

The rapid growth of deep learning applications has pinpointed a fundamental issue within the domains of electrical and computer engineering: the need for hardware that is both more powerful and more energy-efficient. Present computing systems, dependent on high-power hardware accelerators, do not meet the green and efficiency criteria demanded by today's computing tasks. Memristors are electronic devices expected to significantly improve the fields of machine learning and artificial intelligence, on issues of energy efficiency and overcoming von Neuman's architecture bottleneck.

The memristor (a resistor with memory) is one of the four basic two-terminal circuit elements (apart from the resistor, inductor, and capacitor). Its resistance depends on the historical patterns of current traversing the element or the voltage applied across it. Memristors were theoretically introduced in 1971. Almost four decades later, in 2008, memristive behaviour was recognized in a nano-scale double-layer of titanium dioxide film. The existence of memristive behaviour in nano-scale opens a large spectrum of opportunities in the realization of low-power, high-density memories, which could replace existing technologies. Since memristors can handle analog values, and moreover the memristor is capable to simulate synaptic connections between neurons, some future devices based on memristors could be possibly designed to mimic biological functions and be used in the construction of brain-like computers.

Memristors stand out for their proven ability to drastically lower energy consumption and to elevate the efficiency of computational operations. These circuit elements are considered as a significant improvement over traditional memory cells, as they eliminate the need for constant memory refreshing, minimize the typically high computational costs of reading and writing data. Their ability to carry out computations directly in memory opens a possibility to build more efficient computational units.

The goal of the project is the development of methods for analysis and design of electronic systems with memristors for neuromorphic applications. The research is structured with several essential goals that leverage the distinctive attributes of memristors. Primary among these is to formulate a new methodology that enables detailed analysis of the behavior of memristor-based neuromorphic systems, including developing a complex framework that can manage various memristor-based neuron models and analyse their behavior under different conditions. Furthermore, the research involves development of algorithms and carrying out simulations that enhance comprehensive understanding of these systems. An integral aspect of this research project is the development of novel design approaches for neuromorphic circuits incorporating memristor-based components that emulate biological neurons and synapses, ultimately enabling networks that perform similarly to the human brain.

The key research problems studied in the research project are

- How to design a memristor circuit for applications in neuromorphic computing?
- What types of memristor-based synapses most closely resemble the biological ones?
- What are the best methods for training bio-inspired artificial neural networks based on memristor synapses and neurons?
- How to design a memristor circuit that performs arithmetic and logic calculations in memory?

The impacts of this research are wide-ranging, not just fostering technological advancements but also making a marked contribution to the academic community. By offering a deeper understanding of how memristive systems operate and by developing sophisticated design tools, the research substantially augments the collective knowledge base regarding intelligent systems. Additionally, by driving the development of energy-efficient and high-performance neuromorphic architectures, the study has the potential to revolutionize a spectrum of artificial intelligence applications, from robotics to data processing, and encourages further interdisciplinary investigations.

The research project not only tackles a significant scientific challenge of reducing the energetic footprint of machine learning tasks but also signals the emergence of a new wave of computing technologies that are in tune with biological models and environmental sustainability.