TOWARDS OPTO-BIOLOGICAL COMPUTERS

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Received June 28, 1988

Abstract

The difference between the computer of today and the not yet realistic-to-make biological computer is the same as the difference between nonliving and living material, i.e., the difference between "functional stability" and "functional mobility" is to be discussed. Based on Gabor's communication theory, the signal processing in a constant and in a permanently changing substrate structure is analysed to get some insight into the rules that govern "intelligent" signal processing. The advantages of an opto-biological computer are discussed.

Introduction

Although it is not yet realistic to plan for a general purpose opto-biological computer, it is possible to think seriously about a new generation of computers which are basically different from the most sophisticated computers of today and those of the very near future, i.e., on computers which, instead of having a "functional stability", have a "functional mobility". With other words, in this new generation of computers the signal pattern to be processed propagates in a *permanently changing* substrate structure, in contrast to the present computers, where the signal pattern propagates in a *constant substrate structure*. This, however, means that the difference between these two computer concepts falls into the same category as the difference between living and nonliving material.

Looking a little closer into the nature of this difference we find that the signal processing of the living material is ruled — in contrary to nonliving material — not only by the laws of physics and/or chemistry but it also shows homeostasis, the degree of which depends upon the evolutionary level of the living material. It is lowest at biomolecular level, and highest at vertebrate level.

Since homeostasis is of oscillatory character, it seems to be at first sight similar to the feedback scheme used by present-day computers, nevertheless, it differs from it in essence by performing in a permanently changing substrate.

Permanently changing substrate means that its architecture or its composition or both may change, thus, one has to analyze not just one variable, i.e., time *or* frequency, but a function of two variables, time *and* frequency *simultaneously*. With other words, living matter uses a method of analyzing signals in which *time* and *frequency* play a symmetrical part. However, it can be shown that the functional mobility character of the living matter results in the fact that it cannot process the signal with any degree of accuracy, only beyond a certain limit, therefore, it would be inferior in this aspect to conventional computers using von-Neumann-architecture, but it would be superior at context-depending data processing, in tasks that require complex weighing and recognition functions, and integration of information carrying signals, and computation from different sources. These systems, the biological computers, would be capable of saying not only yes and no, but also *may be,* which is the fundamental characteristics of being "intelligent".

What is a biocomputer?

In recent years a number of scientists and engineers have already considered the possibility of building computers in which silicon chips would be replaced by large organic molecules or genetically engineered proteins, and they named this hypothetical chip as "biochip". These biochips would differ from the present chips only inasmuch as that they would consist of organic compounds rather than anorganic material. However, these organic materials are nonliving materials since, in general, they do not show homeostasis that is essential for biological, i.e., "intelligent", signal processing.

My definition of biocomputing is the application of concepts that are identical with, or similar to, that what living (and not only organic) material uses in processing signals reaching it in a 3-D space. To my best knowledge, the only signal processing theory which treats "time pattern" and "frequency pattern" not separately but simultaneously, — in a way without which intelligent computing in its true sense is inconceivable, — is Gabor's Theory of Communication [1]. His theory differs from Shannon's theory [2] so far that it is concerned with the possible events of an *analog* (or *wave*) nature, which requires no preexisting notions about probabilities of the event's occurrence, while Shannon's theory — most computer strategies of today are based on — is concerned with the probability of possible occurrence of *digital* events.

Although in living systems both analog and digital signal processing can be observed, my belief is that the very first step in general is analog processing since high throughput is important, and after some of the resulting "maybe"-s are more or less weighed, the processing switches for digital for higher accuracy, and the result of which may be later processed in an analogous way ,and so on. This mixture of analog and digital indicates that the capability of making "intelligent" decisions, i.e., the capability of complex computing, may not rely on high degree of accuracy.

According to Gabor's theory, when dealing with analog processing, the concept of "elementary signal" should be introduced, which is the modulation product of a harmonic oscillation of any frequency with a pulse of a form of a probability function, and is represented by a signal which occupies the minimum area $\Delta t \Delta f = 1/2$, where $\Delta f = \overline{[2\pi(f-\bar{f})^2]}^{1/2}$ is the effective signal bandwidth, and $\Delta t = \overline{[2\pi(t-\bar{t})^2]}^{1/2}$ is the effective signal duration. This elementary signal was named by Gabor as "logon".

This sort of treatment of frequency and time so far exactly mirrors that of coordinates and momenta in quantum mechanics, i.e., $\Delta t \Delta f = 1/2$ closely reassembles the Heisenberg's incertainty relation between momentum p and positions x:

$$\Delta p \Delta x \geqslant \hbar/2$$

where $\hbar = h/2\pi$, and h represents the Planck constant.

Since — as we have already shown elsewhere [3], [4] — the living matter has to have a signal processing scheme where frequency and time are treated simultaneously, — otherwise it could not survive in a 3-D environment, — it is a logical step to follow Gabor's reasoning and to introduce the "biologon", the elementary signal processed in a living system. However, by using this formalism and resemblance we do not claim to explain "life" by means of quantum theory, we only wish to point at one of the directions which may lead to develop a strategy for "intelligent computing".

Why opto-biological computer?

As we have seen, the signal processing strategy of living matter is based on the formation of an information diagram of minimum area defined by the r. m. s. duration of the signal, and its r.m.s. frequency width. Let us now assume that life uses a factor $\sqrt{(2\pi)} = 2.506$, the resulting information diagram will be equal to the numbers of independent data which the homeostatic scheme involved in processing can handle. It will consist of "cells" of size one half which transmits exactly one data of information in such a way that it contains two elementary signals, i.e., two biologons, a sine and a cosine type, which means that the time-frequency space of the living matter is represented by two orthogonal logons with carrier 90° in phase.

This recognition has several consequences, one of these is that living matter can process a signal solely if it "knows" not only the past but also the future, i.e., a situation emerges which in modern physics is often being called "the break of causality". Life solves this problem of "converting the future into past" by delaying the transmission of the signal. However, this results in reduction of accuracy the degree of which depends upon the delay time, but accuracy will also be reduced if only the sine or cosine part is taken into account.

That at least in some instances living matter processes in this way may be backed up, e.g., by the experiments of Pollen and Ronner [5], who measured the electrical output of two neighbouring cells in the visual cortex of a cat subjected to drifting sine wave grating, and found that the two outputs differred by 90° in phase, or that some echolocating animals when getting into real trouble, i.e., when they really need the *complete* information carried by signal patterns, they use double pulses shifted 90° in phase [6] .

Before going one step further, we have to remind that *t* and *f* can only be processed simultaneously if the "coherence length" of the signal carriers is adequate and is taken into account, i.e., this indicates that temporal and spatial coherence have to play a definite role in the signal processing of living matter. This recognition may be one of the reasons why some investigators are in search of an "optical brain" [7].

My belief is that to understand the mechanics of how the brain does its computation, how it organizes, processes, stores, and retrieves information, one has to understand first how signals are processed at lower level than the central nervous system (CNS). This is the only way to get closer to the rules that govern "intelligent" signal processing. Since optics is quite powerful in solving both analog and digital problems by using coherent signal carriers, it sounds logical to explore the possiblities of developing an opto-biological computer, i.e., a computer with "functional mobility".

Holograms, solitons, and similar suggestions

The introduction of biologons means that we assume a sesquilinear integral transformation which performs a planar encoding of time and frequency domains of signals simultaneously by means of interference pattern as in holography. From biological point of view several types of holographic operations can be considered [3], e.g., Schempp demonstrated that the holographic transforms of the Hermite (or oscillator wave) functions can be calculated explicitly in terms of Laguerre and Poisson-Charlier polynomials in such a form that a series of holographic identities for digital signals are established, [8], which is in good agreement with the fact that living matter uses both analog and digital computing.

One probable reason why biological materials utilize their computational resources more efficiently than computers of today is that there is a natural relationship between their material structure and the task they perform. However, little is known about the 3-*D* structure and electrical properties connected to it in living matter, nevertheless, it can be assumed that homeostatic subsystems maintain their quantum-mechanical coherence. This, however, means that the biologon propagation could be considered as a wave-like electric perturbation, i.e., as a soliton propagation. Solitons are namely pulses with constant form, width, and amplitude, the parameters of which do not change during propagation even if dispersion and self phase modulation act *simultaneously*. This, on the other hand, is in accordance with the statement we have started with: living matter as signal processor has a functional mobility, i.e., the signal propagates in a permanently changing substrate. Since the use of optical solitons in fiber optics communication is already on its way, we are considering the possibility of an opto-biological computer model based partially on solitons.

Acknowledgements

The author is grateful to Professors Walter Schempp (Universität Siegen, FRG) and Ervin Laszlo (UN University, USA) for stimulating discussions. Moreover, he acknowledges the constant support and constructive criticism of Professors H. John Caulfield (CAO, UAH, USA) and Joseph Shamir (TECHNION, Israel).

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