Simulating LGN Response to Background Irradiance on SpiNNaker

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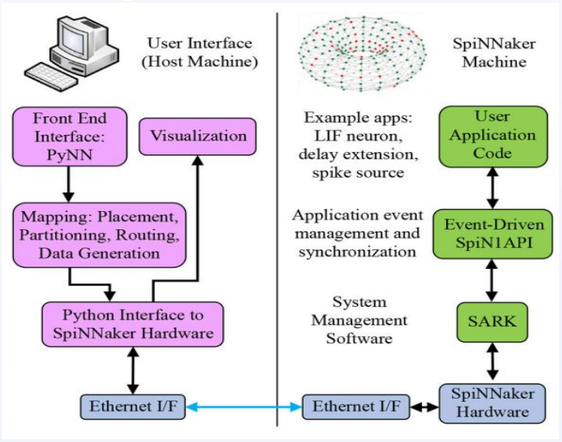
Introduction

Much work has been done recently through physiological experiments to investigate the role of background visual stimuli in causing fast narrowband oscillations in areas of the visual thalamus. Luminance has been found to have a direct relationship with the amplitude of these oscillations in the retina and dLGN [1,2] and contrast is known to affect and control their gamma-band power spectra [3].

SpiNNaker [4] is a massive 1 million core parallel digital supercomputer with a low power ARM processor based architecture inspired by connections in biological neuronal systems. It can be used for large scale simulations of spiking neurons at biologically plausible time-scales. It can be interfaced with software models using the sPyNNaker [8] a PyNN-based interface to SpiNNaker.

Using SpiNNaker to model spiking neurons, we aim to **validate these physiological LGN experiments with simulated results on a spiking neural network model of the LGN**. We use the Izhikevich neuron based sPyNNaker model developed in [5] as the building block.



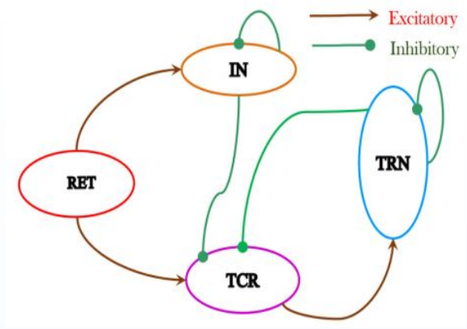
Users create SNN models via PyNN scripts, sPyNNaker translates into a suitable form, and loads to SpiNNaker memory via Ethernet. SpiN1API processing libraries uses loaded data for realtime simulations of neurons and synapses.

Source: [8]

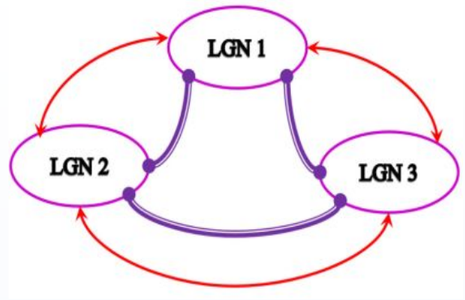
Related Work

The response of LGN cells to varying background light intensity was first studied by Storchi et al. in [1] via physiological experiments on mice. Some relevant results are as follows:

1) Irradiance results in a higher dLGN firing rate and fast periodic spiking in the beta/gamma range of the frequency spectrum. This is illustrated by the images below, from [1].



(A) The single node LGN consists of 3 kinds of cells: TCR, TRN, IN. TCR connects the cortex to the thalamus with excitatory synapses while IN and TCR inhibit TCR to regulate the circuit.



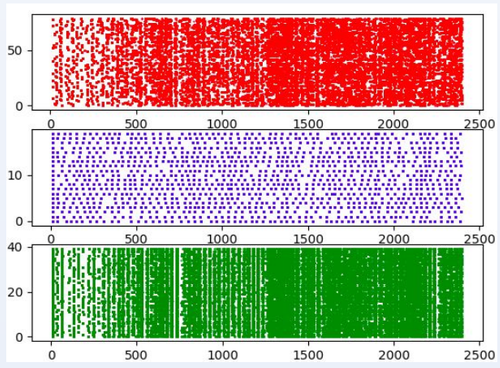
(B) Multi node LGN with nearest neighbour connections which involve TCR-TRN excitatory and TRN-TCR, TRN-TRN inhibitory connections
Source:[5]

Experiments

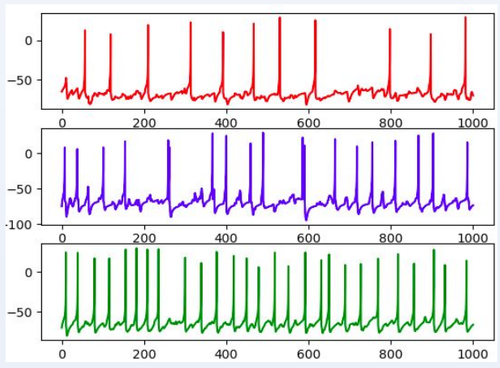
In our experiments, we use a circular chain of 200 LGN nodes with nearest neighbour connections. Luminance is represented by DC bias that spreads from 40 central nodes to others as intensity increases. Contrast is simulated by varying Poisson rates of external noise inputs.

As expected, luminance values are observed to be directly related to spiking frequency of TCR and IN cells and less so in TRN cells [1] when subject to a constant contrast. However, the amplitude of the voltage oscillations does not vary with changing luminance, which is also expected for a model whose contrast is constant. Also, we have not yet identified the L0 luminance value and hence, varying contrast at our current luminance also does not affect the amplitude.

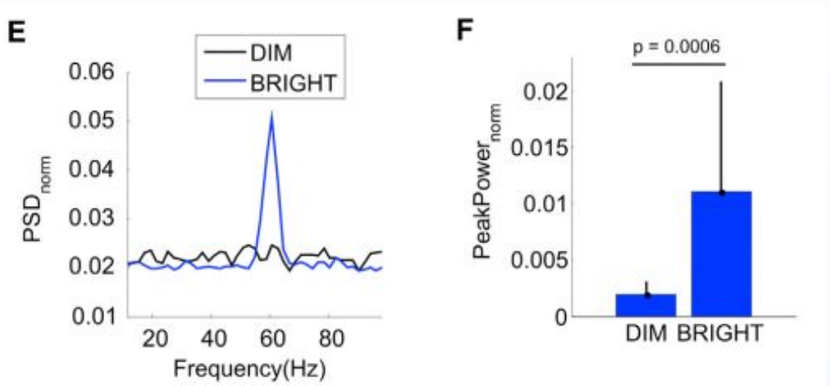
A



B

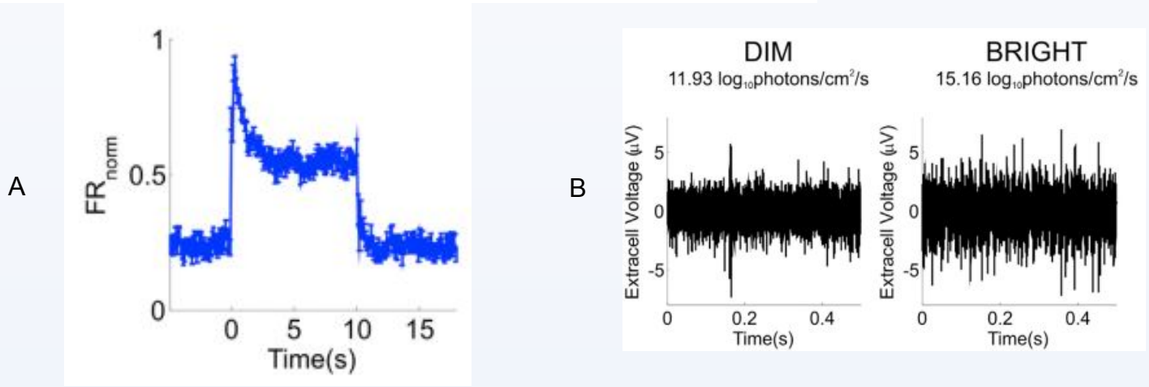


2) Power is modulated by contrast of background light at lower luminance. Further work by Storchi et al. in [6] suggests that at mid-range luminance/intensity ranges, contrast modulates both power and frequency and only frequency at very high (Michelson) contrast values.



(E) and (F): Irradiance causes a significant increase in power spectral density (PSD) and maximum power. As we can see from (E), the frequency observed after irradiance is in the gamma range of oscillations.

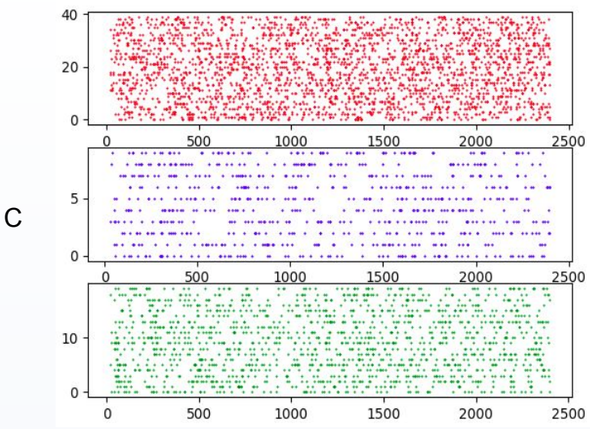
Source: [1]



Higher irradiance causes an increased normalised firing rate(A) and faster spiking(B). The frequency of spikes lies on the gamma band and is betweeen 25 and 50 Hz

Source: [1]

Computational spiking neuron models offer an alternative to tedious and time consuming physiological experiments. In [5], Sen-Bhattacharya et al. developed a spiking neural network model of a single LGN node and a string of LGNs using the sPyNNaker frontend for the SpiNNaker neuromorphic computing platform [4]. This model consists of 3 populations of Izhikevich Neurons [7]; TCR, TRN and IN connected to each other through excitatory and inhibitory connections as shown in the following image from [5].



(A) Spike raster showing spikes for TCR, TRN, IN cells at different values of luminance each for a total duration of 2400 ms

(B) Membrane voltage plot of TCR,TRN,IN cells for total duration of 1000 cells with varying luminance

(C) Spike raster showing Poisson spiking rate noise populations

Ongoing and Future Work

We plan to continue our work in the following ways:

- We are currently working on simulating conditions for synchronous oscillations by varying synaptic weight values in the single node LGN model [5].
- Following this, we will proceed to introduce variability in contrast and initial membrane voltage with a constant DC bias on the multi-node LGN string model, in order to identify the L0 luminance value i.e. the luminance at which the voltage amplitude is modulated by contrast.
- After identifying the L0 luminance value, it should be straightforward to identify the L1 and L2 luminance values (L1 - both amplitude and frequency modulation, L2 - only frequency modulation) which are generally linearly separated.

References

[1] Storchi R et al., Neuron 2017. DOI: 10.1016/j.neuron.2016.12.027
[2] Saleem AB et al., Neuron 2017 . DOI : 10.1016/j.neuron.2016.12.028
[3] Henrie JA & Shapley R, J Neurophys 2005. DOI : 10.1152/jn.00919.2004
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[5] Sen-Bhattacharya et al. Frontiers in Neuroscience 2017 DOI: 10.3389/fnins.2017.00454
[6] Storchi et al. Irradiance tuning of narrowband oscillations in the mouse visual thalamus (Poster)*
[7] Izhikevich. IEEE Transactions on Neural Networks 2003. DOI: 10.1109/TNN.2003.820440
[8] Rhodes et al. Frontiers in Neuroscience 2018. DOI: 10.3389/fnins.2018.00816