EJECE, European Journal of Electrical and Computer Engineering
Vol. 3, No. 6, December 2019

Stochastic Computing: An Introduction

Matthew N. Sadiku, Emad Awada, and Sarhan M. Musa

***Abstract*—Stochastic Computing (SC) essentially represents numbers as streams of random bits and reconstructs numbers by calculating frequencies. It employs random bits to calculate via simpler circuits and with greater tolerance for errors. As a computing paradigm, SC is currently undergoing a revival. Since stochastic circuits have a small size, SC has regained interest recently due to its potential usage in some emerging nanotechnologies. In this paper, we briefly present stochastic computing and discuss its applications, benefits, and challenges.**

***Index Terms*—Stochastic computing, unconventional computing, probabilistic computing**

I. Introduction

The continuing capability of manufacturers to produce smaller devices with each technology generation has resulted in exponentially increasing circuit density structures. The manufacturing challenges that accompany technology scaling have led to ambiguity in devices performance and reliability [1] which threatens the continuation of Moore's law. As variability in circuit behavior increases, conventional approaches that aim to enforce deterministic behavior on a non-deterministic substrate become gradually expensive [2]. As semiconductor technology approaches the deep nanoscale regime, the stochasticity of the device and circuit fabric will need to be addressed. There is a need for unconventional computing methods that directly address these issues. A new vision for stochastic computing has begun to emerge as the solution

In the 1960s, Stochastic Computing (SC) was proposed as a low-cost alternative to conventional binary computing. It performs operations using probability [1] instead of arithmetic. Its operations convert a fairly complicated computation into a series of very simple processes on random bits. Although the stochastic computer has similarities to both analog and digital computers, it is fundamentally different from both.

It is uniquely different in that it represents and processes information in the form of digitized probabilities.

Published on December 27, 2019
M. S. is with the Electrical Engineering Department, Prairie View A&M University, Prairie View, TX 77446 USA (e-mail: sadiku@ieee.org).
E. A. is with the Electrical Engineering Department, Applied Science Private University, Amman 11931 , Jordan, (e-mail:e_awada@asu.edu.jo).
S. M. is with the Electrical Engineering Department, Prairie View A&M University, Prairie View, TX 77446 USA (e-mail: smmusa @pvamu.edu).

II. STOCHASTIC COMPUTING BASICS

Stochastic Computing (SC) was introduced in 1953 by John von Neumann. He addressed the problem of reliable computation in presence of unreliable components. Active research on stochastic computing dwindled over the next few years due to the fact it could not compete with more traditional digital logic. Although stochastic computing was a historical failure, it has shown promise in several applications and still remains relevant for solving certain problems [3].

As a new approach, stochastic computing can be seen as an alternative to conventional real arithmetic. It is an unconventional computing technique originally proposed to reduce the size of the digital arithmetic circuit. It can provide compact, low cost, error-tolerant, and low-power implementations of complex problems. Unlike deterministic computing, stochastic computing does not assume that hardware always produces the same results if given the same inputs. It allows for noise and uncertainty and tolerates transient errors in input data. Similar to human brain structure, stochastic computing is a move in the direction of processing and computing by parallel configuration structures [4, 5] to allow for extremely low cost and low power implementations of common arithmetic process.

Binary encoding systems operate on a positional representation of data. In SC, the signal value is encoded by the probability of obtaining a one versus a zero. The stochastic computer achieves distributed computation through its unique peculiar representation of data by the probability that a logic level will be ON or OFF at a clock pulse. A typical stochastic circuit realization of an arithmetic function is shown in Figure 1 [6]. In SC, stochastic numbers are processed as probabilities and they fall naturally into the interval [2]. The value of a bitstream is encoded by the number of constituent 1s and 0s and SC arithmetic circuits operate on the bitstreams. Many operations in SC do not yield exact results.

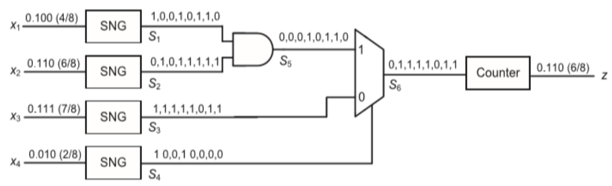

Fig. 1: Stochastic circuit realizing the arithmetic function [3]:
z=x1x2x4 +x3(1−x4)

Conventional digital circuits require thousands of transistors to execute the arithmetic operation, while SC

DOI: http://dx.doi.org/10.24018/ejece.2019.3.6.158

performs mathematical manipulations using little power [7]. SC typically involves considerably fewer hardware resources than conventional computing requires while performing the same algorithm [8].

III. APPLICATIONS

What was holding stochastic computing back was the lack of suitable devices to make it practical. There was no hardware available which would make the construction of the complex computing structure required in SC.

Although stochastic computing has a number of defects, there are certain applications that highlight its strengths. SC techniques have been proposed and projected at almost all levels of the computing stack. It has been recognized that SC is potentially useful in specialized systems, where small size, low power, or even soft-error tolerance are required, and limited precision or speed are acceptable [9].

Stochastic computing has been investigated and examined for a variety of applications such as addition, multiplication, division, and square-rooting. It has also been applied in

artificial neural networks, control machine, machine learning, image processing, and vector quantization. New applications have been in energy, security, digital IIR filters, and medicine.

IV. BENEFITS AND CHALLENGES.

The major attraction of stochastic computing when it was first presented back in the 1960s is that it allows for very low-cost executions of arithmetic operations using standard logic elements. Another major attractive feature of SC is a high degree of error tolerance [6]. SC provides a rough estimate very rapidly. It is robust against noise; a minor error has no substantial impact on the outcome. Stochastic computing elements can tolerate skew in the arrival time of the inputs and consume low power. Besides saving power, SC enables progressive precision, i.e. the precision of the calculations depends on the length of the bitstream used.

In spite of these benefits and its inherent error tolerance, SC has some drawbacks. SC was assumed as unsuitable because of long computation time and relatively low accuracy. One major issue of SC is that applications implemented with this technique process are limited by the available computational elements. Tradeoffs between precision and memory can be very challenging. By nature, stochastic computing is random. SC requires a means of generating randomly biased using pseudo-random number generators, which can be expensive. These main challenges must be addressed if the full potential of SC is to be valued.

V. CONCLUSION

Stochastic computing is an emerging computing technique that promises low power, high density, and error tolerant solutions. It is an unconventional method of computation that treats data as probabilities. It has significant theoretical appeal as a very unconventional way to compute. It has lately regained major attention due to its fault-tolerance property.

The main performance measures of a computer include physical size, the range of possible problems, speed, and accuracy of solution, reliability, and cost of the computer. In this regard, it is expedient to trade the accuracy of the digital computer and the speed of the analog computer, for the economy of the stochastic computer [10]. More information on SC can be found in the book in [11].

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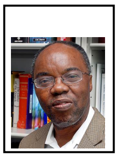

Matthew N.O. Sadiku is a professor in the Department of Electrical and Computer Engineering at Prairie View A&M University, Prairie View, Texas. He is the author of several books and papers. His areas of research interests include computational electromagnetics and computer networks. He is a fellow of IEEE.

Emad Awada is an associate professor in the Department of Electrical and Computer Engineering at Applied Science Private University, Jordan. He received his B.S., M.S., and Ph.D. in Electrical Engineering from Prairie View A&M University, Prairie View, Texas. He is the author of several papers. His areas of research interests include mixed signals analysis, signals computational, and electrical machine faults detection.

Sarhan M. Musa is a professor in the Department of Engineering Technology at Prairie View A&M University, Texas. He has been the director of Prairie View Networking Academy, Texas, since 2004. He is an LTD Sprint and Boeing Welliver Fellow.

DOI: http://dx.doi.org/10.24018/ejece.2019.3.6.158