BIO-TECHNOLOGIES IN COMPUTING: THE PROMISES AND THE REALITY

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In this paper we try to answer the question how the knowledge of biological processes can be used in computer science. It is well known that understanding of such processes and phenomena was quite useful to develop computer theories and practical applications of computers. For example, Artificial Neural Networks (ANNs) are modeled on some models of brain, genetic algorithms (GAs) are based on evolutional principles of living organisms, and the fuzzy logic models real decision-making with information partially unknown or incorrect. On the other hand, information from biological objects has unique features that help in person's identification and recognition. For solutions of many tasks that cannot be solved with modern computer paradigms, the researchers turn to bio-systems. Therefore, the research area of bio-computing is being established, based on some principles of organization of living objects. In this paper we analyze selected recent achievements in this domain, and we discuss mapping bio-technologies into computer science problems. Identification and recognition of biological objects based on feature extraction from biometric data (voice, thermal images, fingerprints et.al.) is considered.

1 Introduction.

Bio-informatics is a quickly developing scientific direction. It studies processes of creation, transmission, reception, storage, processing, displaying and interpretation of information in all channels of functional and signaling systems of living objects studied by biological and medical sciences[21]. At present, modern natural sciences are in a need to update their image of the world. We believe, the essential contribution can be made by the biometric and biomedical methods.

So far, only the simplest (i.e. statistical) forms of bio- information have found their applications (to person's identification), but their success raised general expectations with respect to using these identification methods in information technologies. Recently it has been intensively studied how to use the bio-principles to other applications, for example, in computing based on biomolecular and DNA principles [22].

Bio-informatics is an interdisciplinary discipline that uses results from biology, medicine, genetic engineering, computing sciences and others. Two main directions of modern bio-technologies are especially attractive for many applications: (i) identification of biological objects and (ii) technical realization of some principles of organization of biological objects. Here, we will concentrate on these directions only.

First direction, used for identification of biological objects, uses special type of information, the so-called *biometric information*. This information (extracted from voice, fingerprint, handwritten samples, hand geometry and other), is processed by methods of recognition, identification, image analysis and so on. Biometric methods can be classified as *contact* and *non-contact*. For example, the recognition of biological objects by voice or identification of a person by eyes, do not require contact with the biological objects, so that these methods of recognition and identification are classified as *non-contact* methods. The *contact methods* need direct or indirect contact with a biological object. For example, person's identification methods based on fingerprints or signatures need physical contacts with paper sheets or special devices for inputting respective data features to a computer. Note that many more exotics methods have been also reported. For instance, the electromagnetic fields as a recognition object are intensively investigated at present. New results have been also obtained in fractal analysis, which explained some paradoxical phenomena such as morphogenetic fields, distant cells communications, anomalously high sensitivity of organism to near-zero frequency perturbations, regulation processes critical dependence on the fractal features of noisy environment, etc. [6,24].

The main idea of the second direction is developing new paradigms for computer science based on some principles of organization of living objects, including their intellect. A number of well known examples can be cited here. *ANNs* resulted from the study of a human brain. *Genetic algorithms* are directly inspired by Darwin's theory of evolution. These algorithms constantly mutate into new software patterns. Once a better way to solve a problem is found, the improved method is adopted, and the mutation and selection cycle start all over again. *Fuzzy logic* is the result of studying the ways how humans make decisions in many situations in which non-correct and uncertain information is involved. Fuzzy logic methods are already used for many practical applications such as the automatic camera deciding which part of image should be in focus. Fuzzy logic is a more realistic model of thinking process in some cases. Also, some very advanced, machine-learning approaches, called

Constructive Induction are applied to recognize patterns in complex data and to analyze problems [18,19], thus forming one more biologically inspired model of human thinking, applied to recognize biological patterns. Apparatus of multiple-valued logic, fuzzy logic and abductive logic is used to extract hierarchies of new concepts from rough data such as databases, functions, images or experimental measurements. Similarly to ANNs, the constructive induction approaches can be used with any preprocessing/postprocessing methods to create systems for automatic knowledge acquisition, thus creating, for instance, medical diagnostic systems.

Very promising approach to design new generation computer systems is based on biomolecular and DNA principles, recently intensively studied [22]. Biomolecular computer is based on a dynamism of biomolecular activities. High efficiency of this computer is related to parallel distribution of logical information represented by varieties of biological molecules [1]. It can be stated that the main advantage of biomolecular computing is its *massive parallelism.* Unfortunately, biotechnological infrastructure is not yet mature enough, so that we cannot practically use the biomolecular computers yet. However, because they are based on pattern matching operations, they are well suited to be modeled in a new type of digital computers, reconfigurable computers, [2] which are based on fast hardware reprogrammability using Field Programmable Gate Arrays. This will allow to create and evaluate DNA algorithms and answer many practical questions even before the biomolecular computing will become a mature technology.

It is important to understand achievements in these new directions of computer research and technology because their synergy can be used both ways; to create new application method for solving biology-related questions with existing computer technologies, and to create new computing principles based on understanding of biological phenomena. Thus, the organizational principles of living objects will be used in bio-information processing applications, which in turn will be using new general or specialized computing principles derived from our new understanding of biological phenomena. From this quite general starting point, we can now anticipate new approaches to solve problems. This paper is an invitation to a discussion. We are looking for answers to the following questions:

- Which type of knowledge about living objects is already used in computer theory and industry?

- How the bio-principles and bio-concepts can be introduced to computer science?

2 Terminology.

We were not able to find a clear definition of *bio- informatics* in many studied references. However, the main feature of this research area can be clearly stated: using biometric information and biometric concepts (principles). The information obtained from biological objects is called *bio-information.* The methods, algorithms and tools for bio-information processing are called *bio-technologies.* Bio-information and bio-technology are quite general concepts and they include *biometric information* and *biometric technologies* (Figure 1). In many papers and in common use these terms are treated equivalently with terms *person's identification* and *recognition methods and tools.* Many types of information are being used: acoustic, visual, electromagnetic. Many methods and algorithms of computer science are based on different bio-principles: evolutionary principles in genetic algorithms, principles of brain's structure in ANNs, principles of biomolecular structure and dynamism of biomolecular activities in bio- computers (Fig. 1).

3 Classification.

It would be very useful to try to classify the bio-information and the bio-principles that are being already used in bio- computing, or that may be used in the future. The classification presented below is far from being complete. We can evaluate, however, the state of the art in many directions of computer science and engineering which either use biometric information or are based on some biometric principles. Modern methods and devices extract the bio-information from biological objects in many ways. Fig. 2 illustrates some of the more popular nowadays: from the visual image, voice (acoustic), size and configuration (geometry), thermal image, biomolecular, and the electromagnetic field. By processing of the extracted information we can obtain unique features of a living objects. Now these approaches are used mostly for person's authorization and recognition, and in medical diagnostics applications, such as pap-smear analysis, or breast cancer detection. But the goal of study can include also various other fields (such as electromagnetic) related to living objects, as well as how to control such fields. Answers to these questions will open new possibilities in communication, computation, diagnostics and therapy [21].

4 Levels of Understanding and Modeling of Biological Objects in Computer Science.

Fig. 3 illustrates the living object principles which are the basics of approaches in computing. Fig. 4 illustrates our viewpoint on levels of applications of understanding of biological objects. They are also mapped to respective computer science problems. The first level includes methods and tools used to solve problems involving analysis of biometric information. Predominantly, the problem of person's authentication and recognition (*biometrics technology* - BT). The second level is based on using biometrics principles and concepts in computational approaches to solving problems. For example, ANN is the model of brain's construction, genetic algorithm is the model of evolution, fuzzy logic is the model of making decision when part information is unknown or have fuzzy character. At the third level, the principles of biomolecular structures, are used in approaches to computing. The main feature of this level is that real biomolecular structures are used, and not their models. The research issue is to find methods of building and controlling the bio-molecular processing devices and systems. The fourth level includes principially new and tremendous opportunities in communication and computing. Recently, many phenomena of living objects related to special kinds of fields have been studied. In some papers the results were reported of experiments with such fields, which can be considered as a new type of memory, an environment of processing and communication. In few cases these fields can be controlled. Note, that developing and improving practical applications of our knowledge of living objects at the first level is based on achievements of the second level. For example, ANN, GA and fuzzy logic are powerful tools in studying and processing of biometric information. In other words, it means that for study of biological objects, the methods based on bio-principles are used, a fact that has deep philosophical meaning. Respectively, some papers forecast that this trend will tend to even increase in the next levels of practical applications of knowledge about biological objects.

5 State of the Art of Biometric Technologies.

Nowadays term BTs means: voice and speech recognition, dynamic signature and handwriting capture, eyes (iris and retinal) identification, hand geometry, fingerprint (palm print) identification, face recognition and keystroke dynamics (Figure 5). In a number of cases, thermal imaging of living objects is also used [7]. Many investigation areas of biometrics are studied, but they have not yet outgrown their laboratory phase, so we don not discuss them (although many experts predict development of non-touch BT methods, i.e. methods to allow identification of a person at distance.

The areas of BT applications grow dynamically, and problems of information safety become priority for the present stage of development. The hopes in BT are in many respects justified and their use gives frequently good results. The modern BT applications concentrate mainly on the following areas: medical technology, law and order, banking and finance, immigration control, visual and voice communication, access control. No doubt, everybody already encountered some biometric devices.

5.1 Fingerprints Identification.

The application which most people are familiar with in this area are Automatic Fingerprint Identification Systems (AFIS) as used by police forces across the world (PRINT-PAK-ORION Systems, MORPHO Systems, NEC Systems, COGENT Systems, and others). BTs have quite a long history in this application (from the mid 1880) and enough experience accumulated in criminology [6]. The problem of automation of this activity has been solved during last decades, and rather impressive results were achieved. Numerous other applications of the fingerprint authentication products are, as a rule, special cases of AFIS. Most automatic systems for fingerprint comparison are based on minutiae matching (local discontinuities in the fingerprint pattern). The American National Standards Institute has proposed a minutiae classification based on four classes: terminations, bifurcations, trifurcations and undetermined [5]. Many approaches to automatic minutiae extraction have been proposed, recently [10,14,15]. However, always the following technology is realized: Inputting the fingerprint image, Improvement of legibility and smoothing out, Outlining, Binarization, Thinning, Extraction of minutiae. It is typical for the fingerprint image that the finger is usually not printed uniformly: one part of it is extremely light and other part dark, so the methods based on global threshold finding fail. There are also other causes to make necessary the pre-processing of fingerprint images. Thus, for example, an ANN method based on self-organizing feature maps was proposed for fingerprint classification [10]. The results show that an ANN trained with a sufficiently large and representative set of samples can be used as an indexing mechanism for a fingerprint database, so that it does not need to be retrained for each fingerprint added to the database. ANNs are often applied to compress fingerprint images: by learning with self-supervision, ANN finds near-optimal clustering from image data and builds a compression codebook in weight connections.

5.2 Signature and handwriting authentication.

Nowadays automatic investigations of handwritten objects such as: handwritten text, signature, short letter, notes, have been widely used; to confirm the document authenticity in the financial sphere; to solve the expert problems in criminology; to diagnose the physical and psychic state of patients in medicine; to make the psychological individual analysis in psychology, and others. This area of BT is well explored by specialists in graphology, psychology and medicine, and modern systems apply often results obtained in criminology. However, many top approaches differ essentially from the classic ones. Computer analysis of handwriting is a very interesting research area. Most of the work done has used real-time input, so that the time sequence of strokes in the signature and handwriting is known [9,26,30,33]. Automatic reading of unknown signature and handwriting is a difficult problem. Signature and handwriting varies greatly, even for a single individual. It is hard to segment an unknown signature and handwriting words into letters or strokes. This becomes much easier, although still not trivial, when the words are known (the case of the signature of a known person). The task of handwriting object verification is to determine whether a given signature or handwriting is genuine or a forgery. Many papers consider the problem of detecting free-hand forgeries, where the forger made no attempt to simulate or trace a genuine signature. In the latter case, the forged handwriting object has the proper shape, but differs from the genuine object in the quality of the strokes. It should be noted, that the ways to solve the problems of authentication signature and handwriting are different. It is connected with the fact that the problem of signature verification is always solved in the conditions of indefinite information. Therefore in graphology an additional information is frequently used, generated by other ways, such as chemical analysis. It is obvious, that there is no such opportunity for commercial (non-professional) applications, and it stimulates researchers for searching new, non-standard approaches. The problem of handwriting verification requires other approach, as it is possible to gather from the letter, slip or address on the document, as a rule, enough for acceptance of a reliable decision. It should be noted, that there is a large difference between professional and commercial versions of such systems. In a number of cases the design of such systems means the automatization of methods that have been well investigated and widely used by police. The typical example is considered in [17]. A dynamic signature verification system which analyzes signatures dynamically by considering their shape, time, domain characteristics such as speed and acceleration, and force domain characteristics, i.e. applied pressure, is presented there. Experimental results demonstrate 92% authentic signature detection accuracy and 100% forgery signature detection accuracy. In [13] an on-line dynamic signature verification system with a database of more than 10 000 signatures was proposed. In [12] an ANN was proposed for signature verification. Experiments showed that on average 90% of test samples can be correctly classified on a data set of over 3000 signature images. Artificially generated genuine and forged samples from the enrollment reference signatures were used to train the ANN. The methods of fuzzy logic and evolutionary programming are also often used to solve this and related problems [26,29]. Very good results of off-line signature verification system based on fuzzy logic were also reported in several papers. An example of realization of another original idea is presented in [8]. The hand movement is tightly coupled with spatial recognition (hand shape). Authors propose an approximate recursive partition to perform the classification. The experimental results show that the system can achieve a 93,1% recognition rate for test sequences that have not been used in the training phase. Two different approaches have been taken to capture the signature dynamics: an active pen and sensitive tablet. For example, a document can be sent by Email, authorized by a signature which is not in graphic form. This signature includes parameters of pressure, the number of times the pen was lifted from the paper and so on. It is an easy means of security. To be noted, the information stored in such way is insufficient to match criminological expertise, which required from 6 to 20 original objects (depending on signature complexity). Some approaches to professional signature and handwriting identification systems were reported in [23,24,30]. Such systems are expected to meet requirements accepted in criminology. Attention should be also paid to papers [3,20] and [13], where very high quality results were achieved. As an example of a highly efficient and practical device the so-called SMARTpen (LSI Computer Group N.V., USA) can be given. SMARTpen is a ball-pen that includes sensors allowing authentication of persons through the biometric characteristics of their signatures. This device is very user-friendly and based on the modern technique of signature authentication; the pen tip's trajectory, as calculated, will be a 3D curve near to the writing surface. The curve is projected on that plane representing the pen tip's path along the paper, this path is the text written, incorporating unique characteristics of the writer. Therefore signature verification with this device does not depend on graphic image of the signature but on the dynamics of the act of signing. The experts-graphologists have accumulated large experience in handwriting and signature authentication, that now begins to be used in various commercial applications. It is well-known, that handwriting and signature of a person strongly correlates with his mood and feeling. As one of paradoxical examples, few signatures of Emperor Napoleon the Ist made at the most significant shocks in his (and Europe!) life can be considered. It was stressed in the beginning of this section that commercial systems use often the experience of the police. However, the classic approaches are mainly not automated. At the best it is possible to speak about automation of some stages of signature and handwriting verification.

6 Eyes identification.

Traditionally two approaches to identify the eyes are used. They differ in accordance with the zones of an eye from which the attributes are obtained: (i) the blood vessels on the retina, and (ii) the iris. These systems are the most secure in biometrics, and require to apply rather complex methods of image processing. The iris identification systems look promising for the future, as they allow to use standard means (telechamber and processor), whereas retina systems require special and expensive devices (retina scanning devices). Many papers concentrate on radial basis function feed-forward ANNs, which are more assimilated for the given type of objects. One of problems is an iris localization for a head-mounted eye tracker. The tracker must gaze direction to be measured by supplying simultaneous views of a subject's eye and of the world from a head-mounted camera. Finding gaze direction relative to the head requires accurate and robust measurement of the iris outline under a wide range of lighting conditions, in the presence of highlights, and when the iris is in an extreme position. Some recent successful approaches for eyes identification are presented in detail in [4,11,30].

7 Face Identification.

In facial recognition, the computers perform three classical tasks: verification, recognition. One of the problems is face recognition under varying poses. The following technology can be used: (i) representation of faces with templates from multiple model views that cover different poses from the viewing sphere, (ii) recognition of a novel view, the recognizer locates the eyes and nose features, uses these locations to geometrically register the input model views, (iii) using the correlation on model templates to find the best match in the database of base of people. One of the very important steps of this process is determination of the best facial features [12,31]. An edge-enhancing preprocessor and some separately trained backpropagation ANNs are often applied to this problem. Many authors report about good results on using the ANNs at the first stage of face recognition: determines general properties of the input, such as whether the facial image contains glasses or a beard. It is connected with many problems that have not been solved yet. The idea is to search of conformity of face model to face image. In [9] the image-based model is constructed using example views of the face, bypassing the need for any three-dimensional computer graphics models. A learning ANN is trained to associate each of the example images with a set of pose and expression parameters. In [28] the method to detect human face regions precisely, without imposing any constraints on the face size, position or features (glasses, beard, and so on), employs a genetic algorithm. The proposed method detects the edges in input image, and it searches elliptical regions. It is necessary to emphasize, that using tomography methods allows to solve many problems of face recognition. However, these methods require large computational costs. It is the not a complete list of original ideas in this area. Visual communication is another application of BT. This approach has been recently extensively studied, especially in psychological literature. Commercial applications of such systems are known, however they require a number of strong restrictions.

8 Methods of BTs.

The overhelming part of BTs is realized using image processing and pattern recognition approaches. It is interesting to compare storage requirements for various BTs. The storage varies between nine bytes to more than one thousand. It is feasible to store the large numbers of templates in standard memory media. For instance, instead of storing an actual image of the fingerprint as the template, most verification devices store a code which relates to the location of the minutiae points on the fingerprint. The template cannot be used to recreate an image of the fingerprint so it is of no use to law enforcement agencies. The templates range in size from 25 to 2000 bytes so can be stored as a bar code, on a magnetic stripe card, smart card or on a central database connected to the owner by a PIN. To identify a person based on the retina scanning technology, it is enough to process 200-300 pixels of the image and then to compress the results using a traditional way. From 40 to 200 bytes are enough to store one image.

9 Open Problems in BTs.

As any new area of human activity, BTs lack today a system approach to design them. For example, techniques and criteria of choice of particular BTs for application purposes have not been developed. This stimulates interest of many experts. At the same time, comphrehensive experience of designing AFIS has been accumulated. The simple engineering solutions to AFIS are widely used in banking, financial and access control. BTs application will involve many new problems, in particular, legal and social, alerts to ethical use, privacy considerations, industry standards, biometric and Internet security. On estimations of experts, many of these problems will require non-traditional approaches. Frequently, however, life accelerates decisions with respect to ethical and social problems. Connected to wide use of BT systems, are, for example, national safety, terrorism, immigrations' problem, large losses of financial institutions and etc.

10 Conclusions

Modern practical applications of BTs make a small part of our knowledge about living objects. The distance methods of person's identification are used at the moment in the elementary variants and presently are the subject for laboratory researches. It means, that it is possible to effectively automate processes of identification of a person under these forms of biometric information, and to satisfy equirements of many practical applications. Design of biometric products requires knowledge of results from many areas of human activity. Realization of any system BTs for commercial application requires interdisciplinary researches. BTs are one of the areas, for which system approaches to design are not yet developed. The main obstacles are absence of standards, not enough experience with existing BT-systems (except for fingerprint devices and systems). The effective use of BT will require to solve many social questions of law, etiquette and morality. Use of BT methods in education gives many interesting effects, main of which is stimulation of inquisitiveness of students. It is reasonable to expect an increase of interest in BTs.

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