CSL7330 - Assignment 1

Topic: Modelling the Encoding pipeline of a Neuromorphic System
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Problem Statement

With the concepts that has been covered so far in the lecture, this assignments strives to characterize the hypothetical relationship between the stimulus and the individual response of a neuron. Here the relational response which is recorded as a spike in the neuron caused by the input stimuli is to be modelled to obtain the internal encoding structure of a Neuromorphic System.

To study the neuronal coding and how it is actually generated we need to describe and analyze the neuron firing with the help of statistical methods and methods of probability theory and stochastic processes.

1 Neuron Coding Schemes - An Overview

We live in a complex sensory environment and receive many signals. Each of these signals activate distinct pathways. The basic premise of sensory neuroscience is that, as we move from the periphery to the internal workings of the brain, individual neurons become increasingly selective for particular features in the sensory world. In other words, neurons are feature-selective and this helps us form our perceptions of the outside world. Hubel and Wiesel first identified feature-selectivity in the visual pathway. Since their findings, the race has been on to identify complex feature selectivity in sensory pathways. Other inference of the biological neuronal models, such as human brain was understood to work similarly, and in with a temporal aspect. This makes is different than the artificial neural networks that are currently prevalent, though they might be incorporating a similar idea behind them.

A sequence or 'train' of spikes contain information. These spikes are influenced by the external stimuli that the person or the organism is subjected to.

1.1 Encoding and Decoding

The knowledge of the internal functional block of a neuronal system can be understood by the process of Encoding and Decoding. **Encoding** would help us to understand how a stimulus causes a pattern of responses. We would be building a mechanistic model from a descriptive model (from stimulus to response). **Decoding** would be help to obtain a model that would tell of the responses and how they relate to the stimulus.

The Encoding and Decoding can be modelled through a probabilistic behaviour. Where, $P(response|stimulus)$ would model encoding and $P(stimulus|response)$. To feature vector can be obtained by calculated the spike

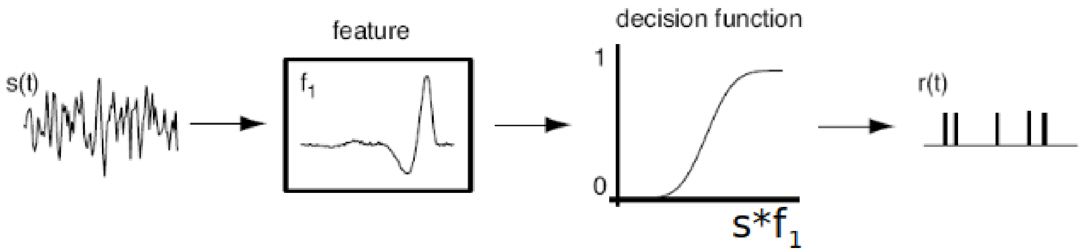


Figure 1: A Neuromorphic Modeled System

triggered average, which is the average of all the temporal window data that would have resulted in the triggering of a response as a spike. The STA is explained in detailed in the next section.

If S is taken as the stimulus then the averaged filter would be the feature vector that is leaned from the given responses, we need to convolve the signal S with the feature vector to obtain the filtered signal S_f that would help us to model the non-linearity function shown by the bayes rule as given below:

$$P(response|S_f) = \frac{P(S_f|response)P(response)}{P(S_f)} \tag{1}$$

1.2 Spike Triggered Average

Event-triggered averages are used to try and determine what caused an event to happen. They look at what preceded a number of events and take the average. In neuroscience, events are often spikes recorded from a neuron in response to a sensory stimulus. For example, let's say the stimulus is white noise. We would then extract a small piece of data before the spike (time window) and average it with the actual spike. This average waveform represents the average stimulus that caused the neuron to fire.

Theoretically, let x_i denote the spatio-temporal stimulus vector preceding the i^{th} time bin, and y_i the spike count in that bin. Then STA can be given as:

$$STA = \frac{1}{n_{sp}} \sum_{i=1}^{T} y_i x_i \tag{2}$$

Where,
n_{sp} = The total number of spikes
x_i = The stimulus vector
y_i = The response vector

1.3 Distribution Relations

The distributions that have been obtained are also called as *Tuning Curves* that plot the non-linear relation between the input function (smoothed using the averaging filter). The two distributions that are of importance are $P(S_f|response)$ and $P(S_f)$. Here, $P(S_f|response)$ is obtained by sampling the filtered stimulus at the points where the firing of the neuron has occurred and $P(S_f)$ is the distribution of the filtered stimulus.

The diagram below shows the distribution and their plots. The ratio between the two distributions plots the nonlinear relation of the encoding model.

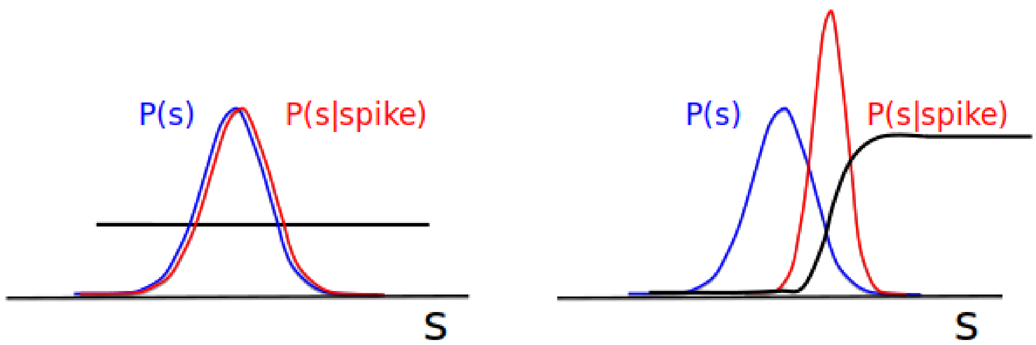


Figure 2: Distributions or tuning curves

2 Algorithm

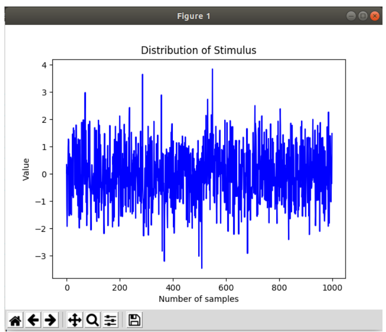
- Generate the stimuli using a normal distribution, in python the `numpy` library contains the function `numpy.random.normal()` that returns an array of samples with a specified mean and standard deviation. Also, we need to generated a random response using the binomial distribution from then library using the function `numpy.random.binomial()`.
- The distributions can be verified by getting a histogram of the distribution.
- We need to define the probability of the neuron firing in the system that we are modelling, which is very random in our case as we have picked a random distribution. We can also model a deterministic model of the neuron firing by assuming that the neurons will fire at the instance when the threshold of the signal or stimulus exceeds a certain value.
- Find the Spike Triggered Average by taking a sampling window w, which includes all the samples that precedes the instance when then spike has occurred. These samples need to summed and averaged.
- The Stimulus is then convolved with the averaging filter using the function `numpy.convolve(s_1, s_2)`.
- Now the smoothed signal is sampled at the spike intervals so as to plot a histogram of the stimulus at the spike response instance and also the histogram of the distribution of the smoothed stimulus.
- The two distributions are used to approximate the relation or non-linearity by taking a ratio of the two vectors that contains the values of the distribution and plotting it.
- For several different values or mean, standard deviation, window size and firing probabilities are to be analysed and recorded.

3 Results

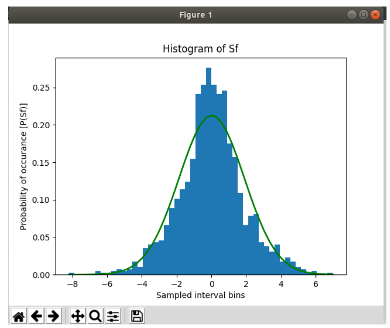
The above explained algorithm is executed on the python platform. The first set of results is drawn using the values as tabulated below. The distribution that explains the neuron firing rate is the *Binomial Distribution*.

[htp]

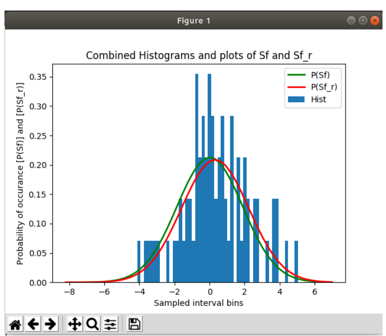
P(r)	Mean(μ)	STD(σ)	Window(w)	Samples(N)
0.1	0	1	300	1000



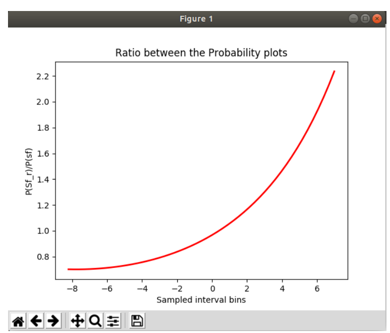
(a) Plot of the 1D stimulus



(b) Probability Distribution of Sf (Filtered Reponse)



(c) Combined plot of the two Distributions

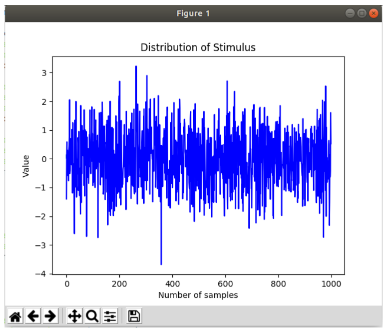


(d) Ration of P(Sf_r) to P(Sf)

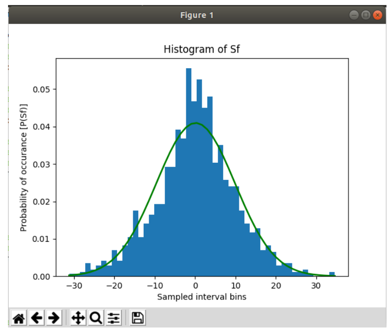
The firing rate is assumed to be on a particular threshold that is set to be greater the 2.5 for the particular sampled stimulus. Which mathematically denotes that when the input stimulus is greater than 2.5 then the response of the neuron is 1, or which means that it fires.

[htp]

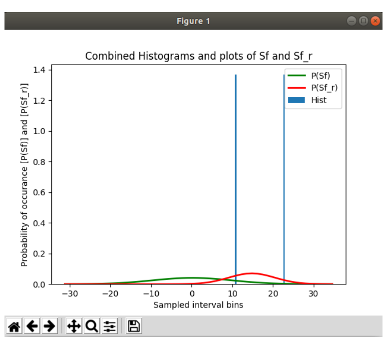
P(r)	Mean(μ)	STD(σ)	Window(w)	Samples(N)
0.2	0	1	300	1000



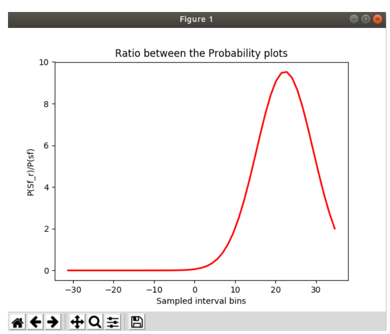
(e) Plot of the 1D stimulus



(f) Probability Distribution of Sf (Filtered Reponse)



(g) Combined plot of the two Distributions



(h) Ration of P(Sf_r) to P(Sf)

4 Conclusion

The assignment dealt with the modelling of internal properties of neuron system, that can be broken down into a feature model of the input stimulus and then adding a non-linearity to obtain the resultant response. The model is considered to be probabilistic in nature and can model the system fairly well.