# The memristor in the context of neuromorphic computing.

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Abstract. The abstract is in 10 point Times New Roman font and is justified. It should provide a brief summary of the content of the report. If possible you should avoid references in the abstract but, if they are needed, you must include the full reference.

## 1. A network of neurons and synapses

There are postulates that the human brain can be modelled by an interconnected network of neurons and synapses [1]. This postulate and further research in the field of neuroscience have led to revolutions in what a computer can do. The brain is a powerful computational device, through the attempted analysis and replication of it we are living in an age of unprecedented technological advancements [2].

### *1.1. An important distinction to be made*

Due to recent developments and publicity computational neural networks have garnered in recent time, it is important to make a distinction between neuromorphic computing and computational neural networks. A computational neural network refers to implementing a brain like network of nodes and synapses through software alone, it will not be the focus of this report. Whereas neuromorphic computing differs in that the components at a fundamental level resemble a brain like structure, in other words the brain is not programmed in this instance, instead resemblance of the brain becomes an innate hardware property.

## 2. Comparisons between MOSFET computing and a memristor-based architecture

### *2.1. MOSFET computing*

A Metal–oxide–semiconductor field-effect transistor chip, or MOSFET chips as it will be referred to throughout this text, is a branch of field-effect transistors which encompasses the typical transistors used in computer chips, a typical processor such as the recently released AMD Instinct™ MI300A has 146 billion of these present [3].

A fundamental property of computers designed with MOSFET chipsis the separation of processing and memory, MOSFET chips will only be used to ether process or store data. While there are techniques used to mitigate this effect, such as the use of high-speed cache near a central processing unit, this separation will eventually bottleneck the speeds of the MOSFET.

Some papers might refer to a technology called Complementary metal–oxide–semiconductor chips (CMOS). These chips fall under the umbrella term of MOSFET, and differences are beyond the scope of this report. For all intents and purposes in the context of neuromorphic computing, these are the same.

*2.2. Memristor-based architecture, an alternative to MOSFET?*
A memristor-based architecture is a hypothesised architecture that allows memory and processing to be done by the same chip at a fundamental level, the separation between a block of processing and a block of memory is now more. This breaks one of the fundamental bottlenecks of the MOSFET architecture.

Part of the inspiration behind a memristor chip is the nodes and synapses of the brain, the better we get at making memristor-based architectures the more the components will resemble a brain like structure as seen in figure 2.

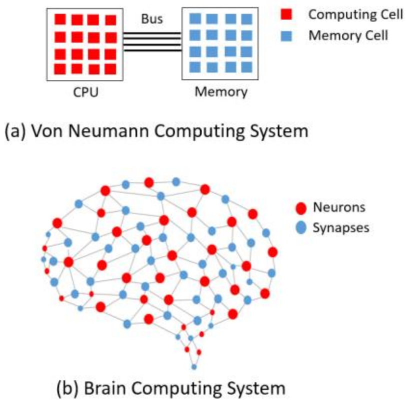


Figure 2. Taken from [4] with minor formatting edits. Top is a heavily simplified version of current computer architecture referred to as a Von Neumann computing system, the MOSFET chips are part of the system. The image shows clearly that for MOSFET chips, or cells as they are referred to here, processing and memory are 2 individual components. The lower half of the image shows how a brain is contrasted with the MOSFET architecture, The Neurons and Synapses which handle the processing and memory are intertwined which is how a memristor-based architecture is theorised to behave.

**3. Memristor–The missing circuit element (Primary paper 1 [5])**

*3.1. Why is this chosen as a primary paper, and evidence for it being a primary paper*
This paper is the first to coin the term 'memristor' and it postulated the existence of a memristor as the fourth basic circuit element. It also defined the properties a component would have to be labelled as a memristor.

*3.2 Symmetry argument to predict the memristor*
There are four fundamental circuit variables; current $I$, voltage $v$, charge $q$ and flux-linkage $\varphi$. There are 6 possible relations between them.

Two of them in integral form given by

$$q(t) = \int_{-\infty}^{t} I(t)dt \ ,$$

And

$$\varphi(t) = \int_{-\infty}^{t} v(t)\ dt \ .$$

The three other relations are given via fundamental circuit elements; v and I *by the resistor,* $\varphi$ and $I$ by the inductor and, $q$ and $v$ by the capacitor.
This leads to a missing relation, the relation of $\varphi$ *and* q. Leon O. Chua states 'From the logical as well as axiomatic points of view, it is necessary for the sake of completeness to postulate the existence of a fourth basic two-terminal circuit element which is characterized by a $\varphi$-$q$ curve.' He named this component a memristor due to its behaviour and similarity to a nonlinear resistor with memory.

3.3 *Electrical properties of the memristor*
The main property that is of interest to us in the context of neuromorphic computing and a memristor based architecture is the voltage across a charge-controlled memristor. It is given by

$$v(t) = M\big(q(t)\big)I(t).$$

Where the incremental memristance *M(q)* is defined as

$$M(q) = \frac{d\varphi(q)}{dq}.$$

From this we see that for a given time the memristor behaves like a resistor which has the definition

$$v(t) = RI(t),$$

But with a Resistance that depends on the history of the memristor current.

## 4. The missing memristor found (Primary paper 2 [6])

*4.1. Why is this chosen as a primary paper, and evidence for it being a primary paper*
This paper, wrote by a team at HP, is the first to present a physical model that follows most of the properties predicted by Leon O. Chua, and it was confirmed by Leon O Chua himself that he considers this physical model is a memristor.

*4.2 The found memristor*
As seen in figure 3 the team at HP invented the memristor using a thin semiconductor film sandwiched between two metal contacts, the semiconductor consists of 2 regions, one with a high concentration of dopants and thus low resistance, the other with a low concentration of dopants and might higher resistance. The application of an external voltage moves this boundary between the 2 regions changing the size of each of them and therefore changing the resistance. This is memory-based resistance.

Furthermore, this technology has proven useful especially in the context of cryptography in [7] by 'addressing the memory access bottleneck and eliminates stand-by power in conventional computers'. The paper also highlighted the reduced energy consumption and the potential for hybrid MOSFET and memristor technology as an area for future research.

*4.3. The missing memristor has not been found*
Sascha Vongehr & Xiangkang Meng [8], claim that the devices discovered by [6] in 2008, have already been discovered in 1995 and these are not the memristor that was predicted by the 1971 paper by X. Sascha Vongehr & Xiangkang Meng go onto further claim that authors changed the definition of the memristor to make the discovery of the memristor, when discrepancies between the predicted memristor and the 'found' memristor arose, the team at HP excused them by not having found a 'perfect' memristor, which Sascha Vongehr & Xiangkang Meng argue 'the meaning of which accords to the mentioned tacit redefinition of "memristor" as not-just-memristive'.
Nevertheless as shown in by the applications of the 'found' memristor in [6], while it may not be a perfect memristor that does not detract from its usefulness, and it also won't stop HP trying sell it as a memristor [9].

## 5. Concluding remarks

Much work has been done in the unification of processing and memory in computer systems[6], but the question remains will this ever garner mainstream appeal and dethrone MOSFET chips, while the memristor has found use[7] it has been limited [8], one wonders if a 'perfect' memristor is not found if another approach to neuromorphic computing might be beneficial.

## References

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