Nerual Networks With Spike Timing Dependent Plasticity & Long Short Term Memory Trained To Recognize & Generate Music

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Introduction

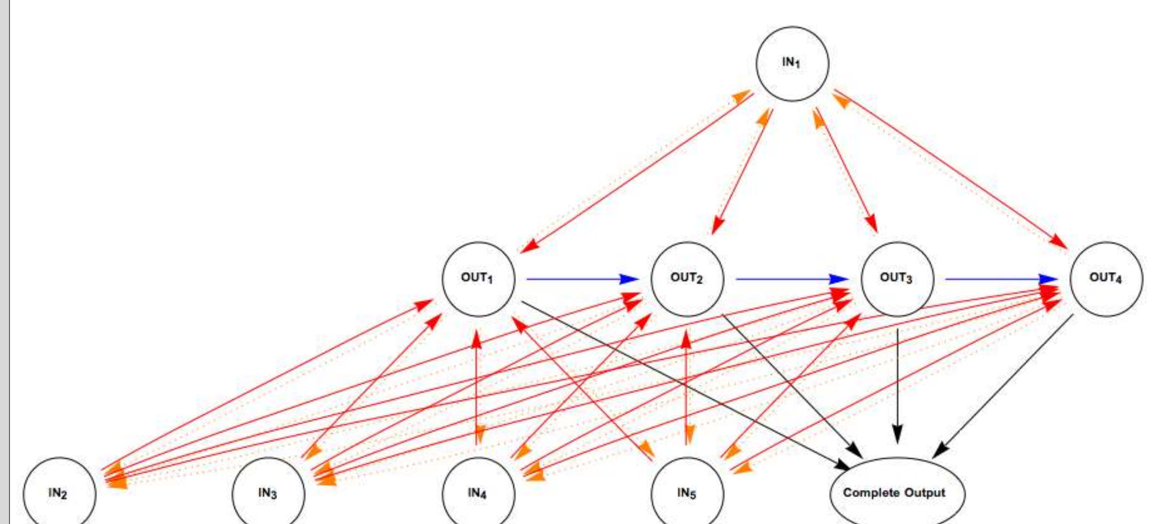
Recurrent Neural Networks (usually know as RNNs) are a unique class of artificial neural networks which utilize data from previous iterations of itself, allowing it to have a sort of short term memory. This kind of artificial neural network has proved especially effective when working with data with sequential and/or temporal significance. However one problem with artificial neural networks is the method through which they are trained: backpropagation. One limitation of backproppagation training is that the model is simply trained and after that the weights remain stagnant. However the human brain, along with every other biological brain, doesn't work using this stagnant learning approach. We learn dynamically. That is where Spike Timing Dependent Plasticity (STDP) neural networks come into play. These neural networks can learn as they are used, a property with immense implications and countless applications. Though these too are limited, as they need special hardware to be implemented effiiciently, hardware that is still in the works. What I have done here is created a theoretical implementation of unique neural network architecture with STDP to achieve a generative/predictive model with short term memory to better emulate the biological brain using acoustic input and output.

Objective & Impact of Professor's Research

Dr. Alice Parker's lab works to employ analog computations (an approach pioneered by Carver Mead at Cal Tech) to emulate neural structures and ultimately implement a spiking based neural network in hardware. This approach is supported by the use of nanotechnology, with structures a few nanometers in dimension, relying on implementation of the functions of neural mechanisms believed to be important for learning and memory, while approximating the detailed implementations of these mechanisms in new neuromorphic hardware.

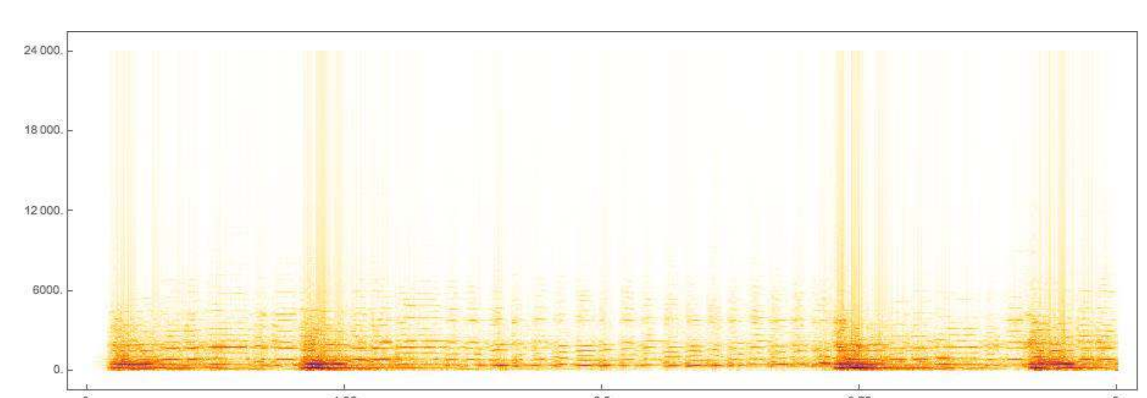
Skills Learned

I've learned much of the process of designing a novel neural network architecture and the various issues and corresponding workarounds which demand flexibility and dynamic problem solving skills. I familliarized myself with some Python modules, a significant one being Brian, a module centered around modeling neurons and spike trains. The neural network model itself demanded background research, but being unique enough to require an innovative new approach to STDP. It is still a work in progress that requires development beyond the confines of this summer's SHINE program.



A simplified illustration of the generative neural network model

A spectrogram, which would be a network input, is a representation of a signal which contains information in a plot with dimensions representing time, amplitude and frequency. This is a far simpler representation than a sound wave for a neural network to understand, recognizing patterns as music, speech or noise and using inherent properties to determine the next part of the sequence (i.e.,"predictive").



An example of a partitioned spectrogram of a five second excerpt of a musical piece.

A spectrogram of a signal can be thought of as a series of Fourier transforms applied to partitions of a waveform or signal and stacked next to each other.

Applications

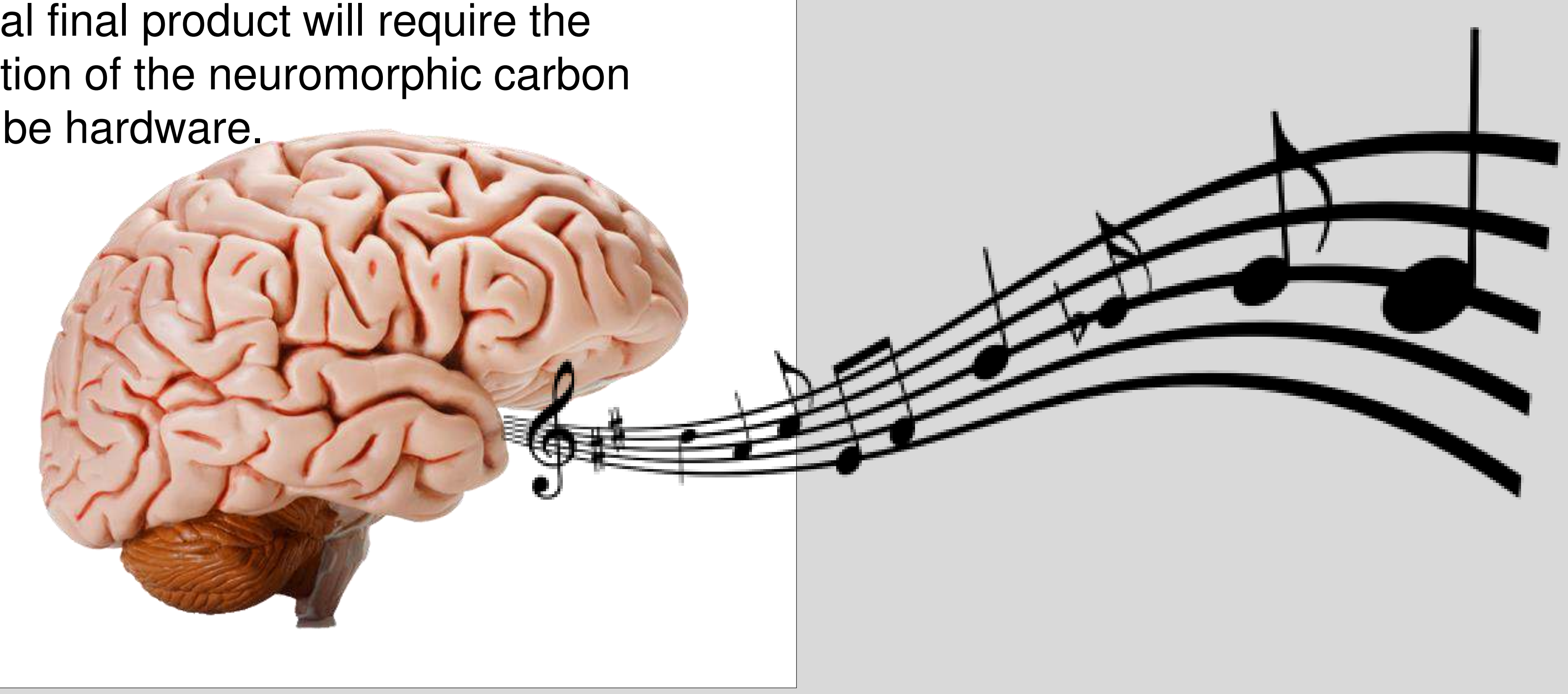
The limitation of current in silico AI programs used to emulate music is that they learn to mimic a musical style without embodying the deeper understanding of the brain's encoding and understanding the essence of music. However, the sucessful realization of this neuromorphic model as a functional neural network will bring our understanding of music to a new level. This AI may transcend mimicry and begin to explore creative composition. For example current AI can recognize harmony and connsonace, but is incapable of harnessing creative use of musical dissonance. Current AI can sucessfully emulate repetitive harmonies such as those common in the works of The Beatles, but is dumbfounded by the more complex composition of Shostakovich.

Equations for synaptic weight changes like the following are often based on the presynaptic trees leading up to the firing of the neuron in question.

$$\Delta w = \eta (x_{pre} - x_{tar})(w_{max} - w)^{\mu}$$

An equation used by Peter U. Diehl in his STDP model

As of now, the current product of my SHINE research is the code used to simulate the neuromorphic hardware in silico. Ultimately, the ideal final product will require the fabrication of the neuromorphic carbon nanotube hardware.



Next Steps for You

I will continue research and development of this neural network model and look forward to continuing collaboration with the fantastic people I have had an opportunity to work with here via the SHINE program.

Advice for Future SHINE Students

My advice for Future SHINE Students would be don't be tentative, jump in, and bring your self into the project.

Acknowledgements

I would like to thank my professor, Dr. Alice Parker; my mentor, Kun Yue, and Dr. Katie Mills.