Analysis of spectro-temporal receptive fields in an auditory neural network

Madhav Nandipati, TJHSST Computer Systems Lab

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.

Introduction

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. A basic, linear transform neural network has been used to generate the initial receptive fields

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.

Background

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.

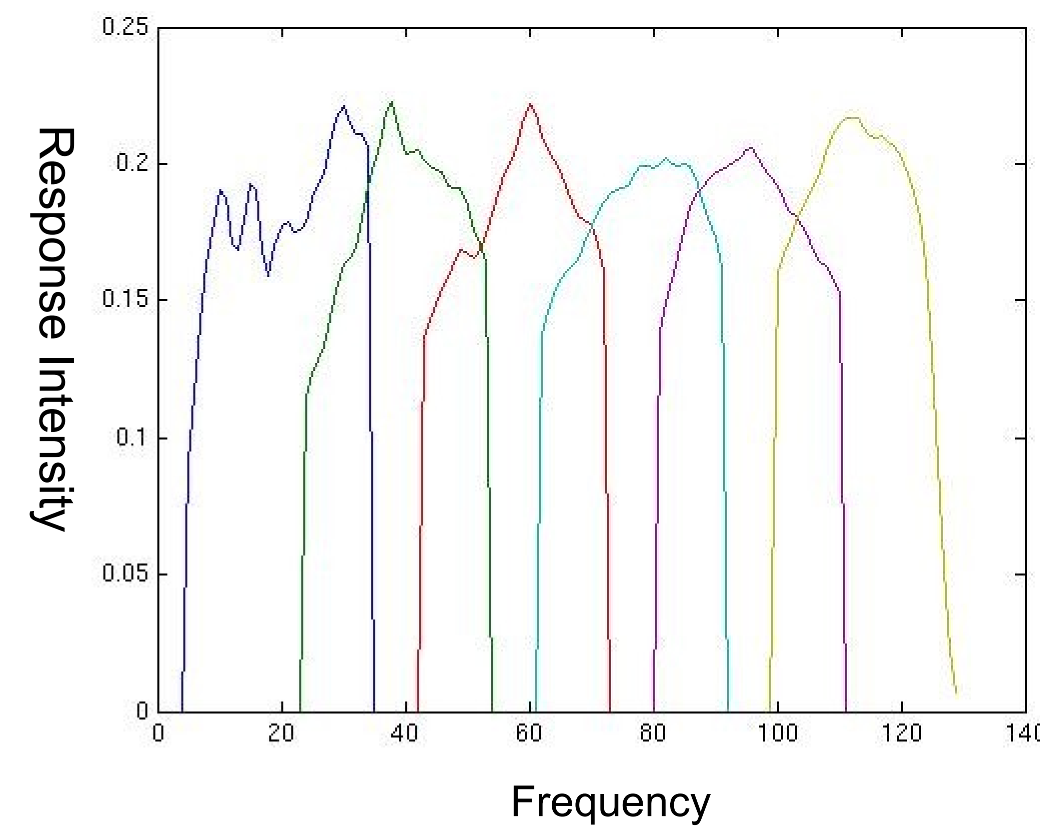
Scientists have a relatively clear idea on how some basic processing takes place in the brain. But scientists also want to know some specific properties of neurons. Receptive fields have been used quite extensively to determine those properties of the neurons. Spectro-temporal receptive fields (STRFs) 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. The use of STRFs is promising in both biological and computational systems.

Development

The current neural network is a two-layer, forward feeding and linear model of the early auditory processing stages in the brain. The first layer is the input layer. The input to the neural network is a spectrogram, a graph of frequency v. time, which was converted from a waveform of the sound stimulus using a Fourier transform. The first layer receives one timestep of auditory information at a time. A timestep is about 10 ms of auditory information. The second layer is the output layer, a matrix product of the input vector and weight vector. The weights between the two layers were first set at random values, then trained using Oja's rule. After the weights were trained, they were plotted and analyzed.

Results



Discussion

The above graph shows that after training, the weighted connections between the input layer and the output layer became frequency selective. The peaks in the graph show at which frequency a neuron responds most intensely to. This graph is an equivalent of tuning curves, because the graph shows which frequencies a neuron responds to. The disadvantage of this graph is that it does not show any temporal components, an integral part of auditory neurons.