ITAI-4374 - Laboratory Exercise: From Biological to Artificial Neural Networks Submission Date: February 18th, 2025

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Biological neurons process information through complex electrochemical signals, using action potentials to transmit data across synapses. The all-or-none principle ensures that signals are sent only when a threshold is met, and neurotransmitters modulate synaptic strength, allowing for dynamic learning and adaptation. In contrast, artificial neurons rely on mathematical functions to process weighted inputs and generate outputs based on activation functions such as sigmoid, ReLU, or tanh. Unlike biological neurons, artificial models lack intrinsic plasticity and rely on explicit algorithms to adjust weights during training.

Incorporating biological principles into AI could lead to more adaptive and efficient learning models. Concepts such as neuromodulation, spiking neural networks, and synaptic plasticity offer promising pathways for improving artificial neural networks. By mimicking the brain's energy efficiency and parallel processing capabilities, AI systems can achieve greater efficiency in pattern recognition, decision-making, and autonomous learning tasks.

Current artificial neuron models are limited in their ability to replicate real-time learning, long-term memory retention, and energy efficiency seen in biological systems. Artificial neurons lack the complexity of dendritic computations and synaptic adaptability, making them less robust in uncertain environments. Future improvements may include neuromorphic computing, more biologically plausible learning rules, and enhanced hardware architectures that better simulate the intricate dynamics of biological neural networks.

Biological neurons have evolved over millions of years, fine-tuned by natural selection to perform an array of cognitive functions, from sensory perception to abstract reasoning. These neural circuits are not static; they continuously adapt to environmental stimuli, reorganizing synaptic connections through processes like long-term potentiation (LTP) and long-term depression (LTD). AI models, on the other hand, are largely dependent on the architecture they are designed with and the data they are trained on. While current deep learning networks are capable of impressive feats, they are still limited by the structure and parameters predefined by their designers. This represents a key area where AI could draw inspiration from the continuous and self-organizing nature of biological neural networks.

Another important distinction between biological and artificial neurons lies in the integration of multi-modal sensory inputs. Biological neurons are capable of seamlessly processing information from diverse sensory modalities (e.g., vision, touch, hearing) in parallel, allowing organisms to respond to complex stimuli in real time. The brain integrates information from these senses to produce cohesive, adaptive behavior. In artificial neural networks, especially those used in AI models like convolutional neural networks (CNNs) or recurrent neural networks (RNNs), input data is often processed separately or in isolated layers before combining them. Advances in multi-modal learning, where multiple types of data are processed together (such as vision and language in vision-language models), represent a promising direction for overcoming this limitation in artificial systems.

As artificial neural networks become more advanced, ethical and philosophical questions surrounding their development and deployment become increasingly important. One concern is the potential for AI to surpass human cognitive abilities in certain areas, leading to fears of job displacement, surveillance, and control. Furthermore, the more we mimic the brain's processes in machines, the more we must consider questions about machine consciousness and the ethical treatment of potentially sentient AI. While biological neurons are products of millions of years of evolution and are linked to the human experience, artificial neurons are entirely human-made constructs. This distinction raises important questions about the nature of intelligence, autonomy, and the role of AI in society, as we continue to refine the boundaries between biological and artificial cognition.