TJHSST Senior Research Project
Analysis of spectro-temporal receptive fields in an auditory neural network
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Abstract

Neural networks have been utilized for a vast range of applications, including computational biology. But the realism of these models remains in question. In the models of the auditory cortex, for example, the properties of neuronal populations are hard to fully characterize with traditional methods such as tuning curves. Spectro-temporal receptive fields (STRFs), which describe neurons in both the spectral and temporal domains, have been obtained in a variety of animals, but have not been adequately studied in computational models. The aim of this project is to address these issues by generating the spectro-temporal receptive fields on a basic, neural network model of the early auditory processing stages in the brain. As purposeful additions to the computational model are made, the new STRFs can be used to further analyze the changes to the properties of the neurons.

Keywords: neural network, auditory processing, spectro-temporal receptive field (STRF)

1 Introduction - Purpose and Scope

Purpose.
Computational biology is a growing field of computer science made to better

model the complexities of the brain and other biological organs. The visual domain has already been studied to a great depth, but the auditory domain is still relatively new territory for computer models. Although many models have been created for the auditory domain, the actual realism of these models is hard to judge.

One way to judge the realism of the models is to compare them to their biological counterparts. But how can one compare computer-generated neurons to the real ones? Spectro-temporal receptive fields (STRFs) have been used in many different animals including birds and ferrets. These receptive fields characterize the linear response properties of neurons in the spectral (frequency) and temporal (time) domains. In order to generate these STRFs, the responses of neurons to moving ripple stimuli are collected and transformed. The STRFs from the computational models can then be compared to STRFs from the literature, and can be quantitatively and qualitatively be analyzed.

In addition to analyzing the STRFs in a neural network, I also want to be able to generate a more realistic model of the early auditory processing pathways in the brain. A basic, linear transform neural network can be used in the initial analysis, but I also want to add some type of temporal coding and lateral inhibition. Temporal coding allows the neural network to respond to a stimulus over time, analogous to neurotransmitter reuptake. Inhibition models another class of neurotransmitters that inhibit the response of a neuron. Lateral inhibition is theorized to take place in almost all biological sensations, including hearing. With these two aspects in a neural network, the computational model will be able to more accurately mimic the complex biological processing.

Even as computational power exponentially increases, without the use of models and neural networks, the utility of that processing power goes to waste. With neural networks, computers will be able to perform many functions originally thought only humans can possess, such as pattern recognition and reasoning. Furthermore, neural networks of the brain will help scientists understand ourselves and our capabilities and aid doctors in complex medical pathologies.

Scope of Study. In this project, I will primarily be involved with creating an auditory neural network and evaluating the network with the STRFs. Subsequently, I will improve the model with additions such as temporal coding and lateral inhibition. These aspects will provide a greater degree of authenticity to a model of the auditory processing. If one of these aspects takes too long to code, then I can simply ignore that aspect and analyze the results with the code that I have. For every new aspect that I implement, I plan to analyze the STRFs obtained from the new neural network and also compare the output of the STRFs to tuning curves, a traditional description of neuronal populations. STRFs have also been used to predict neuronal responses to novel stimuli. If possible, I want to try to use STRFs to predict the output of neurons.

2 Background

Background and review of current literature/research in this area.

The ear is the first step in a long, auditory processing chain. In the inner ear, mechanical signals are converted into electrical ones in a processing known as transduction. The cochlea is largely responsible for this process. In the cochlea, the coiled tubes respond to different frequencies of sound at different places. For instance, a frequency at 3 kHz will trigger different cells to respond than a frequency at 10 kHz. In computational biology, this phenomenon is represented through the use of spectrograms, frequency v. time distributions of sound stimuli. Although there are many ways to represent sound stimuli in the brain, spectrograms have been quite popular with many scientists.

As neurons respond to stimuli, they communicate with other neurons using neurotransmitters. Dr. Hebb, a famous psychologist, hypothesized that two neurons that are simultaneously active, then the connection between the two neurons would be strengthened. This process is known as synaptic plasticity, and is also important in training neural networks of the brain.

Scientists have a relatively clear idea on how some basic processing takes place in the brain. But scientists also want to know some specific properties of neurons. Receptive fields have been used quite extensively to determine those properties of the neurons. Spectro-temporal receptive fields (STRFs) are no new topic in the auditory biological systems. The STRFs have been analyzed in many types of animals, including ferrets and birds. The literature shows that STRFs plot not only the responsive areas of the sample neurons, but they also illustrate the interaction between excitatory and inhibitory processes.

In general, receptive fields have been analyzed in a multitude of computational models. One paper by Rao and Ballard describes the construction of a model of the visual cortex that employs predictive coding. Predictive coding is a phenomenon theorized to take place in the brain where different cortices employ both top-down and bottom-up processing to analyze information. These cortices receive data from lower cortical areas and predictions from higher cortical areas, and relay the error in those predictions to the higher cortical areas. Clearly, this is a vast simplification of the whole process, but it is a very interesting approach to computational models. This paper also illustrates the receptive fields that were generated using natural images as training stimuli.

This paper was an inspiration for my computational model in the auditory cortex. There are two main differences between my project and the visual predictive coding model. The first is that my model does not have any predictive coding capabilities. If there is time at the end of the year, I would like to pursue some type of combination of top-down and bottom-up processing using Kalman filters. The other obvious difference is that my neural network models the auditory processing instead of visual processing. Humans are visual creatures, and that is why a great deal of research has been put into visual computational biology. But auditory processing is also important to us, and it is important for scientists to understand our hearing also.

3 Procedures

Procedure and Methodology

I plan to create a new neural network of early auditory processing stages in the brain. Input to the model will be represented as spectrograms, frequency v. time plots of sound stimuli. The neural network will be trained on real-world, environmental stimuli from CDs and the Internet in order to make the weights in the network as realistic as possible. The neural network will be further improved with additions such as temporal coding and lateral inhibition as the year progresses. At each step of the way, the STRFs will be generated from the computational model in order to compare these to the hypothesized STRFs to the STRFs in literature. Both the weight vectors and the STRFs are the results of the program. Currently, I only use qualitative methods to evaluate these results, but I plan to add some quantitative comparisons between STRFs and tuning curves.

The neural network will be programmed entirely in Matlab, a powerful platform used extensively in matrix applications. Matlab also has various tools to generate graphs and plots. It will be used to generate plots of STRFs, weight vectors, and outputs of the neural network to stimuli. I also want to construct simple visuals of the actual neural network, but that will not require Matlab.

My research is a continuation of an internship at the National Institute on Deafness and other Communication Disorders (NIDCD) branch of the National Institutes of Health (NIH). I will continuously communicate with my mentor at NIH, to receive advice on my program and results.

3.1 Testing

The testing is the most difficult aspect of this project. The results, the STRFs and weight vectors, are hard to test because there must be some right answer to compare them to. Since my use of STRFs is relatively novel, I can only compare them to the sparse pictures in the literature. I can compare the STRFs to tuning curves, but that would only test out the spectral components of the STRFs. If I finally decide to predict the output of neurons using STRFs, then I can easily compare the predicted output with the real output. Fortunately, the weight vectors at the first stage of the project would be easy to test. Since I will use Oja's Rule to train the weights, I can correlate the weights to the eigenvector of the covariance matrix of the data. But once I start adding non-linear components into the model, such as temporal coding and lateral inhibition, it will be very difficult to compare weights to a 'known value'.

The construction of the neural network will additionally be hard to test. Throughout the entire process of building a better neural network, I will try test out the structure of the network using artificial stimuli. For instance, I can input a frequency of a certain value to make sure neurons are properly connected to each other. Otherwise, I will just have to analyze the graphs of the output of certain neurons and make sure there are no glaring inconsistencies between theory and the actual output.

To keep track of my progress, I plan to create simple timelines on either my computer or on paper. These timelines would include dates on my own deadlines, school deadlines, and what I have accomplished so far. This will most efficiently keep track of my progress.

I plan on using the following tools and sticking with the proposed time scale below.

3.2 Software

Computer language(s) I'll use

1. Matlab - use to create neural network, ripple stimuli, STRFs, graphs

3.3 Algorithms/Programs

I'll be using the following algorithms/programs, in addition to designing my own:

1. Oja's Rule - to train the model on realistic stimuli
2. Moving Ripple Stimuli program - to generate ripple stimuli in order to create the STRFs

4 Schedule

In the first quarter, I will focus on the initial, linear, stages of my project that will involve a trained neural network with their STRFs. I also want to try to enter this project into the science fair, so I would want to start composing a scientific paper on my project.

In the second quarter, I will begin to research the biological processing of temporal coding and how it is done in neural models. My program at this point would be able to have some sort of temporal coding, responding to sound stimuli over a period of time. In addition, I would like to research and incorporate lateral inhibition. Since lateral inhibition would vastly change the structure of my neural network, it would take a bit longer to code.

In the third quarter, I will bring together both earlier parts to form a complete and running application. It will be able to respond to sound stimuli over time and neurons within the network would be interconnected to inhibit each other.

5 Expected Results

My final results from this project would be the STRFs in a visual plot. These STRFs would show that neurons respond to different frequency-time patterns to sound stimuli. For example, the STRFs should show that neurons that are connected to the lower frequency ranges would respond to lower frequencies. STRFs should also be able to show differences when temporal coding and lateral inhibition are incorporated into the model. The temporal component of the STRF should widen when temporal coding is incorporated into the model because the neurons would respond to sound stimuli over a longer period of time. Also, with lateral inhibition, the STRF should show an inhibitory patch immediately after the excitatory area as indicated in the literature.

I hope that my project would be of value to researchers and modelers. Computer models are notoriously difficult to analyze, and I hope that STRFs would provide an elegant way of analyzing the models. Also, I hope that STRFs would be able to show that greater realistic programming in a model equals greater realism in the STRFs. That would enable modelers to more easily understand their computer model, and pinpoint areas in which the model needs improvement in. I look forward to pursuing this project this year.