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Subject review: A foundation of bio-computing

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Abstract

For many years, computer scientists have designed several computational methods and algorithms all inspired by the biological systems. Biological computing is the use of living organisms or their component parts to perform computing operations or operations associated with computing. The various forms of biological computing take a different route than those used by quantum or optical computing to overcome the limitations to performance that silicon-based computers face. In this paper a review of fundamental concepts are introduced and the various advantages and challenges to implement the biological computer technology are explored.

Keywords: Biological computers; Biocomputing; DNA computers: Bio-inspired computing: Biomolecular: Biochemical computers:

1. Introduction

Computer scientists have relied on biological systems for inspiration to develop new, nature based techniques for solving computational problems. Back in the 60s, works from artificial intelligence highlighted the development of a class of computational methods known as neural networks which are related to the activity of neurons in the brain. Other works were inspired by common operations in Deoxyribonucleic Acid (DNA) sequence evolution which led to the development of genetic algorithms used to solve optimization problems. A number of additional inspired methods, including what the human immune system can teach us about protecting computer networks has also capitalized on biological insights to derive new computing paradigms [1].

Computation can be broadly defined as the formal procedure by which input information is processed according to pre-defined rules and turned into output data. Since this definition does not specify the type of information and rules involved in the process, it is applicable to electronic devices as well as to biological systems. In other words, biological systems do perform computations [2].

Biological computers are special types of microcomputers that are specifically designed to be used for medical applications. The biological computer is an implantable device that is mainly used for tasks like monitoring the body's activities or inducing therapeutic effects, all at the molecular or cellular level. The biological computer is made up of RNA (Ribonucleic Acid – an important part in the synthesis of protein from amino acids), DNA (Deoxyribonucleic Acid – nucleic acid molecule that contains the important genetic information that is used by the body for the construction of cells; it's the blue print for all living organisms), and proteins .Biological computers are similar to quantum computers in terms of strategy [3].

Electronics have invaded all walks of life and we depend on electronics to accomplish most of our day to day activities. As predicted by Dr. Gordon E. Moore, modern day electronics has progressed with miniaturization of electronic components. According to Dr. Moore, the miniaturization of integrated electronics will continue to be bettered once

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every 12 – 18 months with a reduction in cost .True to his prediction modern day chips have up to 1 million transistors per mm2. However as with other things, miniaturization cannot continue forever, the laws of nature and in particular physics will soon catch up to impose a limit on the silicon chip. Such limitation will not prevent us from progression. The route is clear but the ways to reach it may be unusual. Imagine having billions of Deoxyribonucleic (DNA) acids instead of silicon chips powering the computer. The fact that silicon chips will even be replaced will be anathema to some but we are well on our way for some surprises. Hence it is imperative that software engineers have an understanding even if it just includes the basics of microorganisms and how they will impact computing [4].

The development of biocomputers has been made possible by the expanding new science of nano biotechnology. The term nano biotechnology are often defined in multiple ways; during a more general sense, nano biotechnology are often defined as any sort of technology that uses both nano-scale materials (i.e. materials having characteristic dimensions of 1-100 nanometers) and biologically based material. A more restrictive definition views nano biotechnology more specifically because the design and engineering of proteins which will then be assembled into larger, functional structures [5].

2. Logic networks

Logic circuits are the workhorse of silicon computers. Researchers who pursued logic circuit ideas drew parallels between the passage and alterations of voltages in electronic circuits with changing concentrations of molecular species in networks of coupled chemical reactions. For example, if two chemicals A and B were simultaneously required to catalyze the production of a chemical C, this would be interpreted as an "AND" logic gate between the inputs A and B with an output C. In the molecular circuit paradigm, the importance of digital information stored in DNA sequence is greatly diminished compared to the state machine-based approaches. Instead, an entire molecular species is either in state Off (*i.e.* low concentration) or On (*i.e.* high concentration). An inherent difficulty with both interpreting and engineering digital reaction networks lies in the arbitrary definition of Off and On states. Clearly, concentrations can take any value between zero and infinity, and while defining the Off state is easy, doing so for the On state has to be justified. Fortunately, in the biological world the On states can be compared to what is known as "saturating concentrations", that is, levels beyond which the effects exerted by a molecule stops being concentration-dependent. This is due to the fact that almost all natural processes are catalytic in nature and easily lend themselves to saturation [6].

Currently, biocomputers exist with various functional capabilities that include operations of "binary" logic and mathematical calculations. Using this method as computational analysis, biochemical computers can perform logical operations during which the acceptable binary output will occur only under specific logical constraints on the initial conditions. In other words, the acceptable binary output is a logically derived conclusion from a group of initial conditions that function premises from which the logical conclusion are often made. In addition to those sorts of logical operations, biocomputers have also been shown to demonstrate other functional capabilities, like mathematical computations [5].

The Benefits of Biological Computing

The various forms of biological computing possess a number of benefits over their silicon-based counterparts. There are six main benefits that biological computing can offer.

First, a biological computing process can be far more energy efficient than the computational processes of silicon-based computers. In the case of DNA computing, the biological reactions involved produce very little heat, wasting far less energy in the process. This allows for these computing processes to be up to one billion times as energy efficient as their electronic counterparts.

Second, DNA is capable of storing an astounding amount of information for a given volume. To illustrate, one gram of DNA can hold as much information as one trillion audio CDs. This offers the possibility of computers with previously impossible storage capabilities. For businesses, this ability to store and access data in a far smaller space could sharply reduce costs associated with storing and accessing data.

Third, the component materials are plentiful in supply and easily obtained in most cases. Also, the components, e.g. DNA, are non-toxic. This compares quite favorably with silicon-based computers, which are composed of toxic materials and require the production of large amounts of toxic waste as byproducts of their production. In most cases, the biological components can be synthesized in a lab quite cheaply. In addition, the structure of genetic material makes possible computers that in the future could assemble themselves out of simpler components.

Fourth, biological computing allows for massively parallel computing. While silicon-based computing has already shown itself to be capable of limited massively-parallel processing of information, biological computing is able to do it to a far greater degree. For comparison, the fastest supercomputers can perform around 1012 operations per second, but even current results with DNA computing has produced levels of 1014 operations per second or one hundred times faster. Experts believe that it should be possible to produce massively parallel processing in biological computers at a level of 1017 operations per second or more, or a level that silicon-based computers will never be able to match.

Fifth, some forms of biological computing, e.g. the genetic "programs", promise the ability to control cellular level chemical production events that offers a level of intimate interface with biological processes that is simply not possible with existing computing technologies. The implication is that genetically engineered life forms incorporating such control mechanisms could provide businesses engaged in chemical production with a new form of cheaper and far more efficient factory. Vats of such life forms could produce a wide variety of chemicals cheaply.

Sixth, computing devices that are living or composed of living components have the potential to share two characteristics that allow living organisms to adapt so well to changing conditions: the capability of healing injuries and the capacity to self-improve. Development work is being done to give non biological human technology such capabilities, but it is doubtful that such technology will ever be able to do these things as well as biological components can [7].

3. Conclusion

Traditional computers use microchips, which heat up quickly. Supercomputers are usually a collection of several high-speed traditional computers, combined into a single unit. Generally, they are not qualitatively different from traditional computers. Even so, supercomputers use a lot of energy, heat up quickly, and require massive cooling units in order to function at full speed. On the other hand, biological matter can perform calculations and process data without using as much energy, and without heating up significantly.

A number of problems with biological computing must be resolved before it can reach its full potential.

- In some cases the types of genetic sequences that would have to be synthesized to make full functioned genetic or genetic "robots" possible would be too expensive using current methods.
- DNA computing requires quantities of DNA that can only be used once, since reuse would contaminate reaction vessels and lead to less accurate results. Within the scientific community, there is much debate as to how much DNA would be required to perform useful calculations.
- DNA computing is prone to errors at a level that would be considered unacceptable by the silicon based computing industry.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that they have no conflict of interest.

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