Dendrites endow artificial neural networks with accurate, robust, and parameter-efficient learning

Spyridon Chavlis[1#], **Panayiota Poirazi**[1*]

[1] Institute of Molecular Biology and Biotechnology, Foundation for Research and Technology-Hellas

Presenting author: SC, email: schavlis@imbb.forth.gr
* Corresponding author: PP, email: poirazi@imbb.forth.gr

ABSTRACT

The biological brain is remarkable in its ability to quickly and accurately process, store, and retrieve vast amounts of information while using minimal energy [1]. Artificial intelligence (AI) systems, on the other hand, are notoriously energy-hungry and often fail at tasks where biological systems excel, such as continual and transfer learning. The most widely used AI method is deep learning (DL) [2], which is applied in areas like computer vision and natural language processing and can even achieve superhuman performance in very specific tasks. However, the number of trainable parameters needed to achieve such performance is large leading to generalization failures due to overfitting, as well as energy consumption levels that are not sustainable. Moreover, unlike the brain, DL methods still fail to achieve high-performance accuracy under noisy settings and tasks where information changes in a continuous manner. This dichotomy between biological and artificial intelligence systems suggests that drawing inspiration from the brain may help enhance the efficiency of DL models, bringing them one step closer to emulating the biological way of information processing.

DL architectures rely heavily on multilayered artificial neural networks (ANNs) that imitate the structure and function of biological neurons. While artificial neurons capture the somatic and axonal functionalities of biological neurons, the dendritic computations are currently missing from these networks. Biological dendrites, because of their ability to generate local regenerative events, share a similar spiking profile as the neuronal soma. As a result, biological neurons can act as multi-layer ANNs, able to perform complex computations, such as logical operations, signal amplification and segregation, coincidence detection, multiplexing, and filtering of irrelevant or noisy stimuli. Consequently, dendrites are thought to underlie complex brain functions, including perception, motor behavior, fear learning, and memory linking. Moreover, dendrites can help achieve such functions in an efficient manner [3].

Our research reveals that a new ANN architecture, incorporating the structured connectivity and restricted sampling properties of biological dendrites, can effectively counteract these limitations. We have observed that dendritic ANNs are more robust to overfitting and outperform traditional ANNs in several image classification tasks, all while using significantly fewer trainable parameters. These advantages are likely a result of a different learning strategy, where most nodes in dendritic ANNs respond to multiple classes, unlike classical ANNs that strive for class-specificity. Importantly, our findings suggest that the incorporation of dendritic properties can make learning in ANNs more precise, resilient, and parameter-efficient. Furthermore, they shed new light on how biological features can impact the learning strategies of ANNs, inspiring further research in this direction.

REFERENCES

[1] Attwell D and Laughlin SB. 2001. *Journal of Cerebral Blood Flow & Metabolism*, **21**:1133 – 1145.
[2] LeCun Y, Bengio Y and Hinton G. 2015. *Deep Learning*, **521**: 436 – 444.
[3] Poirazi P and Papoutsi A. 2020. *Nature Reviews Neuroscience*, **21**: 303 – 321.