Rough Information Processing : A Computing Paradigm for Analog Systems(<Special Section>New System Paradigms for Integrated Electronics)

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LETTER Special Issue on New System Paradigms for Integrated Electronics

Rough Information Processing — A Computing Paradigm for Analog Systems

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SUMMARY In this paper, a new computing paradigm suitable for analog circuit systems is described in comparison to the digital circuit systems. The analog circuit systems have some disadvantages especially in terms of accuracy and stability, but there are some applications that don't require accuracy or stability in circuit component. The new computing concept for such applications, 'inaccurate' information processing, or 'rough' information processing, is proposed and described as well as some examples of such applications.
key words: *VLSI, Analog Circuit, Information Processing, Vision Chip*

1. Introduction

In the highly developed information society, where we currently lives, systems are based on digital computing, such as digital computers, digital networks, digital communications, digital audio, and digital videos. The digital computing systems are based on 'digital' or 'numerical' computing paradigm. There is also another type of the computing paradigms, an analog system, but the digital systems have a lot of advantages over the analog system; accuracy, system stability, and so on. This is why the digital systems are so widely used in our information society. However, the digital systems have some disadvantages as well, such as larger power consumption and clock timing restrictions for higher computing. Therefore, such digital systems' disadvantages can be one of the serious problems for the further development of digital computing systems.

In this paper, a concept of new computing paradigm suitable for analog computing systems in certain applications are described. The idea is to dare to accept an accuracy problem in analog system, and a new computing paradigm, rough information processing, based on this idea is described.

2. Digital System vs. Analog System

As described in the previous section, the digital systems have advantage over the analog system in terms of computing systems as follows.

Accuracy: More accurate since having 'numerical unit'(or binary unit, 'bit' in most digital systems). The noise smaller than this unit will be eliminated.

Stability: better temperature stability and low sensitivity for device and process parameters. The transistors are operated in saturated region, and they are also stable in 'scaled' size.

Speed: Faster computing. The transistors are operated in saturated region, and quick charge / discharge operations are possible.

The analog systems are inferior to the digital systems in terms of these points in general. On the contrary, the following problems in digital systems can be serious for the further development.

Size: Both circuit size and signal bus line size are generally larger, since data is represented by a pair of bits. The sizes of signal bus line and input / output ports are especially becoming problems in the recent digital systems.

Power Consumption: The power consumption is one of the most serious problems for further development of digital systems. The major factors of power consumption are transistor leakage and charge / discharge of capacitor. The former factor can be improved by fabrication process development, but the latter factor is essentially hard to be solved.

Timing: Clock timing control in the synchronous digital systems is another serious problem in the recent digital systems.

High speed computing systems are, of course, essentially important for the recent information society, but there are some applications that are not suitable for the digital systems in terms of the digital computing paradigm that don't require the advantages of digital systems. Some of these applications must be extremely suitable for analog computing paradigms in spite of their disadvantages. The concept of the new computing paradigms suitable for analog systems for some applications is described and discussed and some examples of such applications are introduced in the following sections.

3. Rough Information Processing

3.1 Concept

Digital systems calculates the numbers in equations

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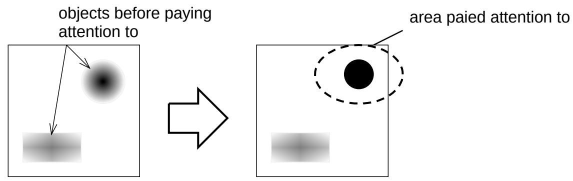

Fig. 1 Steps we see something

completely accurately so far as neither overflows nor underflows exist. For example, the digital multiplier calculates 1.1×1.1 (decimal) as follows:

$$1.1 \times 1.1 = 1.21 \tag{1}$$

In most steps in practical applications, this result is rounded to 1.2 by omitting the last digit. These two steps here, calculation and omission, are always carried out in all the calculation procedures in the digital systems. Viewing these two steps from a different angle, the part of calculation for the last digit, which will be finally omitted, is a kind of 'wasted' calculation. If we can omit this 'wasted' calculation in the total computing system, the powers as well as the circuit size will be saved.

The analog systems have a disadvantage on the accuracy over the digital systems, but in some applications, it can also be regarded as 'no execution for omitted digit calculation' in nature. In other words, the analog systems are applicable in some applications with keeping its disadvantage and, on the other hand, with keeping the least but sufficient accuracy. This computing concept, named as 'rough information processing', can be suitable for analog circuit systems in some applications that don't require the absolutely accurate results.

3.2 Example: Vision chip

Vision chip is a concept of integrating photo receptor and signal processing circuitry into one chip[1], and a lot of studies on vision chip are reported[2]–[6]. Analog circuitry, such as resistive networks is used in the early vision chips, but the analog system architecture usually requires the calibration mechanisms for clear image. Some vision chips aim at extracting 'abstracted information' from the captured image, such as centroid and motion of objects, and the truly clear image are not important in these applications, since a clear image is necessary only for human eyes.

A vision chip aiming at extracting centroid of objects in the captured image is reported[7], and a concept of vision chip for 'rough information processing' is proposed. It aims at using the extracted centroid as a preprocessing for image recognition for restricting the area to be recognised by finding the objects' positions and sizes. The detailed image recognition should be carried out for these restricted small area for faster and stable vision systems. This procedure is based on our action when we see something. When we see something, we'll think that there are something in our visual field at first, and then pay attention to existing objects, as shown in Fig.1.

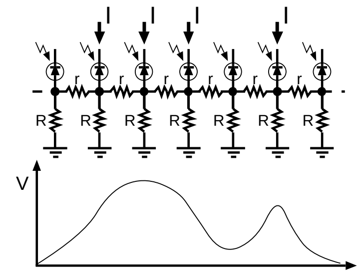

Fig. 2 Voltage distribution in resistive network

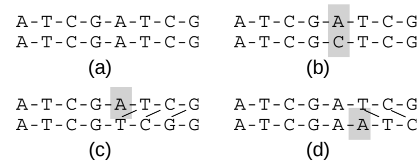

Fig. 3 Patterns of similar two sequences

Analog circuitry, resistive network and comparator array are employed for detecting the objects' centroids as shown in Fig.2, as well as a new type digital circuit architecture for coordinate generation. The variety of resistors in the conventional fabrication process are one of the serious problems in general, but this vision chip dares to take the simplicity of circuit, in spite of the inaccuracy, since its target is to find a rough position and size of objects more quickly for detailed post-processing. More efficient algorithm for image binarization as image preprocessing can also be employed at the photo receptor circuit.

This computing paradigm, simple and fast while non-accurate, is a kind of 'rough information processing' using analog circuit in the some applications for vision chips.

3.3 Example: Genome analysis

Another example of 'rough information processing', genome analysis is introduced in this section. Genome information analysis is one of the most important scientific and technical problems in our future life, and a lot of studies are carried out all over the world.

Homology search is one of the most common information processing in genome analysis, which is a similarity calculation for two sequences with consideration of some patterns of differences into account as shown in Fig.3. The homology search is basically performed by Dynamic Programming (DP) algorithm which completely compares the whole sequences as well as other approximate algorithms, such as FASTA[8] and

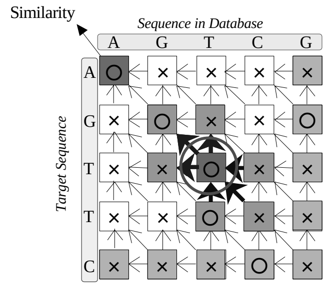

Fig.4 Matrix of elements with two sequences

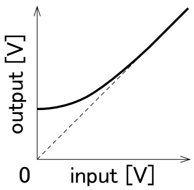

Fig.5 Characteristics of non-liner voltage buffer

BLAST[9] for faster processing. An accelerator hardware for BLAST algorithm is also developed[10] as a plug-in for PC-based system.

A parallel architecture with analog circuit elements performing 'complete search', DP algorithm, is proposed[11]. Two target sequences are given at the top and the left side of the matrix as shown in Fig.4, and their similarity is represented by the magnitude of voltage generated by the voltage propagations among elements; the voltage is reduced for mismatched characters in sequences in propagation step, while no reduction for matched characters. A linearity of voltage propagation buffer in each processing element is important for accuracy in general. From the viewpoint of genome analysis, the comparatively low similarity is not significant; such two sequences are 'not similar.' In other words, the difference of low similarity, such as 30% or 40% is not an important matter, while the that of the high similarity, such as 94% or 95% is an interesting similarity of two sequences. The voltage buffer's linearity for the region of higher similarity, or higher voltage is absolutely important in order to keep the accuracy for higher similarity, while the linearity for the region of lower similarity are not as important. This concept of a kind of 'rough information processing' gives the wide margin of the voltage buffer circuit design; a designer has to mention to keep high linearity only for small regions as shown in Fig.5 with consideration of the variety of device parameters or temperature.

This computing paradigm, simple and stable with smaller linearity, is a kind of 'rough information processing' using analog circuit in the some applications for information processing systems.

3.4 Example: Bio-inspired processing

A biological system cant be one of the most stable systems against the variety of device parameters and environments. For example, our brain, that is composed of millions of neurons, are in proper operation while the characteristic of each neuron are neither uniform nor accurate. In other words, the biological systems are stable for inaccurate device parameters and derived timing uncertainness, since the operation is implemented as the total network of whole devices.

Some studies on bio-inspired information processing concepts and their implementation in analog circuitry are reported[12]. Although analog system may be less accurate than the digital systems, circuit size and stability against device parameter variety and derived timing uncertainness of analog systems are superior to those of the digital systems. If we don't require a completely accurate result, that is often the case in many applications indeed, these bio-inspired information processing systems are suitable in the viewpoint of both practical accuracy and circuit size.

4. Conclusions

In this paper, a new computing paradigm, 'rough information processing' as well as some applications are descried. The digital systems require a lot of power and circuit size in order to obtain the absolute accuracy, that may not be so important in some applications indeed. Analog systems generally have disadvantage in accuracy and device stability over the digital systems, but they can be applied for such rough but conventional information processing systems.

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