Sristi Bafna
Professor Debayan Gupta and Professor Bittu

CS-IS-3039-1 Computational Cognitive Neuroscience ISM Report

Through this Independent Study Module, I got the chance to explore the interaction of cognitive psychology and neuroscience with computer science. Aspiring to work in this very area, the unique opportunity to curate course syllabi on my own, design and structure it, as well as have the chance to discuss and brainstorm ideas helped me narrow down areas of interest even further. The course was designed around weekly assigned readings and a discussion with the students and the Professors post each week's readings. All the reports, reviews and presentations mentioned on this report can be found in the course drive. There was also a final project towards the end of the course. Here is a list of points I worked on throughout the course:

- Module 1 –
    - Chinese Room Argument Review
    - Puzzle of Consciousness Review
    - Human-level AI review
    - Turing Review
    - ToM in LLMs Review
    - Braitenberg's Vehicles and Subsumption Presentation with Aryan Yadav
        - I was responsible for discussing the ideas behind Braitenberg's vehicles, what concepts they spoke about, looking into the connection with subsumption and perception of mind and the possible real world applications.
    - Meeting Notes every week
- Module 2 –
    - The Neuroscience of Learning Review
    - A manifold of spatial maps in the Brain Review
    - Meeting Notes every week
- Module 3 –
    - Generalizability, Similarity and Bayesian Inference Review
    - Neuroeconomic Foundations of Economic Choice Review
    - Meeting Notes every week
- Module 4 –
    - Vision Review
    - Language Review

In the final project, we attempted to construct a more 'neuroscientifically' plausible approach to the training pipeline of an image classification computer vision model. We focused on two main sections to get to this goal – curiosity and spiking neural networks. I was responsible for the Spiking Neural Networks aspect of the project. I implemented broadly 2 different experiments (the notebook for the same is attached in the Final Project Drive folder):

1. Simple SNN (based on the model proposed by Izhikevich)
    a. Single neuron with square current
    b. Single neuron with synaptic current
    c. 1000 neurons with synaptic input
    d. 1000 neurons with recurrent connections
2. SNN with Leaky Integrate and Fire Model (based on the model proposed by Gerstner and Kistler)
    a. Single LIF neuron with square current
    b. Single LIF neuron with random input current
    c. Neuron model with 25 Synaptic Spikes

The idea was to explore and understand how the very basic unit of an SNN (a spiking neuron) is coded up, how it responds to different inputs (basic square current, random current and synaptic input). Then I worked my way up to a neuron model of the same followed by which I worked on a more real world model of Spiking Neural Networks which use Leaky Integrate-and-Fire mechanism. There are several possible experiments that can be further performed beyond this:

1. Working with different **Network Architectures** and topologies for SNNs. We could explore how the connectivity patterns, such as random, hierarchical, or small-world networks, affect the network dynamics, information processing capabilities, and learning performance.
2. Exploring the **Learning and Plasticity** algorithms and rules specifically designed for SNNs. Investigate how to train SNNs efficiently and effectively, considering the discrete nature of spikes. Study spike-timing-dependent plasticity (STDP) as discussed in our ISM and other biologically inspired learning mechanisms for SNNs.
3. What could be interesting is looking into **Hybrid implementations** that could combine the strengths of ANNs and SNNs.
4. Studying the **biological plausibility** of SNN models and their correspondence to real neural systems. Hyperparameter tuning to investigate how different parameters, such as synaptic weights, membrane time constants, and refractory periods, affect the behavior and properties of the SNNs followed by benchmarking the model predictions with experimental data.