

Modeling Biological Neural Networks

Kai Deng

March 6, 2024

1 INTRODUCTION

For a comprehensive understanding of modeling biological neural networks, I recommend reading several seminal works. "Real-time computing without stable states: a new framework for neural computation based on perturbations" by Maass et al. (2002) provides a framework for neural computation that departs from traditional stable state computations. Additionally, Markram et al. (1997) have contributed foundational knowledge on synaptic efficacy and its regulation. To delve into contemporary neuromorphic computing systems, Mead (1990) and Meier (2015) offer significant insights. Finally, for advancements in phase-change memory devices and their application to neuromorphic computing, you might consider exploring the works of Tuma et al. (2016) and Burr et al. (2017). These papers will offer a broad and detailed spectrum of knowledge on the subject.

For additional papers on modeling biological neural networks, you may look into "Neuromorphic computing using non-volatile memory" by Burr et al. (2017), which explores the application of non-volatile memory technology in neural network models, and Davies et al. (2018) discuss "Loihi", a neuromorphic manycore processor with on-chip learning capabilities. For a tutorial on brain-inspired computing using phase-change memory devices, see the work by Sebastian et al. (2018). These papers are at the forefront of combining neuroscience with advanced computational technologies.

Certainly! Here are some recent significant papers related to the modeling of biological neural networks which you may find valuable:

1. A paper on "Reliable interpretability of biology-inspired deep neural networks" delves into how interpretations from neural networks can be influenced by the initialization of weights and the structure of the network itself. The study emphasizes the need for repeated network training to ensure robustness and reliability of interpretations (Nature Systems Biology and Applications).

2. The article "Deep learning incorporating biologically inspired neural dynamics and in-memory computing" discusses learning spatio-temporal patterns and the use of phase-change memristors, highlighting advancements in neuromorphic computing and its potential applications in biological neural network modeling (Nature Machine Intelligence).
 3. In "Biologically informed deep neural network for prostate cancer discovery," researchers have presented a framework for outcome prediction and hypothesis generation in prostate cancer, demonstrating how a deep neural network can incorporate biological pathways to provide insights that could potentially be translated clinically (Nature).
 4. For a more theoretical perspective, the arXiv paper "Learning biological neuronal networks with artificial neural networks: neural oscillations" provides insights into the parameters and simulations of spiking neural networks (SNNs), focusing on how they can be used to understand neural oscillations, which are crucial in various cognitive computations.
- These papers offer a blend of practical applications, theoretical understanding, and the latest methodologies in the field. They reflect the current trends in harnessing deep learning and computational models to gain insights into biological neural networks and their functions.

1.1 BACKGROUND CONTEXT

Biological neural networks are complex networks composed of nerve cells (neurons) in organisms (especially human brains and animal brains) and the connections between them. This network is the basis of the biological nervous system and is responsible for processing and transmitting information, allowing organisms to perceive the environment, make decisions, control movement and perform various complex behaviors.

The main features of biological neural networks include:

- Neuron: The basic unit of neural networks. Each neuron consists of a cell body, dendrites, and an axon. Dendrites are responsible for receiving signals from other neurons, while axons are responsible for transmitting signals to other neurons or muscle cells.

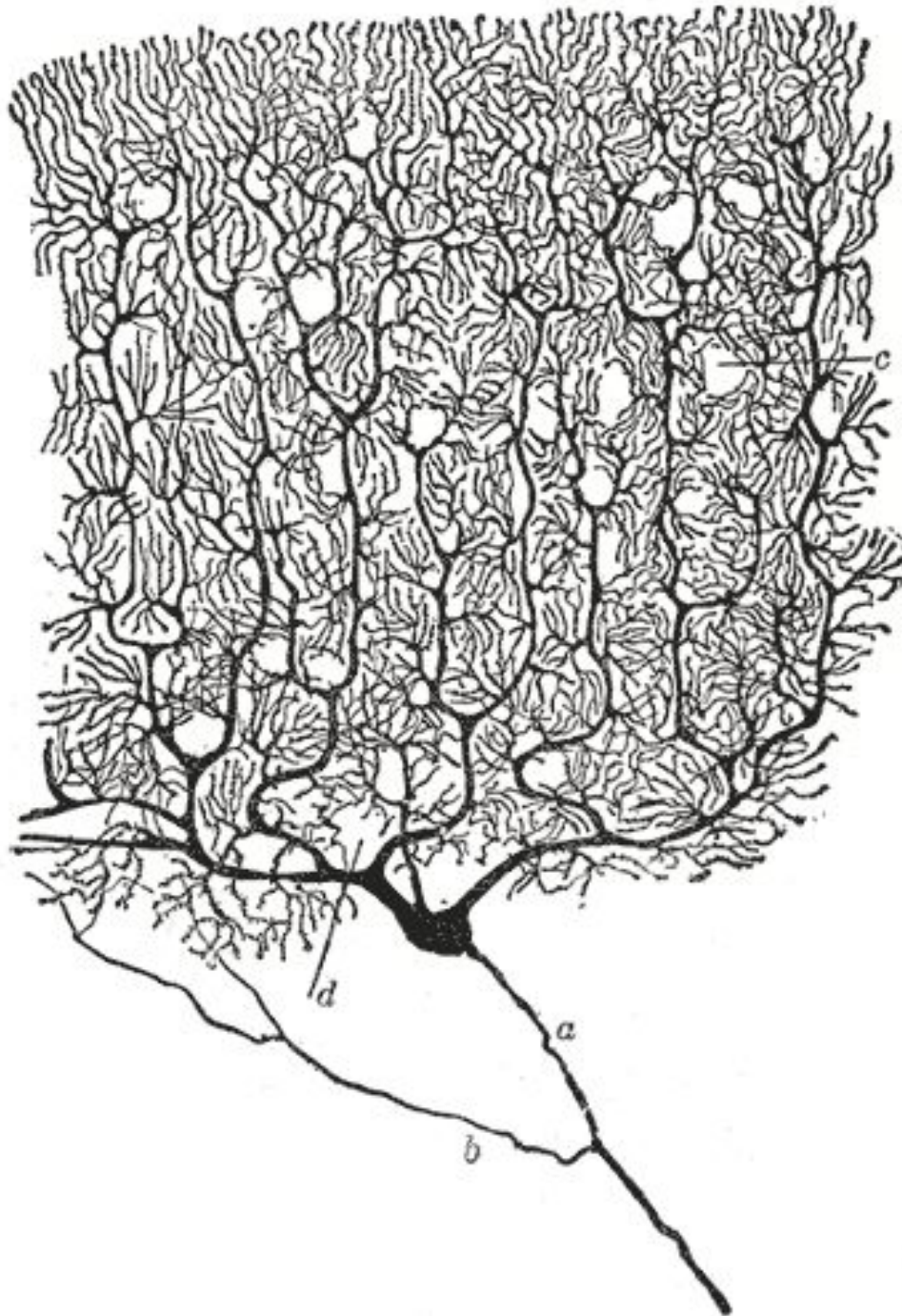
- Synapse: A connection point between neurons where information is transmitted through chemicals (neurotransmitters) or electrical signals.

- Diversity: Biological neural networks contain many types of neurons, which differ according to their structure, function and the neurotransmitters they deliver.

- Plasticity: Neural networks are able to change in response to experience, a process called neuroplasticity. It is the basis upon which learning and memory occur.

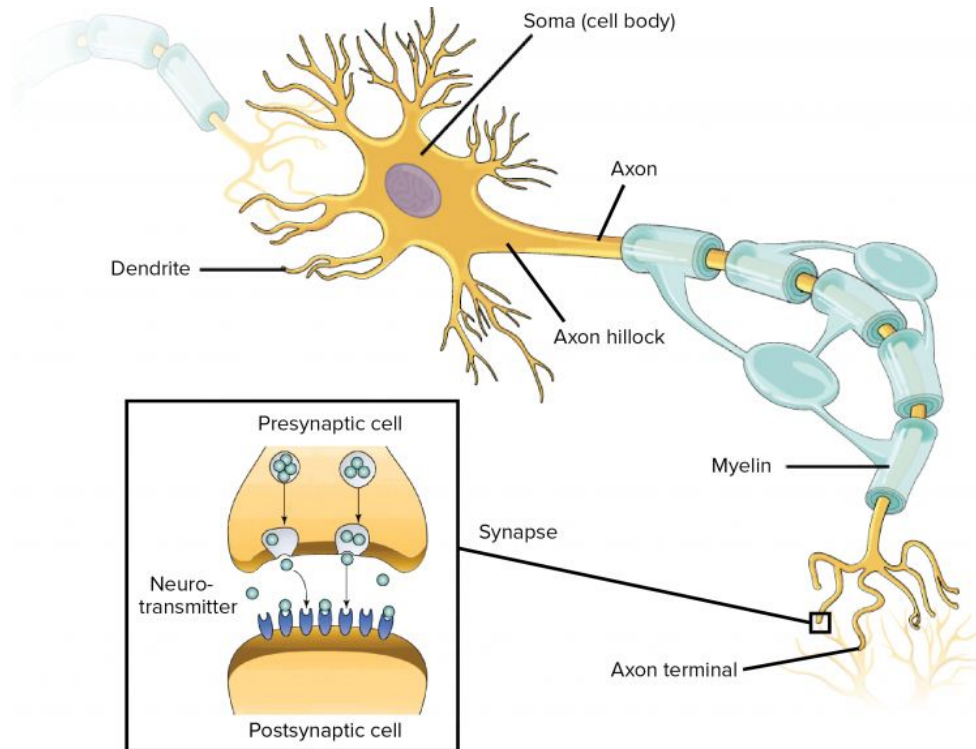
- Parallel processing: Biological neural networks can process large amounts of information simultaneously, thanks to their highly parallel and distributed structure.

Figure 1.1: Human Neural Networks



Source: Cajal's drawing of a Purkinje cell. Notice the complexity and number of dendrite branches..

Figure 1.2: Anatomy of the neuron



Source: "Neurons and glial cells" by OpenStax College, Biology CC BY-NC-SA 3.0 License.

1.2 SIGNIFICANCE OF MODELING

Modeling serves as a pivotal tool in neuroscience, providing insight into the functionality of the brain and the intricate mechanisms of neural processes. It offers a window into the otherwise inaccessible workings of neural communications.

1.3 HISTORICAL OVERVIEW

The endeavor to model neural networks is not new. Groundbreaking models such as the Hodgkin-Huxley and FitzHugh-Nagumo models have been instrumental in advancing our understanding of neural behavior and have set the stage for modern developments in neural modeling.

1.4 CHALLENGES AND LIMITATIONS

Accurately modeling biological neural networks presents numerous challenges. These include the complexity of neuronal dynamics, the nonlinear nature of neural responses, and the vast interconnectivity within the neural network.

1.5 RECENT ADVANCES

Recent advancements in computational power and mathematical methodologies have allowed for the creation of more sophisticated and detailed models of neural networks, pushing the boundaries of what was previously possible.

1.6 APPLICATIONS

The application of neural network models is vast, ranging from the exploration of neurological disorders, such as epilepsy and Alzheimer's disease, to the investigation of cognitive processes.

1.7 OBJECTIVES OF YOUR WORK

The objectives of the presented work are to ... (here, you would specify the goals of your own research or modeling approach).

REFERENCES