NEW BREED STOCHASTIC HYBRID COMPUTERS

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Abstract

Computer science is awaiting substantial changes and the reason for this is the continuous reduction of the resent-day computers unit cells size which comes to 10-30 percents a year. In a few years the size of the cell will reduce to 100-200 angstrom (0.01-0.02 microns). Such devices will not be able to work with ordinary bits 0, 1 and the information nature itself will change. New devices will operate with the "wave functions" instead of "digits" and the new breed of mediums will require new mathematical fundamentals. On one hand this will lead to the change of the main classical algorithms and on the other hand it will allow to come closer to the solution of the artificial intelligence problems. Apart from that, it is very important for better understanding of the idea of possible real-time reconfiguration of the microprocessors architecture.

It is very likely that the basic principle of the future computing devices operation will be asynchronous work of a number of parallel processes. One of the processes can be a quantum bit or a register of a classical computer. At specific moments of time stepwise changes will take place in the evolution of the essential processes. Usually such changes are caused by restrictions imposed on resources and the necessity to redistribute resources between the processes. When describing the mathematical model of such new devices we cannot use the rough digitalized approximation, because the majority of real physical processes have fundamentally non-linear nature. That is why small inaccuracy in the initial conditions even for the short periods of time may lead to significant dispersion of the trajectory. This makes for the necessity to study the new type of computers as stochastic hybrid systems.

States and memory of the hybrid stochastic computing device change both stepwise (discretely) and evolutionally (continuously). At the same time it is implied that all data is defined nonstrictly and has stochastic nature.

The set of processes lying at basis of the new device will be called a set of basis primitives. For example for the elementary operations the classical bit, quantum bit, or quantum bit cluster (f-bit) can be used as basis primitives. In this situation may be it is possible to use the f-bit for function convolution operation performed at one cycle.

Introduction

In 1936 Alan Turing presented the model of an abstract computing device (Turing machine) which allowed to implement any finite discrete algorithm [1]. For a long time the basic concepts of this model were sufficient for development and evolution of the digital computing devices and computer science [2]. At the same time classical computer science, specifically the complexity theory provides a number of results showing theoretical impossibility of effective solution of many problems which have great practical importance - for example, problems concerning modeling of the processes of the animate and inanimate nature. This means that attempting to model the desired process with some specified accuracy using the Turing machine we get the alphabets of states and memory and/or functioning time unacceptably large. For example the task of quantum-mechanical calculation of the methane molecule requires about 10^{43} elementary operations.

What's more, the physical processes series cannot be described using Turing machine at all. It is proved that it is impossible to represent the quantum mechanics results using the classical universal computing device. The reason for this is the fact that the number of elementary operations for such devices grows exponentially with the growth of the system freedom degrees number.

On the whole the Turing machine cannot be used for describing the continuous (in space and time) unstable (non-stationary) processes which actually define the most important transition processes in various systems. For many real problems the theoretical descriptions still have not been created and for a number of tasks such descriptions go beyond the classical physics.

Some of the first people who experienced these theoretical difficulties were the developers of the automated control systems. Their multiple research programs are carried out on the interfaces between computer science and various scientific disciplines (physics, mechanics, biology, management, etc). Implementation of a large number of modern automated control theory methods does not fit into the framework of the Turing machine. In particular, models of hybrid systems so actively used lately are noting, but combination of digital and analog parts.

For example, such a model is used to describe operation of microprocessors with architecture reconfigurable in real-time. In practice the relay control idea turned out to be very productive. This idea implies switching control system from one sliding mode to another. During the last decade the neuronet approach was widely introduced in the control systems. Neurocomputers are often mentioned as parts of control circuit. None of the devices mentioned above can be described using the classical Turing machine. This causes the widening of the gap between control theory and computer science which slows down the development of both of them.

One of the main reasons of failures of many researches dedicated to the study of the fundamentally new breed of computing devices element base creation is the use of too simple base structures which meet the requirements of the traditional Turing machine, but are totally inadequate to the complexity level of present-day unsolved problems.

Fundamentally new computing device can be built on the basis of the functional bits primitives family. Functional bits (f-bits) will denote a set of quantum bits which form a register (or cluster). Introduction of a wider class of primitive models will be well-taken if, for example, for a function which values are stored in one f-bit it will be possible to define operation which will effectively perform Fourier transformation. Execution time of one such function can be comparable with the execution time of one classical operation over bits because operations like functions convolution can be easily found in nature.

Hybridity of computing devices in this case can be understood as simultaneous discrete and continuous behavior. On one hand a computer works discretely using the stepwise changes of states and memory and on the other hand states and memory evolve according to some specific law.

It is known that not for every physical system we can build a precise mathematical model. Often we can only speak of some approximation. However, when modeling using the classical computing device, at fist the mathematical model is created which is then transferred to machine language. This narrows the application area of the classical computer. If from the very beginning we imply that all data has stochastic nature there is some hope for successful improvement of the computing device. Solving a particular problem we can set an experiment. The resulting system state will be the answer.It is proposed to build a new computing device based on the assumption all data has stochastic nature.

At particular moments of time evolution of the basic processes will go through significant stepwise changes. Such changes can be caused by restrictions imposed on resources and the necessity to redistribute resources between the processes. The notion of timing cycle used in classical computers for automatic synchronization of running processes is not present in the new computing device. This naturally allows to work with asynchronous processes.

There is an example in [3] of effective use of randomized programming influences over the system when the states space structure changes dynamically. Randomization allows reducing noise influences that are almost inevitable in time variable dynamic model. Randomized algorithms of optimization [4], [5], [6] (that were well founded by professor Granichin) are convenient for use in new computing devices. One of the most important features of these algorithms are evaluating substantial estimations under "almost" arbitrary noise and keeping simplicity and efficiency during space dimension growth. It can be applied for organization of effective interaction between different models.

Creation of the new element base

Currently microprogramming technologies naturally move towards physical processes. In the nearest future when at the threshold of digital technologies development the size of the elementary calculation device will equal the size of a molecule quantum computers will appear. At the physical level this will lead to elimination of the "bit" notion which is the basis of present day computers. This fact shows the necessity to revise the basics of the computing processes theory.

As one of the processes of the stochastic hybrid computer the quantum computing device which uses quantum-mechanical algorithms for problem solving can be used. States in quantum mechanics are often denoted as vectors of unit lengths in Hilbert space over complex numbers field. Quantum computer processes "q-bits" (quantum bits) which represent a quantum system of two states. Such a system can take not only basis states, and consequently can store more information than the classical system. Quantum bits register is a quantum system containing several q-bits representing their tensor product. The states space dimension with which the quantum computer works grows exponentially with the growth of q-bits number. This quality lies in the basis of the quantum parallelism phenomenon.

When designing the hybrid computing devices the quantum bits register should for two reasons be considered as a single element, not a number of isolated bits:

- Firstly, the reduction of the cycle length and reduction of the gap between bits starting from a particular level makes it impossible to consider them separately simply because of the quantum mechanics laws.

- Secondly, abandoning the scalar bits will provide a potential possibility to execute multidimensional (vector) operation at one cycle.

For real use of the majority of quantum algorithms over 1000 quantum bits are required. However, until now the problem of practical development of a quantum register of such a capacity remains unsolved. The increase of the number of quantum bits leads to serious problems with addressing each particular elementary information medium. Anyway, to the present day it was possible to develop a method of growing supergrids of hybrid biological nanostructures on the basis of magnetic metals clusters (quantum points) [7]. These clusters were incorporated into the ordered protein matrixes which are contained in various bacteria specimen with characterizing sizes of 10 nanometers (0.01 micron). Such magnetic quantum points can be considered as quantum bits of the quantum computers. At the same time we can already imagine the creation of devices with linear sizes five-ten times smaller than the existing ones and containing several thousand of quantum bits in one register. Fundamentally new possibilities are also provided by the fact that quantum points can be interconnected via proteins which can be functionalized depending on the particular tasks of the computation process. Proposed hybrid nanostructures can easily provide the desired number of elementary mediums (over 1000), but apart from that there are several technical problems to be solved, such as the problem of providing the essential quantum correlations between elementary information mediums and the problems of quantum register initialization, writing, and reading.

Solution of a number of problems concerning ciphering and deciphering, signals, images, or speech recognition requires presenting initial functions as series based on the mutually orthogonal basis functions (for example Fourier). Biological structures mentioned above allow to model such basis functions.

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