– ATGCGTGGTCCTGGTGCT –

Basing on Tinker [13] and RasMol [14] programs, the graphic visualization of this fragment of DNA coding of the molecular structure of discussed product, is presented in Fig. 6.

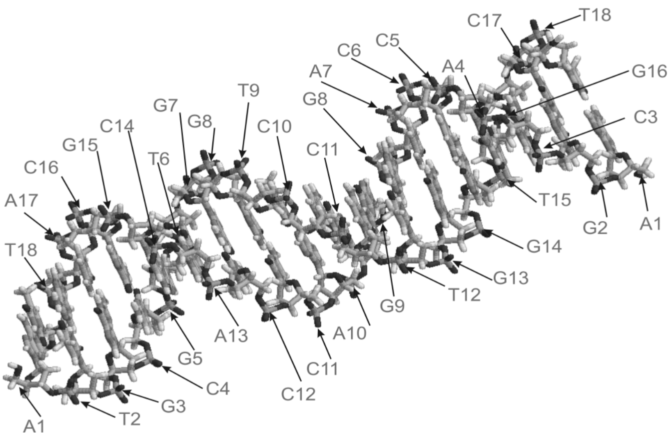


Fig. 6. Fragment of DNA coding the structure of the exemplary protein

As a result of transcription, the RNA strand is created as complementary to its DNA template (the RNA has the same base-sequence as the coding strand of DNA except for uracil in place of thymine) getting the following form:

Strand of RNA

– AUGCGUGGUCCUGGUGCU –

The RNA helix, which establishes the "gluey matrix" for the discussed product is presented [14] in Fig. 7.

An RNA matrix determines the sequence of synthesized amino acids. According to the recorded code in

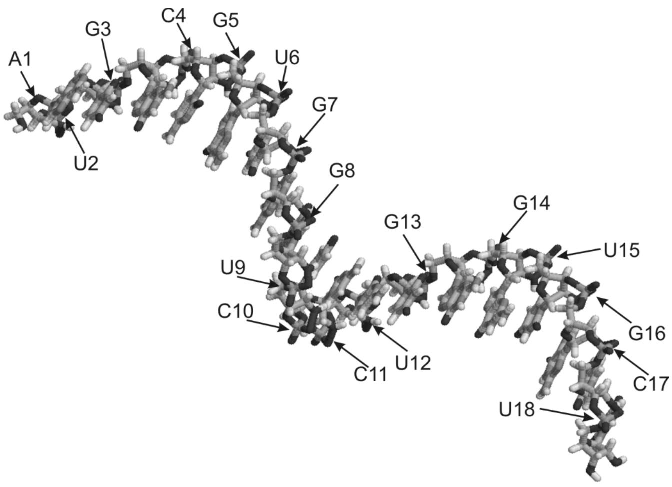


Fig. 7. RNA polymer establishing a "gluey matrix" for the exemplary protein synthesis

RNA, the discussed RNA determines the following sequence of amino acids:

Methionine – Arginine – Glycine – Proline – Glycine – Alanine

A molecular shape of created product is illustrated [14] in Fig. 8.

A phenomenon of cell self-replication process is critical for functioning of systems of informatics in biological organisms [15–18].

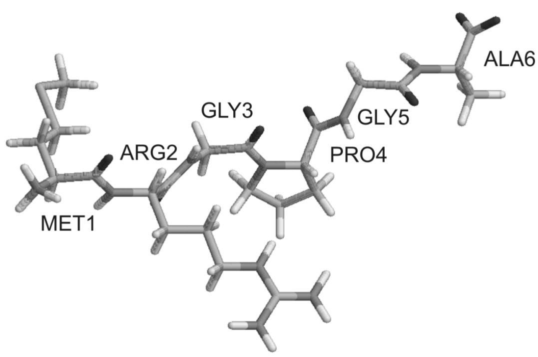


Fig. 8. Molecular shape of a protein created in a molecular synthesis process

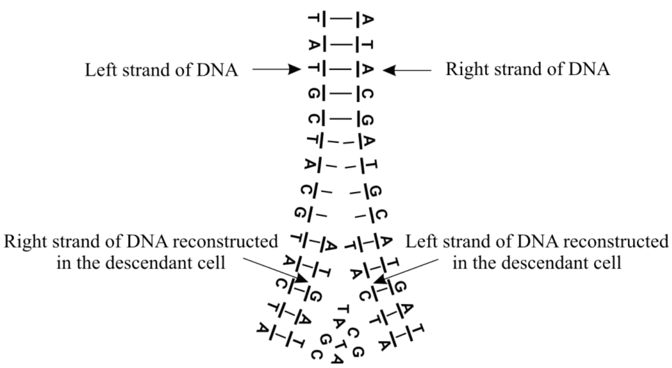


Fig. 9. Process of DNA-chain self-replication

Generally, we may distinguish a simple self-replication of programs and objects as well as a combined self-replication observed e.g. in case of biological objects, i.e. self-replication of the objects with their internal software [19].

For illustration of a self-replication process for the programs recorded in a DNA chains see Fig. 9. An illustration of a connective self-replication process of object with internal software is presented in Fig. 10.

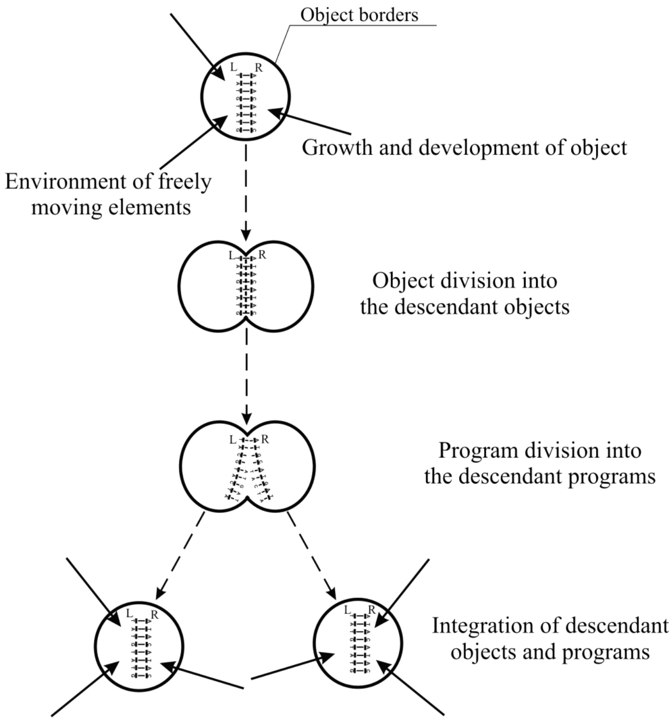


Fig. 10. A connective self-replication process of object with internal program

3.1. Technical nanosystems of informatics. When the terminal symbols of programming languages used in an informatic system are single molecules, and the molecular technologies are technologies conformed to their hardware parts, such a system is called a nanosytem of informatics. We have discussed the biological nanosystems of informatics as a one of example of such nanosystems.

Presently conducted research on technical nanosystems of informatics focuses on developing systems that would imitate biological nanosystems and would execute manufacturing processes that would compete with the synthesis of the demanded products basing on respective informatic programs.

A widespread approach in the design process of technical nanosystems is the utilization of the self-replication and self-organization concepts as the basic features of those systems.

In the first stage, accordingly to the self-replication concept, the system creates copies of elementary manufacturing units (so called assemblers) [12]. In the next stages, when a sufficient number of assemblers occurs, the system moves onto the self-organization phase, essential part of the process. The self-organization process performed on a basis of internal program possessing instructions on object construction (similar to DNA in living organisms), delivered a structural flow chart or control signals sequence, leads to synthesis of expanded structures exploiting additionally the matter from environment and the energy provided from outside (Fig. 11).

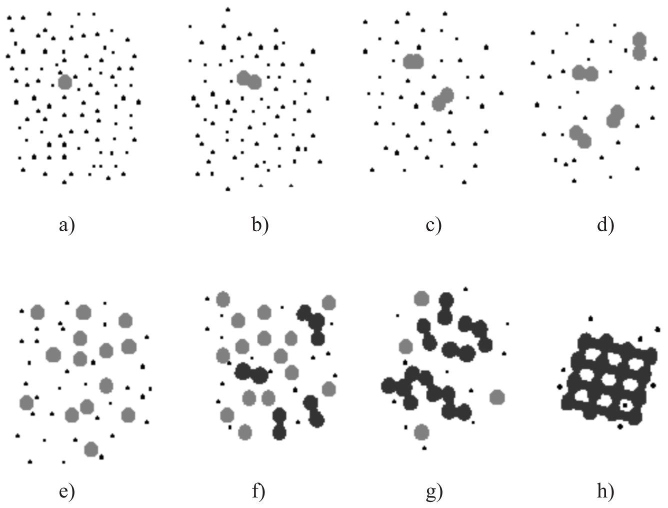


Fig. 11. Self-replication and self-organization in a manufacturing process: a) assembler with internal program of the object construction inserted into the system, b) start-up of the self-replication process, c), d) consecutive self-replication phases with accessible matter processing, e) the end of self-replication phase — an expanded structure preparation (self-organization), f), g) consecutive self-organization phases, h) the manufactured structure

4. Quantum systems of informatics

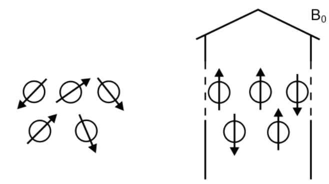
A nuclear magnetic resonance is a basic phenomenon taken into consideration in a current research on quantum computers representing a particular behaviour of the atom's nucleus described by quantum mechanics.

In some cases, this phenomenon consists in resonance absorption of electromagnetic energy in solids, fluids and gases. It is related to the internal angular momentum or spin and magnetic moment, which is observed in the nucleus of elements with odd number of protons or neutrons.

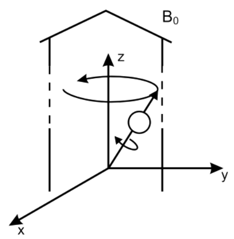
In case of a lack of an external magnetic field, directions of magnetic moments are arranged randomly (Fig. 12a).

When the examined object is placed in a fixed magnetic field with magnetic flux density B_0, then some of nuclei with initially randomly assigned directions of the magnetic moment, will be put in an order with reference to the direction B_0 in parallel or anti-parallel position (Fig. 12a).

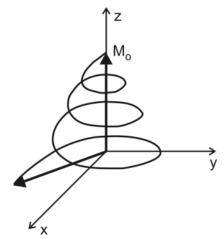
Independently of those two possible positions, the vector of angular momentum rotates in a cone-shaped space, with the atom's nucleus placed on the vertex of cone. This kind of a movement is called *precession* and is caused by the action of external magnetic force (Fig. 12b).



a) Directions of the magnetic moments without and within static magnetic field



b) Precession of the vector of magnetic moment



c) Return of the moment M_0 to the initial state

Fig. 12. An illustration of spin directions in the external magnetic field

The frequency of precession movement depends on magnetic flux density B_0, and can be expressed as Larmor's formula:

$$f_0 = \frac{\gamma \mathrm{B}_0}{2\pi} \quad \text{or} \quad \omega_0 = \gamma \mathrm{B}_0,$$

where γ is the gyromagnetic constant.

In thermodynamic equilibrium, a number of nuclei placed in parallel with direction B_0 (which corresponds to the lower energy level of magnetic state) is greater than number of nuclei in anti-parallel position. Small magnetization (resultant moment of magnetization) M_0 will be recorded in the object, as presented in Fig. 12c.

We can tell then, about the control and echo signals, such as shown in Fig. 13.

There is some research on possibility of utilizing a nuclear magnetic resonance in execution of computing processes applicable in a field of informatics.

In the empirical structure of a quantum computer presented in Fig. 14, the pipe with fluid of known composition and structure is placed in a static magnetic field with magnetic flux density B_0.

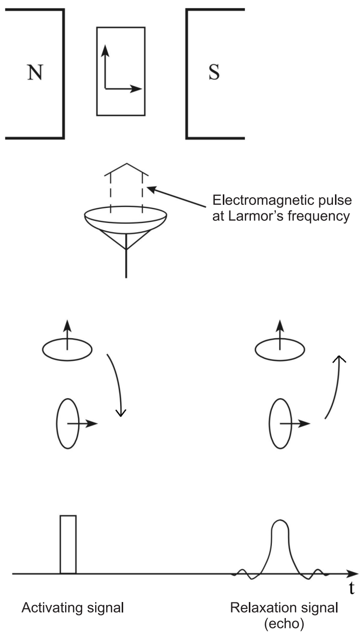


Fig. 13. Control and echo signals

Moments of individual atoms in fluid's molecules are considered as qubits' symbols or elementary computing units. The computation process is a program execution performed through introducing a series of properly established electromagnetic pulses that change the spin's states or the states of qubits, and finally read-out their final states — in other words — the result.

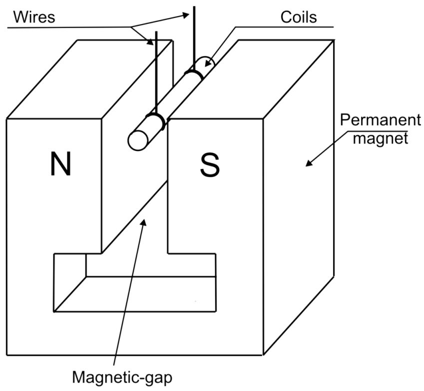


Fig. 14. Structure of an empirical quantum computer

In experimental works of N. Gershenfeld and I. Chuang [20], chloroform ($CHCl_3$) has been used as a required fluid. Chloroform's molecules are composed of carbon (C), hydrogen (H) and chlorine (Cl) atoms. Since a carbon 12 nucleus has no spin, the authors used the carbon isotope with additional neutron, which imparts the necessary spin to the nuclei.

C and H atoms are placed in the chloroform molecule side by side, and therefore are mutually dependent on the state adjoining one. Following experiments have been performed: with initial spin of C parallel to the direction B_0, with a different position of the spin of H, pulses of a variable magnetic field influencing the spin of C were introduced subsequently.

The first one has rotated the spin position of C about 90°, the second one by another 90° to either parallel or anti-parallel position — depending on the direction of the spin of H. For parallel position of the hydrogen, an external pulse has rotated the spin of C by about 180° from its initial direction, while for anti-parallel position of the spin of H, it has been restored to the initial direction. The process is illustrated by the table in Fig. 15.

The behaviour of the spins of C and H can be described by logic equations. Let's denote the spin's state of the hydrogen atom by "a", and the spin's state of the carbon atom by "b", and assume:

$$\mathrm{a} = \begin{cases} 1 & \text{if the spin's state is parallel} \\ 0 & \text{if the spin's state is anti-parallel} \end{cases}$$

and similarly for carbon:

$$\mathrm{b} = \begin{cases} 1 & \text{if the spin's state is parallel} \\ 0 & \text{if the spin's state is anti-parallel} \end{cases}$$

then b_1, the state of the spin of carbon C after two successive 90° electromagnetic pulses, can be expressed in the form:

$$b_1 = b \oplus a,$$

where symbol $\oplus$ denotes the sum modulo 2. This is called a controlled-NOT or CNOT operation. It has been presented in a schematic form in Fig. 16. It is called a Toffoli quantum gate.

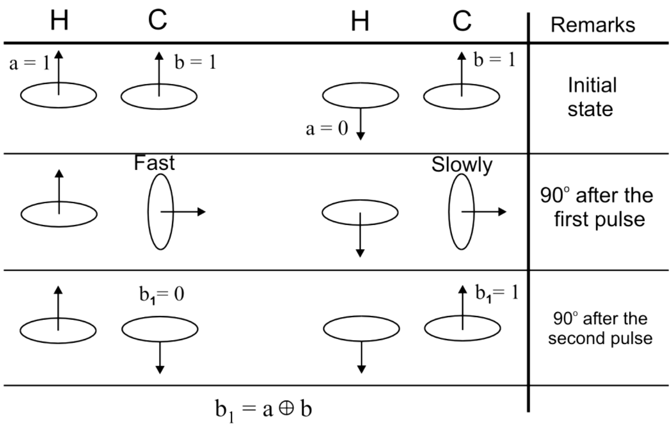


Fig. 15. Gerschenfeld and Chuang's experiments with the chloroform $CHCl_3$ molecule

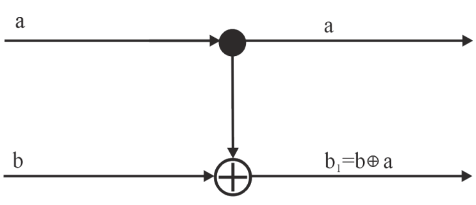


Fig. 16. Schematic denotation of Toffoli's quantum gate

At the present moment, scientists carry out research on relations taking place between the spins of several neighbouring atoms in a given molecule (Fig. 17). Researchers also consider a possibility to construct a quantum computer using ions trapping and quantum dots in a solid.

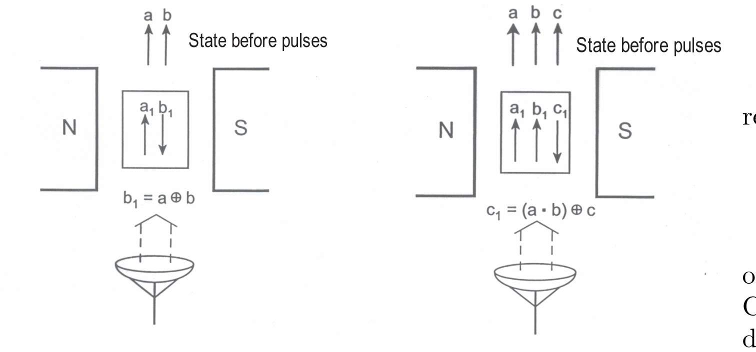


Fig. 17. Control of spin directions by the external electromagnetic pulses

5. Quantum computations

The basic concepts of quantum computations are: qubits, superposition of quantum states, quantum systems of n qubits, quantum gates and quantum circuits [21–24]. Each qubit has two separate basic states denoted by $|0\rangle \in C^2$ and $|1\rangle \in C^2$ and if we think of qubits as spins of atoms, then these states are "spin up" and "spin down", respectively. Moreover, it should be pointed out, that each linear combination of the basic states, with complex coefficients, is also a quantum state, which is two dimensional vector in the linear complex space C^2. Hence each qubit may be expressed as normalized vector of the following form:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle,$$

where $\alpha \in C$ and $\beta \in C$ are complex coefficients such that $|\alpha|^2 + |\beta|^2 = 1$.

Generally, quantum system of n qubits may be considered as 2^n-dimensional normalized vector in the complex space C^{2^n} which is a tensor product of n-copies of the space C^2, i.e.:

$$C^{2^n} = C^2 \otimes C^2 \otimes ... \otimes C^2.$$

The linear complex space C^{2^n} is the state space for our quantum system of n qubits.

For a given 2^n-dimensional quantum system C^{2^n} we may define quantum operators named also quantum gates, which are represented by $2^n \times 2^n$ dimensional unitary matrices. Since unitary matrices are always invertible, hence all quantum operators are reversible. Therefore, unitary operator $U : C^{2^n} \to C^{2^n}$ transforms quantum state $|\psi\rangle \in C^{2^n}$ into quantum state $U|\psi\rangle \in C^{2^n}$.

For example, for the case $n = 1$ we have the following typical unitary quantum operators:

Identity operator denoted as I (quantum gate I) represented by 2×2-dimensional unitary matrix

$$U_I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

Negation operator NOT (quantum gate NOT) represented by 2×2-dimensional unitary matrix

$$U_{NOT} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}.$$

Hadamard operator H (Hadamard quantum gate H) represented by 2×2-dimensional unitary matrix

$$U_H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}.$$

Moreover, for $n = 2$ the most frequently used quantum operator is a *controlled negation* CNOT (quantum gate CNOT or Toffoli quantum gate) represented by 4×4-dimensional unitary matrix

$$U_{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}.$$

Toffoli quantum gates may be easily generalized for greater dimensionality, for example in the case $n = 3$ we have the following CNOT quantum gate represented by the 8×8-dimensional unitary matrix:

$$U_{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}.$$

The suitable defined system of quantum gates forms quantum circuits, which are an extension of the well known Boolean circuits. Hence, quantum circuit realizes certain quantum operation.

Quantum computations may be imagined as finite sequences of quantum operations represented by unitary transformations performed on the quantum states belonging to the state space of a given quantum system. The most important difference between classical computations and quantum computations is that in the classical case we operate with bits which may exist only in two states 0 and 1. In contrast in quantum computations we work with qubits, which are two dimensional normalized complex vectors in the linear space C^2.

Quantum computer uses principles of quantum mechanics for basic operations. Therefore, quantum computer may be seen as a physical system operating according to laws of quantum physics and every time evolution of this system can be considered as an information process. Roughly speaking, quantum computer transforms the initial given quantum state $v_0 \in C^{2^n}$ into the final quantum state

$$v_f = U_N U_{N-1} ... U_k ... U_2 U_1 v_0 \in C^{2^n},$$

using a finite sequence of suitable defined unitary quantum transformations

$$U_N U_{N-1} ... U_k ... U_2 U_1$$

represented by unitary matrices of appropriate dimensions.

Actually, the most evident motivation for studying and developing the idea of quantum computer and quantum computations is the technological progress in physical realization of quantum gates and quantum circuits. Finally, it should be pointed out, that in recent years interest in quantum computations has grown extraordinarily and hence, the possibilities in organizing quantum computers looks very attractive.

6. Quantum algorithms

Quantum systems of informatics make simultaneous execution of multiple computing processes possible. In case of some algorithms, they imply a dramatic decrease in the execution time. As an example, we present two such algorithms: Grover's search algorithm and Shor's quantum factoring algorithm.

6.1. Grover's search algorithm. The goal is to search for a specific element $x_i = \nu$ in the set of N data $\{x_i,\ i = 1, 2, 3, ..., N\}$, which is not put in any specific order (disordered set).

Classic searching algorithms would require on average about $N/2$ steps to find the specific element. Grover's quantum search algorithm is significantly faster and needs on average about $\sqrt{N}$ steps. The idea of the algorithm is following: each element of the set is indexed by i, and the search problem is limited to determining the index pointing to the desired element in the set, basing on unitary transformations [25].

6.2. Shor's prime factorization algorithm for large natural numbers. This algorithm is a quantum algorithm of polynomial computational complexity, designed for quantum computers, decomposing large natural numbers into prime factors. The essence of the algorithm [26] is to reduce the problem of finding a divisor of a natural number N to determining the period of the function $f_{a,N}(x) = a^x \mathrm{mod} N$, where a is a random natural number smaller than N, which can be written as:

$$\mathrm{GCD}(a, N) = 1.$$

For example, let a divisor of N found in this way be p. So $q = N/p$ will also be a divisor of N. Repeating this procedure to find divisors of those divisors, all prime divisors of N can be found, which completes the factorization of N.

7. Nanoscience

Many scientific discipline emerging from recently elaborated principal directions focus on the analysis of phenomena and processes occurring in nano-scale — on the surfaces of atoms and molecules. Such processes need to be understood and investigate while implementing design processes for specific appliances or systems.

Nanoscience is a new science domain that has formed to address those issues [12, 27–29]. In informatics we expect to implement the knowledge from this area in solving some actual problems like e.g. nanotechnical or quantum systems of informatics.

In case of nanotechnical systems of informatics the idea is to support a man not only in his computational tasks, but also in direct implementation of those systems in the production processes for selected products, similarly to the processes existing in biological systems of informatics.

The second critical direction of the informatics development is a substantial acceleration in a computation speed. It seems that the quantum systems of informatics in some cases make the execution time of some computing processes like e.g. prime factorization for very large natural numbers (Shor's algorithm) or data searching (Grover's algorithm) shorter.

In both cases, a crucial driver is the advantage of new technologies such as molecular or quantum technologies. This is illustrated in Figs. 18 and 19.

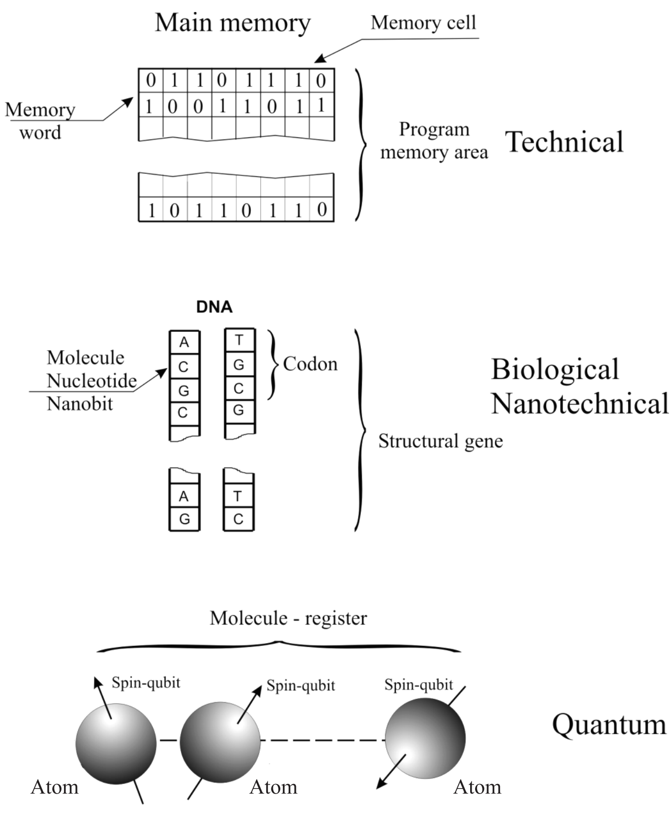


Fig. 18. Logic and physical structures of memory in technical, biological, nanotechnical and quantum systems of informatics

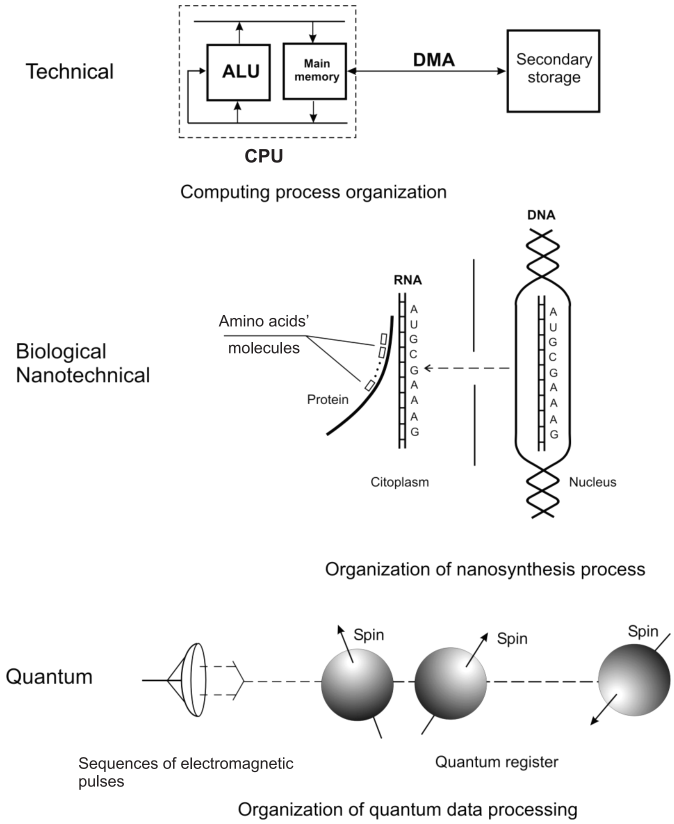


Fig 19. System structures of information processing in technical, biological, nanotechnical, and quantum systems of informatics

Figure 18 presents logic and physical structures of memory in technical, biological, nanotechnical and quantum systems of informatics. In technical systems of informatics e.g. a structure of main memory consists of the ordered set of rows called memory words (memory location), each of them assembled with memory cells. The two possible states of memory cell in case of electronic flip-flop, give two possible values of bit represented by this memory cell.

In biological and nanotechnical systems of informatics, a memory is represented by a DNA chain consisting of ordered set of molecules forming nanobits. In case of e.g. biological nanosystems of informatics these are thymine, cytosine, adenine and guanine molecules. In case of quantum systems of informatics, a memory is represented by the particular quantum registers composed of molecules. Spins of atoms in these molecules represent qubits.

System structures of information processing in different systems of informatics are presented in Fig. 19.

In technical systems of informatics, a Central Processing Unit (CPU) consists of a main memory and an Arithmetic Logic Unit (ALU) performing the arithmetic-logical operations on the input data.

In biological nanomolecular systems, a hardware part of a system sets a mixture of freely moving molecules (building blocks) with a template matrix put into system. Information contained in the template matrix has a format which establishes a core process of ordering and integration of the building blocks on the surface of matrix forming the needed product.

In quantum systems of informatics, data processing is performed in quantum registers. Processing is determined by the registers stimulation with the sequence of electromagnetic pulses characterized by the suitable frequencies and the proper time period fixed between them.

In order to approach informatics in a consistent manner presenting it as a science dealing with information movement and processing, following subdisciplines could be distinguish:

— technical systems of informatics,
— biological systems of informatics,
— nanotechnical systems of informatics,
— quantum systems of informatics.

Biological, nanotechnical and quantum systems of informatics are entirely based on nanotechnologies, while technical systems of informatics to the greater degree exploit the nanotechnologies:

• complete up-grade from the electronic data transmission to fiber-optic transmission,
• in fiber optics, the research is conducted to replace time multiplexing with the light wave-length multiplexing,
• the investigations are conducted on introduction of the Optical Data Processing to the Internet, and to move from so called Optical Internet to the Fully Optical Internet.

7.1. Final remark. Generally speaking, nanoscience [27] or a science of structures and phenomena appearing at the borders of atoms and molecules in a nano-dimensional range, has just started to play a crucial role in the development of many scientific domains including informatics, and has currently become one of the leading trends in nowadays research.

8. Conclusions

Parameters of the discussed systems of informatics and the currently used classic technical system are presented in Table 2, which can be considered as a beginning of the history of informatics evolution as a discipline of sciences dealing with the information movement and processing in technical devices and alive organisms.

Presented analysis shows that thanks to the nanotechnology used in the technical system of informatics, it will be possible to reach features of biological systems of informatics. In other words, processes of nano miniaturization and realization of self-replicating products and objects in the informatic systems would be achievable. On the contrary, the quantum systems of informatics will enable as it seems, a radical shortening of a time required to complete certain operations e.g. searching information in a huge set of data (Grover's algorithm) and factoring natural numbers (Shor's algorithm).

Table 2
Basic parameters of the discussed systems of informatics and the currently used classic technical system

Name	Age	Target	Symbols of alphabet and their representation
Technical	60 years	Support of the realization of computing processes	Bit ::= 0|1 Macrocircuits
Biological	Billions years	Origin and development of the life on the Earth	Nucleotide ::= $A\|G\|C\|T$ Molecules
Nanotechnical	Formation	Products and objects forming	Nanobits Molecules
Quantum	Elaboration	Data searching	Qubit ::= $\alpha\|0\rangle + \beta\|1\rangle$ where: $\|0\rangle$, $\|1\rangle$ are orthonormal base vectors spins

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