Investigating Energy Efficiency in Biological Neurons and Artificial Neural Networks

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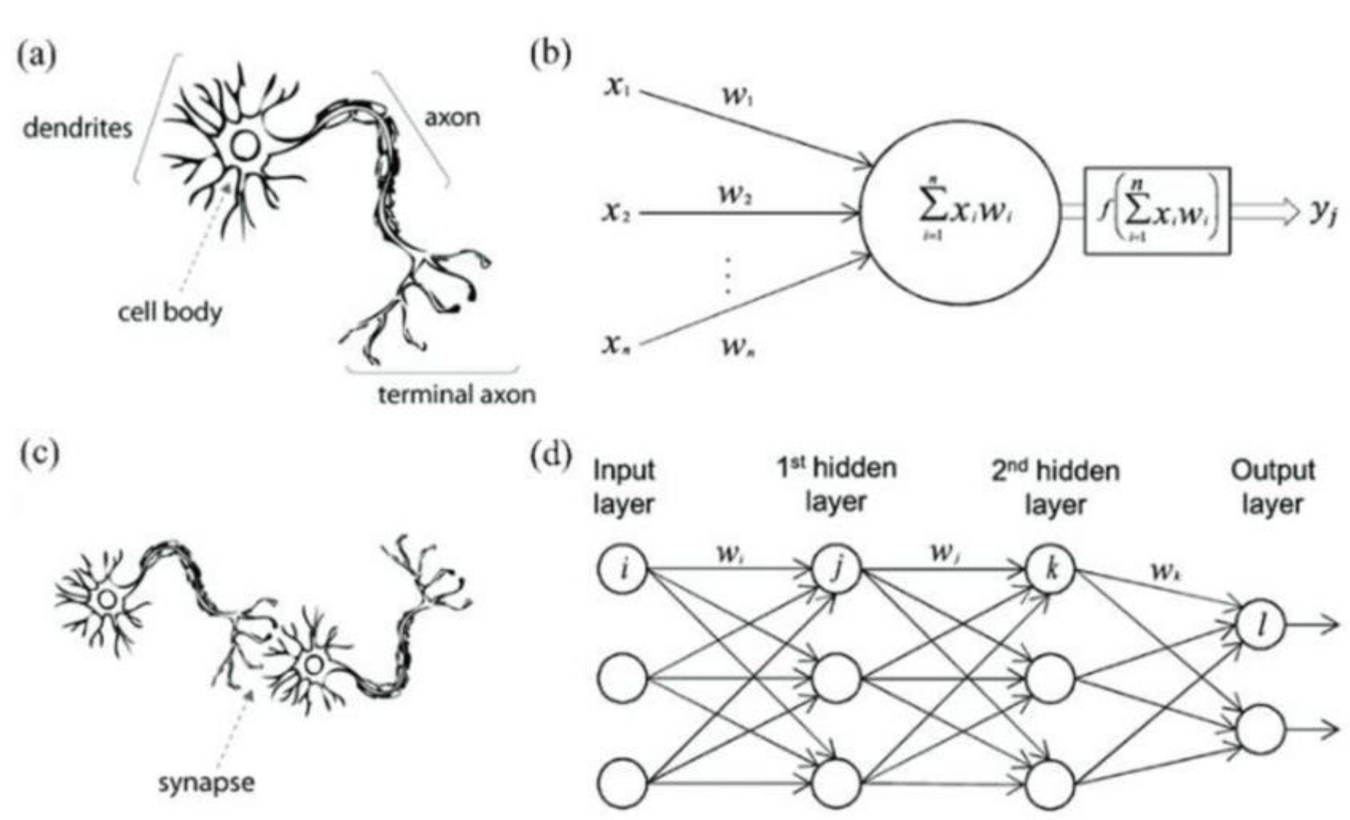
Abstract

This research aimed to examine energy efficiency between artificial neurons used in artificial neural networks (ANNs) and biological neurons. A standard feedforward ANN and an ANN inspired by biological neurons were designed, trained, and tested to perform handwritten digit recognition. The ANN inspired by biological neurons included both trainable and fixed weights. Statistical analyses of their performance revealed similarities in accuracy with increasing number of training iterations.

Background

- Brains exhibit significantly higher energy efficiency compared to artificial neural networks (ANNs)[1]
- ANNs often consist of simple "point neurons" as their fundamental building blocks
- In contrast, biological neurons are more complex, featuring dendritic nonlinearities and other biological structures
- Are these complex biological neurons the source of to brain's remarkable energy efficiency?



A biological neuron in comparison to an artificial neural network. (a) Brain neuron, (b) Artificial neuron, (c) Neuron & biological synapse, (d) Artificial neural network[2]

Objectives

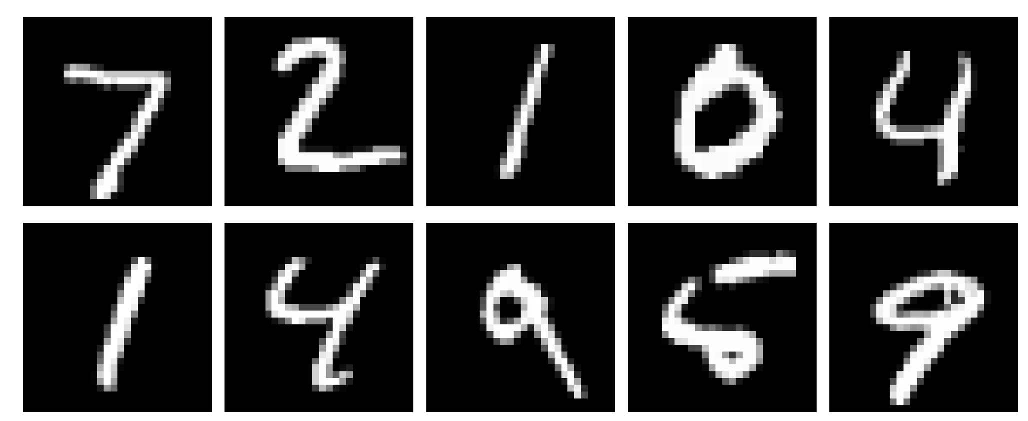
- Discover fair and accurate methods to compare ANNs and ANNs inspired by biological neurons
- Investigate the advantages and disadvantages between ANNs and ANNs inspired by biological neurons to perform a simple task

Methods

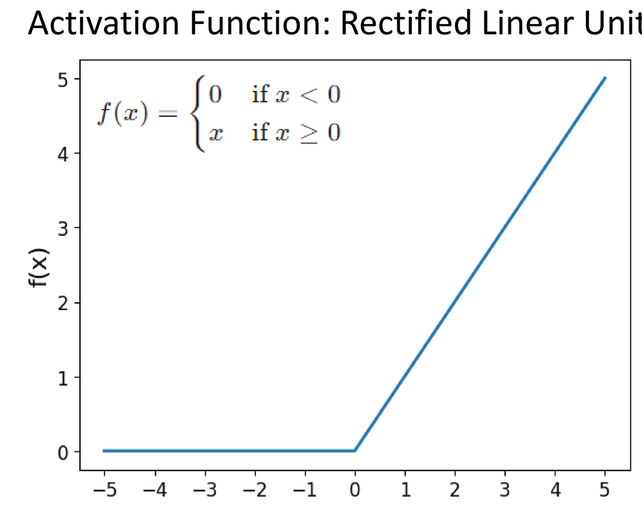
Design, train, and test a standard feedforward ANN and an ANN inspired by biological neurons to perform as handwritten digit recognition using the MNIST dataset

Example Images from the MNIST Dataset

Each image consists of 784 pixels arranged in a 28 by 28 pixel grid



Activation Function: Rectified Linear Unit



Weight Initialization: Kaiming Initialization

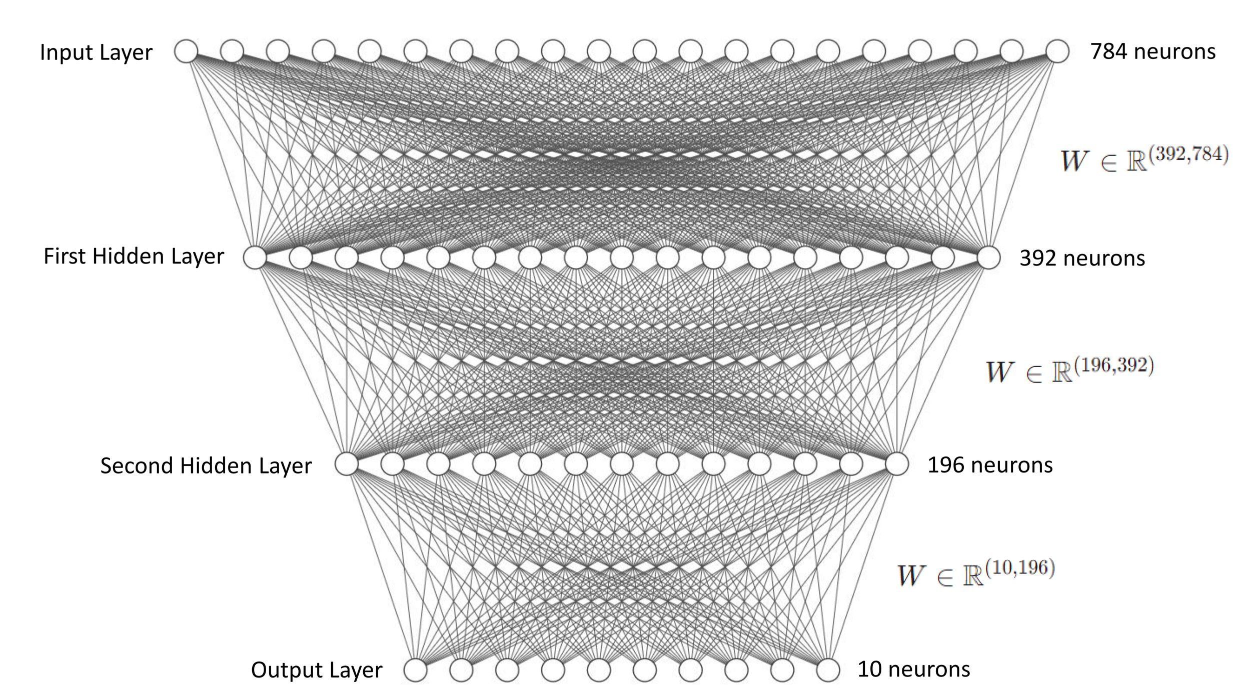
$$U(\text{-bound, bound})$$

$$\text{bound} = \text{gain} * \sqrt{\frac{3}{\text{fan mode}}}$$

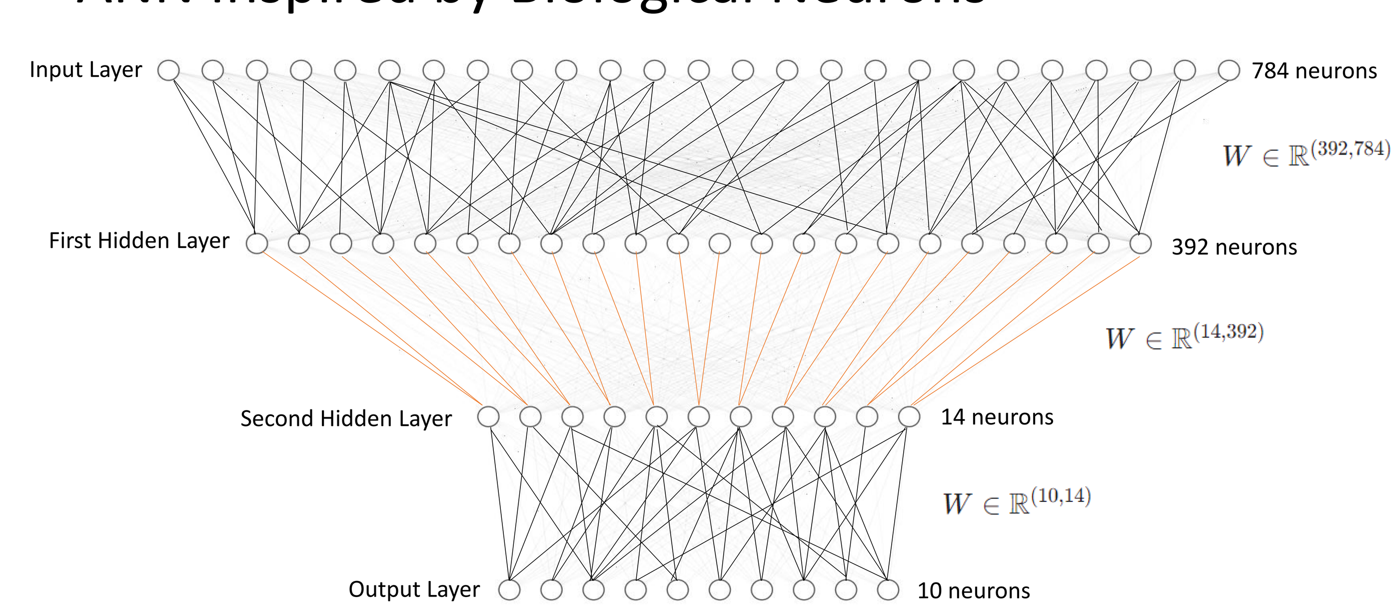
$$\text{fan mode} = \text{fan in or fan out}$$

- Resulting tensors will have values sampled from a uniform distribution ranging from –bound to bound
- The gain is a scaling factor to control the spread of initialized weights
- Fan in refers to the number of input units
- Fan out refers to the number of output units

Standard Feedforward ANN

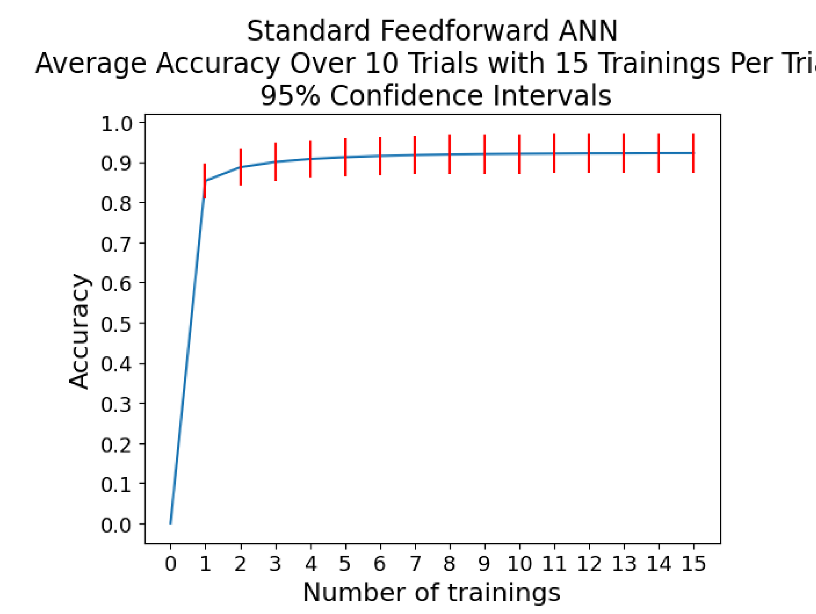


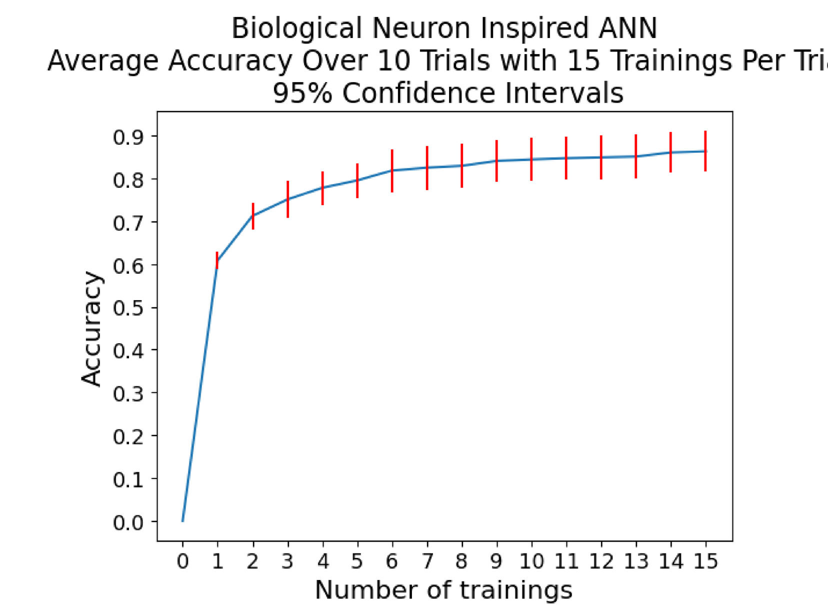
ANN Inspired by Biological Neurons



Results

Compare the performance of the standard feedforward ANN and the ANN inspired by biological neurons





Type of ANN	Number of Trainable Weights	Number of Fixed Weights	Total Number of Weights
Standard Feedforward ANN	386,120	0	386,120
Biological Neuron Inspired ANN	307,468	392	307,860

Discussion

This study examines the energy efficiency of feedforward artificial neural networks (ANNs) compared to biologically-inspired ANNs. The results demonstrate that as the number of trainings increases, the accuracy of both types of networks converges, indicating the role of dendritic nonlinearities in shaping the energy efficiency of biological neurons. Dendritic nonlinearities, along with other complex biological structures, contribute to the computational power and efficiency of biological neural systems. However, further investigation is required to develop robust methods for accurately quantifying and comparing the energy efficiency of these ANNs, considering the complexities of dendritic nonlinearities and their impact on network performance.

References

[1]Lianchu Yu and Yuguo Yu. (2017). Energy-efficient neural information processing in individual neurons and neuronal networks. 95, 11. DOI: https://doi.org/10.1002/jnr.24131

[2]Adapted from Sumari, P. et al. (2021). A Novel Deep Learning Pipeline Architecture based on CNN to Detect Covid-19 in Chest X-ray Images, 12, 2. DOI: 10.17762/turcomat.v12i6.4804

Acknowledgements

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GitHub Repository: https://github.com/BrianLi-hello/neuron_energy_efficiency