Neuromorphic Computing

Carlos Zarco
College of Engineering, California State Polytechnic University, Pomona
cdzarco@cpp.edu

***Abstract*—This research paper introduces the concept of neuromorphic computing. It is a type of computing architecture that is based on the principles of the brain. It goes over the benefits of neuromorphic computing when compared to more traditional computing architectures like Von Neumann architecture, particularly focusing on efficiency and power consumption. Lastly, the paper details some of the applications that neuromorphic computing has in robotics, computer vision, and artificial intelligence.**

***Index Terms*—neuromorphic computing, Von Neumann architecture, power consumption, efficiency, robotics**

I. What is neuromorphic computing?

The most advanced processor that any person will ever have in their lifetime has been with them since birth. This processor is the human brain. It is responsible for memory, logic, decision-making, and more. The neuron of the brain is a small unit that makes up the overall nervous system of the brain [1]. Neuromorphic computing makes use of artificial neurons which are then used to perform different computations. It is a model of computing that is based on the principles of the brain [2].

In his TedTalk on Neuromorphic computing, neuroscientist Henry Markram described the brain as projecting its version of the universe to each person like a perceptual bubble. To find out if their theory was correct, he needed neuromorphic computing to see if a digitized brain could show its perception of reality. His team used one laptop to simulate a single neuron of the brain. Thus, they reached out to IBM for a supercomputer to be able to simulate up to 100,000,000,000,000 synapses. He is exploring neuromorphic computing to test and see if the brain can create a sort of perception of images that are used to stimulate it [3].

This type of computing aims to address some of the shortcomings of other forms of computing architectures and offers exclusive unique benefits.

II. What are the benefits of neuromorphic computing?

There are many benefits to neuromorphic computing however, to understand their significance it is important to delve into a more common architecture to see where computing is currently and where it might be going. In a Von Neumann architecture machine, the system's memory contains both instructions and data in the same area of the RAM [4]. The memory is also segmented into pages with each one containing either instructions or data but not both. The machine also has the following components: a processing unit with an ALU, a control unit, and I/O devices [5]. It is a simple design that is still in use for most computers today. However, it is limited by what is known as the Von Neumann bottleneck. The performance of these types of machines is limited because instructions have to be done sequentially. The CPU has to wait for data to be fetched before execution of the next instruction because they are stored in the same memory. This is because the CPU and memory are connected by a single bus [5]. Despite this problem, this architecture is used for high-level computing which leads to more power consumption.

One of the biggest benefits that neuromorphic computing has over Von Neumann's architecture is that it has the potential to be more efficient. A large group of Cornell neuromorphic computing researchers argue that since it is based on the biological concepts of the brain, future computers can store and process vast quantities of data with lower power consumption than their traditional counterparts. Another massive benefit of neuromorphic computing is the ability to learn or adapt. The same Cornell group argues that Von Neumann architecture computers do not have the ability to learn as well as handle complex data in the same way our brains will [6]. The last benefit to this approach of computing is that the computing speed is exceptionally fast. A neuromorphic computer called BrainScaleS in Germany can run simulations 1,000 times faster than its nonbiological supercomputer counterpart [7]. In short, compared to today's computers using Neumann architecture, neuromorphic computers are faster, can learn, and are more efficient.

III. What are some applications of neuromorphic computing?

These new biologically modeled computers have proven themselves to be beneficial compared to traditional computing forms. There are many use cases in which neuromorphic Computing can be applied. One of the most promising is in the field of robotics. In his paper on the applications of these computers, Steve Furber described the potential for its use in robot control, vision processing, and modeling biological circuits. He described their use in small-scale SpiNNaker Systems. Furber also describes some applications in artificial intelligence. He explained that researchers are exploring how these computers are used to handle real-time cognitive tasks [8]. This echoes similar feelings that the Cornell researchers had about the ability of these types of computers to learn over time [6]. Neuromorphic computers have varied applications that have advantages over other computer architectures because of their unique ability to adapt over time. They are also thought to be better at certain aspects like computer vision because people are able to better identify objects accurately than computers.

Acknowledgment

Dr. Mohamed El-Hadedy Thanks
Cal Poly Pomona Department of Engineering Thanks

References

[1] A. Woodruff, "What is a neuron?," Uq.edu.au, Jul. 04, 2018. https://qbi.uq.edu.au/brain/brain-anatomy/what-neuron

[2] M. Davies et al., "Advancing Neuromorphic Computing With Loihi: A Survey of Results and Outlook," Proceedings of the IEEE, vol. 109, no. 5, pp. 911–934, May 2021, doi: https://doi.org/10.1109/jproc.2021.3067593.

[3] H. Markram, "A brain in a supercomputer," www.ted.com. https://www.ted.com/talks/henry_markram_a_brain_in_a_supercomputer?language=en

[4] "Wayback Machine," web.archive.org, Apr. 25, 2012. https://web.archive.org/web/20120425083227/http://none.cs.umass.edu/ dganesan/courses/fall09/handouts/Chapter4.pdf

[5] "Computer Organization — Von Neumann architecture," GeeksforGeeks, May 09, 2018. https://www.geeksforgeeks.org/computer-organization-von-neumann-architecture/

[6] D. V. Christensen et al., "2022 roadmap on neuromorphic computing and engineering," Neuromorphic Computing and Engineering, vol. 2, no. 2, p. 022501, May 2022, doi: https://doi.org/10.1088/2634-4386/ac4a83.

[7] "Neuromorphic Computing," www.humanbrainproject.eu. https://www.humanbrainproject.eu/en/science-development/focus-areas/neuromorphic-computing/

[8] S. Furber, "Large-scale neuromorphic computing systems," iopscience.iop.org, Aug. 16, 2016. https://iopscience.iop.org/article/10.1088/1741-2560/13/5/051001/meta.