جامعہ ملیّہ اسلامیہ
जामिया मिल्लिया इस्लामिया

Neuromorphic Computing

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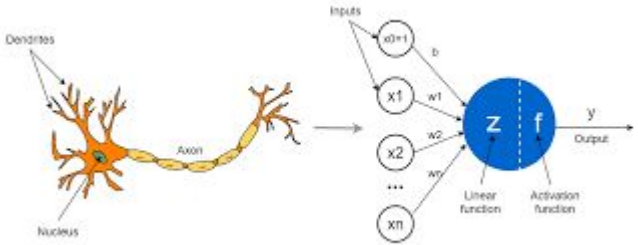
Introduction

Traditional computing faces challenges in tasks such as pattern recognition, sensory processing, and real-time interaction, which are effortlessly performed by the human brain. Neuromorphic computing, inspired by the brain's efficiency and parallelism, aims to overcome these limitations.

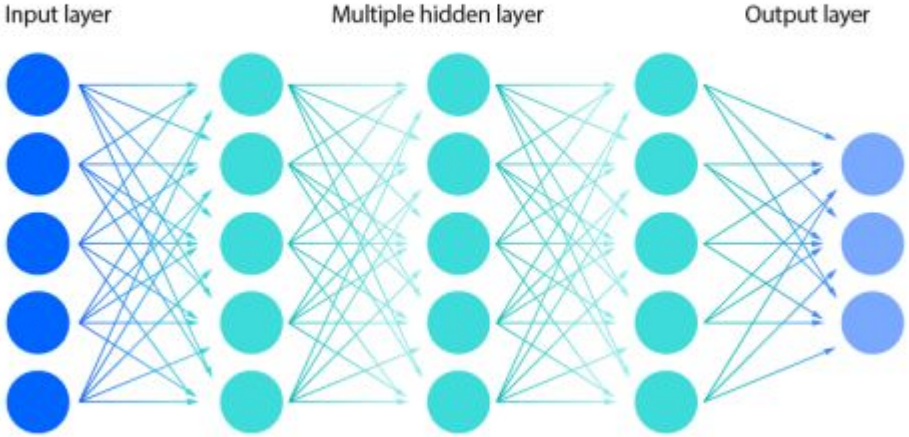
Neuromorphic computing seeks to mimic the structure and function of the human brain using electronic circuits. A key idea in neuromorphic computing is that of Artificial Neural Networks (ANNs). ANNs are computational models inspired by the structure and function of biological neural networks.

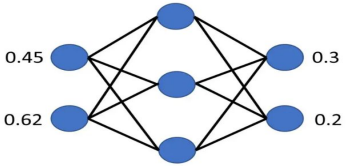


Neuromorphic Computing	Human Brian	Digital Computer
Learning Algorithms	Unknown	Algorithm: Programs/Logic
Neural Networks	Neurons, Synapses, Brain Computing System	Architecture: CPU, Bus, Memory, Von Neumann Architecture
Spiking Signals	Spiking Signals	Encoding Scheme: Binary Signals
Artificial Neurons and Synapses	Biological Neurons & Synapses	Devices: CPUs(Logic Gates, etc.), Memory(SRAM, etc.)

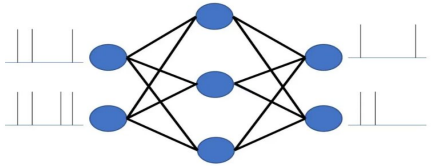
Reverse Engineering

Deep neural network





(a) Conventional ANNs where input and output are floating point numbers

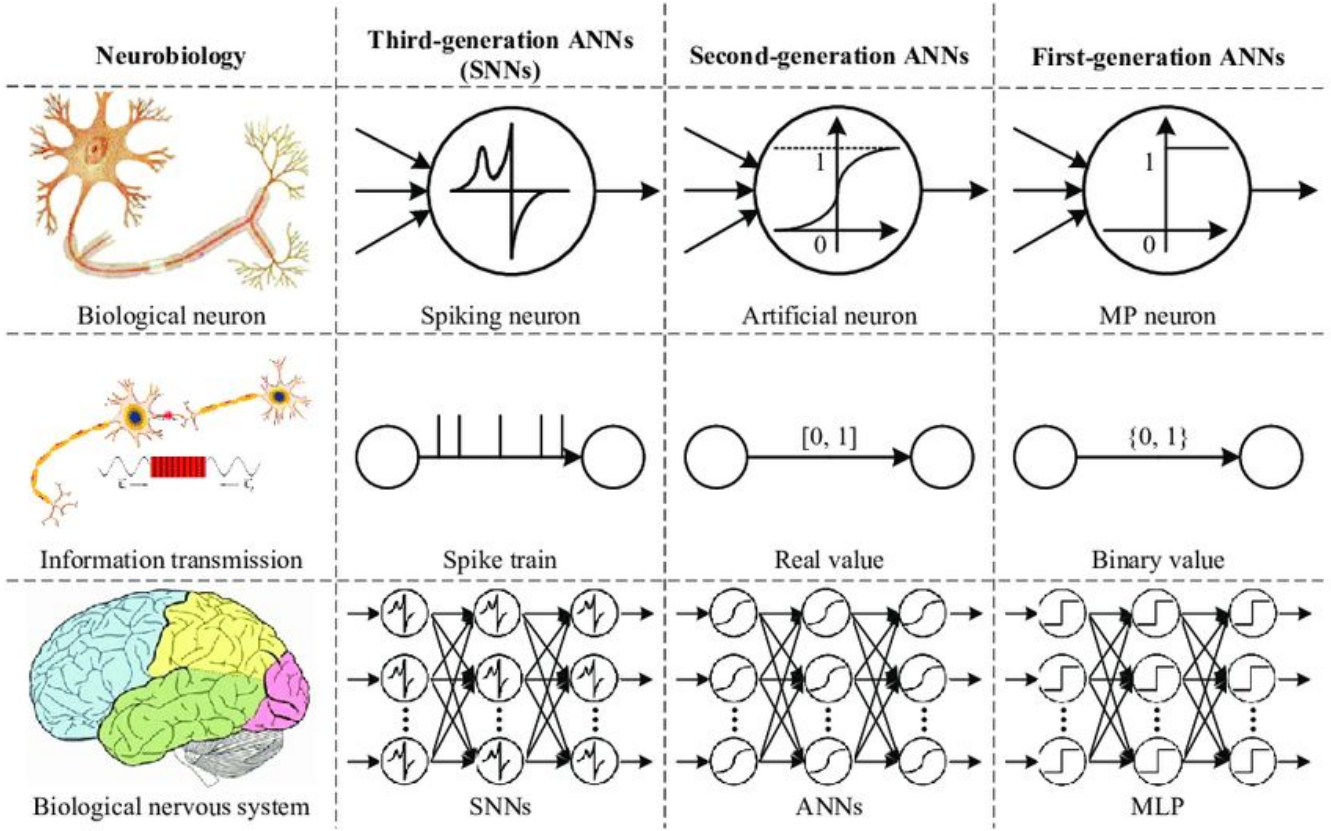


(b) SNN where the input and output are discrete spikes

Literature Review

- Wang, Xiangwen & Lin, Xianghong & Dang, Xiaochao. (2020). Supervised learning in spiking neural networks: A review of algorithms and evaluations. Neural Networks. 125. 258-280. 10.1016/j.neunet.2020.02.011. Talks about the evolution and development of SNNs.
- Gupta, Shikhar, Arpan Vyas, and Gaurav Trivedi. "FPGA implementation of simplified spiking neural network." 2020 27th IEEE International Conference on Electronics, Circuits and Systems (ICECS). IEEE, 2020. Presents an implementational idea for SNNs in hardware.
- Izhikevich, Eugene M. "Simple model of spiking neurons." IEEE Transactions on neural networks 14.6 (2003): 1569-1572. Presents an accurate yet computationally feasible neuron model.

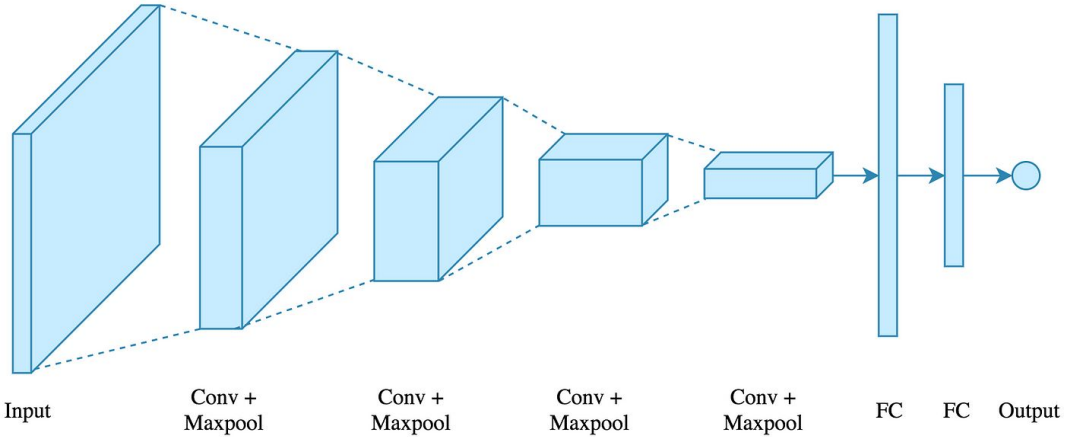
Technical Background



According to their computational units, ANN models can be divided into three different generations.

Convolutional Neural Networks (CNNs)

CNNs allow us to work with big data while keeping the number of trainable parameters reasonable. This is achieved by using convolutional filters to operate on multiple inputs at once, and pooling layers to decrease the size of activations. It is because of CNNs that computer vision and large language models (LLMs) became a reality.



Spiking Neural Networks (SNNs)

- Third-generation ANNs are SNNs that use biologically plausible spiking neurons as the basic computational units.
- Neural information in the spiking neuron is transmitted and processed by precisely timed spike trains.
- Compared with the first- and second-generation ANN models, SNNs can describe the real biological nervous system more accurately, so as to achieve efficient information processing.
- Spike trains make them more power efficient compared to ANNs, which work on analog data.

SNN Implementation

- There exists a trade off between accuracy and simplicity.
- The neuron model used depends on the application.
- Efficacy of SNNs depends on the spike train encoding used.
- A spike can be represented as a “glitch”, which can be obtained when different bit streams travelling along paths with different propagation delays meet.
- Updating of synaptic weights occurs on the basis of spike-timing-dependent-plasticity (STDP).

ANNs vs SNNs

- ANNs can’t capture time and space dependencies present in the data effectively. Therefore, SNNs have more powerful information representation ability than ANNs.
- The state of a spiking neuron is represented by differential equations, whereas ANNs use activation functions for this purpose.
- SNN execution is clock or event driven; ANN execution flows sequentially.
- SNNs reinforce causality using STDP; Hebb’s rule used by ANNs ignores this.

Conclusion

- Efforts to understand and reproduce the functionality of the brain have led to the evolution of ANNs.
- CNNs are computationally expensive and hence are not scalable.
- SNNs emulate the biological neuron and use spikes. They consume less power and can be scaled for future applications.
- Hardware implementation and accuracy are still being explored.

Future Work

The Minor and Major Projects would work towards implementing an SNN on FPGA.

- Most applications of SNNs in hardware have used ASICs.
- FPGAs provide flexibility, simplicity, and parallelism.
- They can be used for rapid prototyping owing to their less power, one-time cost, and fast operation and deployment.
- FPGAs are usually designed using HDLs.

References

[1] Wang, Xiangwen & Lin, Xianghong & Dang, Xiaochao. (2020). Supervised learning in spiking neural networks: A review of algorithms and evaluations. Neural Networks. 125. 258-280. 10.1016/j.neunet.2020.02.011.

[2] Fang, Haowen, et al. "Encoding, model, and architecture: Systematic optimization for spiking neural network in FPGAs." Proceedings of the 39th International Conference on Computer-Aided Design. 2020.

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[6] Izhikevich, Eugene M. "Simple model of spiking neurons." IEEE Transactions on neural networks 14.6 (2003): 1569-1572.