Unconventional Computation Answer on Challenges of Medical Imaging

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***Abstract* — During the last decade both the medical images collection hardware and processing software have gotten the advanced development. As the result, medical imaging meets the challenge of treating extremely large medical images databases as well as complex algorithms. Such challenges are the natural tasks for massive parallel processing that can be provided by unconventional computations. This work reviews several solutions proposed by bio-inspired and quantum branches of unconventional computation for tasks of image processing and retrieval. These solutions are selected as perspective ones for application to medical imaging that has specific challenges. The image retrieval solution, that applies P systems (bio-inspired) computational model, is proposed. The perspectives of application of new computational models, which are under development now, for image processing and retrieval problems are revealed.**

***Index Terms* — bio-inspired computation, extremely large medical images databases, medical imaging, quantum computation, unconventional computation**

I. INTRODUCTION

During the last decade tools of both the medical images collecting hardware and processing software have gotten the advanced development. As the result, medical imaging meets the challenge of treating extremely large medical images databases.

The processing of multitude database entities is the natural task for massive parallel processing that can be provided by unconventional computations, for example, by bio-inspired or quantum computations. While both mentioned computation models are nature-based, bio-inspired computation uses paradigms of biology, whereas quantum computing relies on quantum physics and exploits quantum parallelism. Developed mostly in parallel, these computation models have their own advantages and disadvantages, traditional application areas, and further development directions. But the most important for current work fact is that, on the contrary to the classical computation, unconventional one can execute in parallel such methods as retrieval, database querying, and search with proximity conditions.

From another side, the increasing of the complexity of computational methods in medical image processing applications leads to continuous quest for promising solutions. Besides employing AI techniques, medical imaging makes the attempts to resolve the problems by search for more suitable computation devices. This work reviews several solutions proposed by bio-inspired or quantum branches of unconventional computation for tasks of image processing and retrieval. These solutions are selected as perspective ones for application to medical imaging that has own specific challenges. The author's solution of image retrieval problem by one of the bio-inspired computational model (P systems) is described. The perspectives of application of new computational models, which are under development now, for image processing and retrieval problems are presented.

II. BIO-INSPIRED COMPUTATION

Natural computing is presented as a kind of a bridge between informational and natural sciences. Today the majority of paradigms, principles, and mechanisms, used by human-designed computing, can be traced to natural systems as a source of inspiration.

Following challenges mentioned above, medical imaging became the popular application of bio-inspired computational models like swam intelligence, evolution, genetic or membrane computations. Besides parallelism, the bio-inspired computing techniques allow a simple representation of the knowledge making these techniques suitable for content-based image retrieval (CBIR) implementation.

Among the most important tasks of medical imaging, which are affected by images database size, the image classification is the first that should be noted. The second global task where the massive parallelism can help significantly is retrieval the images from database according the sample pattern. Both classification and retrieval suppose the process of feature extraction that can be implemented in parallel with some exceptions of connected features. Also medical images retrieval implies the parallel features vectors comparison that is usually independent, because of answer: similar or not - has to be given for each image.

Several bio-inspired formalisms were applied as the solvers of retrieval task. Keeping aside the optimization usually performed by swarm intelligence application, the most employed methods belong to genetic computation. Applying both in features extraction and similarity finding, genetic computation implements the main necessary steps of retrieval. First of all it is related to representation. Saying, that the feature representation in genetic terms would be the equivalent to its genotype and the image itself to its phenotype[1], the majority of authors maps pixels as genes. Such representation allows replacing of the ordinary imaging operation by genetic ones (selection, crossover, mutation, etc). Genetic (chromosome) representation of similarity means how the parameters of the problem will be mapped into a finite string of symbols (genes), encoding a possible solution in a given problem space. For example, in the work[2] a chromosome represents the weights assigned to the similarity/distance of the features. The genetic programming, that is another bio- and genetic- inspired technique, is applied[3] for substitution of ordinary similarity search by a form of automatic evolutionary search. The proposal consists on defining a set of image operators, which detect interest point features on digital images and then use genetic programming to search for an optimal solution within the space of possible operators. Evolutionary Computation is applied in, ordinary for retrieval, unsupervised clustering step[4]. The approximate nearest neighbor scheme is usually used for clustering. Then the obtained candidates are refined with, for example, support vector machine (SVM). At this stage the Evolutionary Computation algorithms can be applied to maintain a set of candidates and recombine them using genetic operators.

Our approach uses Membrane Computing (P systems)[5]. The research area of membrane computing was motivated by the structure and functioning of living cells. The original computation model, defined by Gh.Păun in 1998, is based on a cell-like hierarchical arrangement of membranes. Since then, the community of P systems researchers was found. By investigations of these researchers many other models of P systems have been defined, and their computational properties have been investigated.

P systems are a convenient framework for describing polynomial-time solutions to certain intractable problems in a massively parallel way. Division of membranes makes it possible to create an exponential workspace in linear time, suitable for attacking problems in NP and even in PSPACE. P systems demonstrate challenging applications in images processing and analysis. A variant of P system, called tissue-like P systems, shows itself as suitable representation of image: pixel is mapped to cell in tissue. Basing on such representation, a region-based segmentation algorithm of 2D and 3D images is developed by Spanish P systems researchers group[6]. Using the same formalism and representation others members of this research group[7] presented a parallel algorithm to solve the thresholding problem.

Ultrasound diagnostic images are chosen as the best source for our approach test. New techniques of medical imaging are seriously necessary for this domain. Ultrasound is widely available and relatively inexpensive, so it has become the main diagnostic tool for routine medical investigations procedures. Such procedures, being repeated daily, produce large amount of images and, so, required massive parallelism. However, despite the ultrasound images are important information source, their specificity (speckle, tissue related textures and artifacts) creates difficulties in application of imaging technologies to their processing. There are several attempts to apply technologies of different branches of artificial intelligence (AI) for improving of medical ultrasound imaging. We consider as another helping hand the work dealing with noise reduction on grayscale images by cellular automata that is close to tissue membrane formalism[8]. The used in this work collection of ultrasound diagnostic images was obtained during development of SonaRes system[9].

Designing our approach, we starts from results of Spanish colleagues[10], who applied spiking neural P systems[11] for skeletonizing an image.

Image skeleton is a shape with a small amount of information that, however, preserves topological properties of image. Supposing, that keeping visual features is actually keeping the mean of image, image skeleton is often used as image signature. In work[12] the application of skeleton signatures in retrieval process is presented. This work shoes that the images skeletons similarity problem is also the one requiring further development. We propose the skeletons comparison approach based on skeleton representation by spiking neural P systems.

Spiking neural P systems is an extension of membrane computation, in which the functionality is changed from cell-like to neural-like. Neural-like behavior supposes that elements (neurons) are the nodes of a directed graph with edges representing synapses. The computation process is implemented as walks of electrical impulses through the synapses. Spike is the object that represents impulse. Spikes, which are contained in neuron, determine its electrical charge. Calculation controls are, in this representation, the rules, which can be associated with each neuron. The rules drive spikes activity: send them (possibly with a delay) to other neurons (ring rule), or to remove a given number of spikes (forgetting rules) from current neuron.

We take as basis the spiking neural P systems configuration proposed in work[10]. The first step of further development is extension of skeletonization algorithm, working on black and white images, to processing grayscaled images. In chosen formalism, this development mainly concerns the pixel connectivity function (here - ring rule) that is binary (i.e black or white) in basis work. Spiking neural P systems final configuration is, basically, the result of computing. For extension of the process to retrieval, this configuration (the image skeleton in chosen representation) has to be saved in database. After getting the corresponding configuration from pattern image processing, configurations will be compared.

III. QUANTUM COMPUTATION

Quantum computation is another unconventional computation approach, which is proposed for both large database treatment and reducing of the complexity of algorithms of medical image processing applications. Opposed to previously described formalism, quantum computation uses the physical effect instead biological ones.

Quantum computation and quantum information is the study of the information processing tasks that can be carried out using quantum mechanical systems. Quantum mechanics is a mathematical framework or a set of rules for the construction of physical theories. Generally three types of quantum computation models are considered: quantum Turing machine, quantum circuits, and quantum random access machine [13]. Quantum algorithms always begin with the preparation of the initial state of the computation device, then a sequence of quantum operations is applied to the system, and then a measurement fixes the outcome. At the measurement, the resulting superposition of quantum states collapses to a single classical state that is observed.

First of all, the problem of image representation, using quantum computation formalism, has to be solved. The quantum computers representation of image, like conventional computers one, captures the information about each pixel color and the corresponding position. Recently the quantum flexible representation of images (FRQI) is proposed[14]. Basing on FRQI, all stages of quantum image processing: (i) a constructive polynomial preparation for the FRQI state from an initial state, (ii) an algorithm for quantum image compression, (iii) invertible processing operations - can be implemented. The general approach of quantum computation to image processing, implementing stages mentioned above, is presented demonstrably in work[15] and is based on the quantum algorithm of Grover. Two types of problems will be discussed: (i) the detection and the classification of image edges, (ii) the segmentation of image regions. The method starts from generation of full range of possible instances. It means, for example, that the detection of image contours is provided by creation of all translations, all rotations and all scales of possible contours. The comparison is made for each generated instance, pixel by pixel. Then, when the instance figure matches the target figure, the figure parameters (location, angular position and scale) are known from building. This technique, although functional, it is impractical to implement in classical computers.

Next aspect, interesting for medical imaging, is how the retrieval can be organized in quantum computation. The acceleration of retrieval process can be evidently achieved by comparing many pairs of images in parallel on quantum computer. Still the main problem is to propose quantum computation scheme that can evaluate images similarity. The most recent approach to search the images database on quantum systems is realized in work[16]. The researchers propose the equation of search operation that used only a single quantum gate (Hadamard) and several measurements.

IV. PERSPECTIVES OF HYBRID COMPUTATIONAL MODEL

As it was shown in previous paragraphs, medical imaging gives a set of practically important problems for both quantum- and bio- computations. Such significant experience of researchers of both branches guarantees their knowledge about advantages and disadvantages of each approach. This knowledge promises good future for application of hybrid computational models, including applications of medical imaging.

The idea of hybrid bio- and quantum computational model was proposed in 2011[15] by the group of Moldavian researchers that the author belong to. new approach that joins macroscopic (bio-) and microscopic (quantum-) levels. Our confidence in fruitfulness of such integration is proved by co-existence and cooperation of micro- and macro- processes in living cell. The computer prototype does not exist yet, but some processes of this “in cell” cooperation are tested as implementation of bio- and quantum-computation in vitro. For example, the photosynthesis process is most tested biological implementation of quantum computer. The quantum walk is applying to explain the high efficiency of energy transfer in photosynthesis. The search process in photosynthesis from the pigment antenna to the reaction center is compared with the Grover type search [18]. Another attempt to build bio prototype of quantum computer, basing on photoexcitation in proteins, that is another micro-macro cooperation process, was mentioned in work[19]. Coming from medicine example of natural prototype of hybrid model is described in work[20]. This is the process of live tissues answering on laser light penetration (during the photobiomodulation therapy) .

Summarizing the expounded in sections II and III, the problems of medical imaging are seemed suitable for solution by the hybrid quantum- and bio- computational model. The hybrid model building perspectives are noticeable in domain of image representation, image processing and image retrieval.

V.CONCLUSION

The importance of answering last challenges of medical imaging inspires the employment of wide range of AI techniques. Besides the development of methods and techniques for resolving medical imaging problems by traditional computation, the researchers seek for more suitable computation devices including ones which are just oncoming. Unconventional computation presents basis of the software for these oncoming devices. Both quantum and bio-inspired domains of unconventional computation demonstrate success in advancing of medical imaging tasks resolving. These computations show progress even with task known as unresolvable-in-reasonable-time by traditional computation.

The problems of medical imaging have to be includes in list of priority tasks on which the hybrid computational model will be tested.

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