Memcomputing: a Computing Paradigm to Store and Process Information on the Same Physical Platform

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INTRODUCTION

The present von Neumann computing paradigm involves a significant amount of information transfer between a central processing unit (CPU) and memory, with concomitant limitations in the actual execution speed. However, it has been recently argued that a different form of computation, dubbed *memcomputing* [1] and inspired by the operation of our brain, can resolve the intrinsic limitations of present day architectures by allowing for computing and storing of information on the same physical platform. In my talk, I will discuss several possible memcomputing architectures based on emergent memory devices.

HARDWARE

Two-terminal electronic devices with memory, namely, memristive, memcapacitive and meminductive systems [2] (see Fig. 1 for their symbols), offer a different approach to computing due to their ability to store and process information at the same physical location. These devices combine the functionality of basic circuit elements – resistors, capacitors and inductors – with memory features, and, very often, nanoscale dimensions. While the operation of such electronic devices is based on a variety of physical phenomena [3], their mathematical description is universal [2], thus allowing identification of general features without regard to specific physical processes that lead to memory.

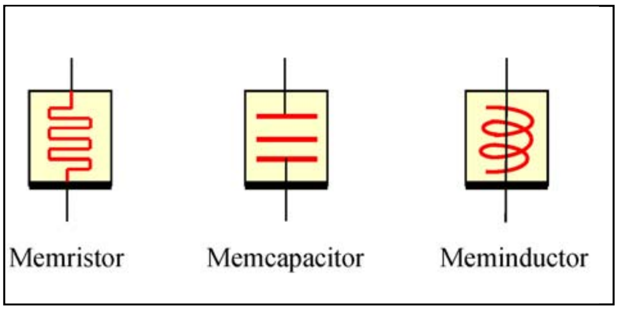

Fig. **1**. Symbols of memory circuit elements [2].

Complex networks of such devices (such as shown in Fig. 2) can be considered as massively-parallel processors performing computation in an unconventional way, which we have named as memcomputing [1].

MEMCOMPUTING CRITERIA

In order to fabricate a viable memcomputing device, several criteria must be met. Specifically, memcomputing requires [1]:

- Scalable massively-parallel architecture with combined information processing and storage.
- Sufficiently long information storage times.
- Ability to initialize memory states.
- Mechanisms of collective dynamics, strong ‘memory content’.
- Ability to read the final result from the relevant memelements.
- Robustness against small variations and noise.

REALIZATIONS

Massively parallel analog and digital computing architectures based on memory circuit elements can be designed in several different ways using a variety of physical systems with memory [3]. In this talk, I will give an overview of several known memcomputing architectures and focus on few particular examples related to our previous work [4-6].

ISBN 978-2-9547858-0-6

In particular, recently we have investigated a representative memcomputing architecture based on two-dimensional networks of memristive devices [4,5] (Fig. 2). The main advantage of this architecture is based on the analog parallel dynamics of many memristive elements. We have shown that such networks can efficiently solve various shortest-path optimization problems [5]. The presence of memory promotes self organization of the network into the shortest possible path(s). One can introduce a network entropy function to characterize the self-organized evolution and show that the entropy decreases as the shortest-path solution emerges in an initially homogeneous network. Additionally, the memristive networks have a remarkable ability to repair damaged solutions (see Fig. 3). This property is very similar to the self-healing ability of our brains.

It is worth mentioning that similar considerations apply to networks of memcapacitors and meminductors, and networks with memory in various dimensions. Some work has already been done along these lines. For example, the recently developed concept of Dynamic Computing Random Access Memory [5] utilizes memcapacitors to store and process information directly in memory at low energy cost.

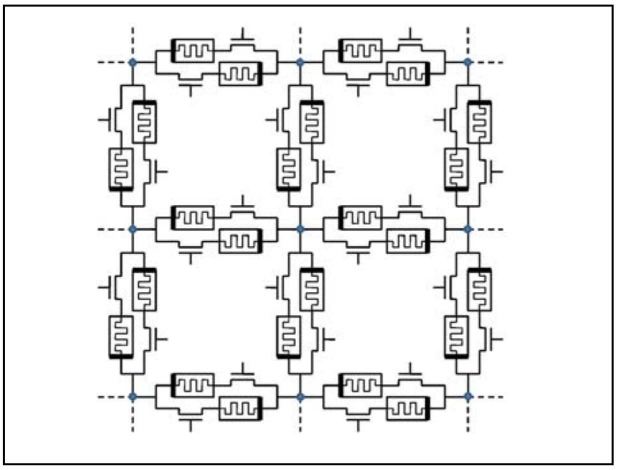

Fig. 2. An example of a memristive processor [5] consisting of a network of memristive elements in which each grid point is attached to several basic units. Each basic unit involves two memristive devices connected symmetrically (in parallel) and two switches (field-effect transistors).

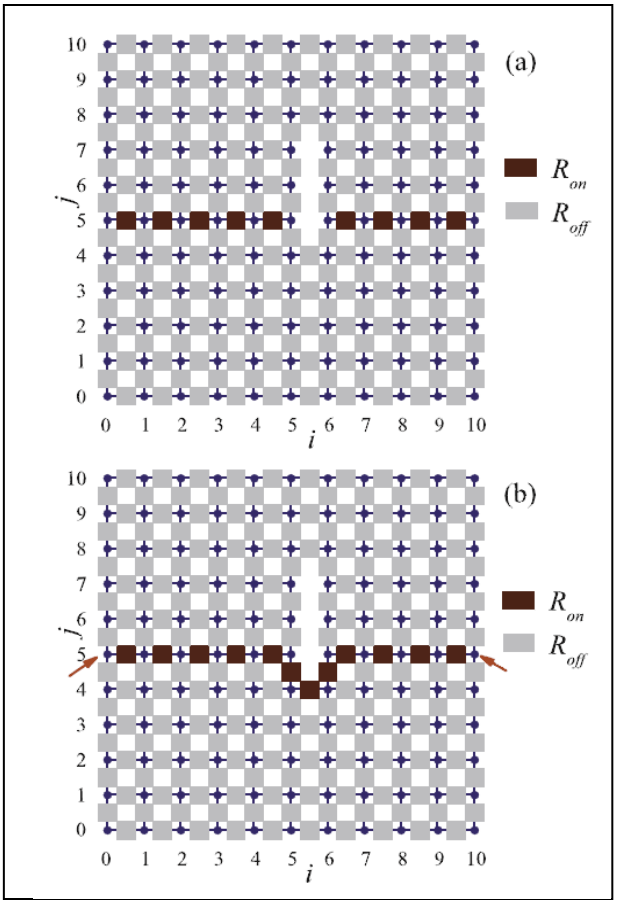

Fig. 3. Healing (b) of a damaged (a) solution. From [5].

ACKNOWLEDGMENT

This work has been partially supported by NSF Grant ECCS-1202383.

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