

## PROBLEM SET 3, Part 1

# Adaptation in linear-nonlinear models

## 1 FEATURE SELECTIVITY OF SINGLE NEURON MODELS

Sensory neurons encode features of the stimulus. One basic aspect of this is the temporal pattern of the input. By virtue of their intrinsic filtering properties, different neurons may prefer different temporal patterns. Using a single compartmental model we will investigate the temporal features and the nonlinear amplification (nonlinearity) preferred by one type of neuron.

### 1.1 ADAPTIVE GAIN SCALING IN THE HODGKIN-HUXLEY MODEL

We will investigate whether or not known single neuron mechanisms are sufficient to give rise to adaptive changes in gain that occur automatically when the input changes. To do this, we will use the Hodgkin-Huxley (HH) simulation. For treatments on the spike-triggered average of the HH neuron, see [1, 2]. The simulation you will be running was published by Mease et. al. [3] (you should read that paper so that you know what to expect).

Again, the basic goal is we would like to understand what single neuron mechanisms could give rise to gain scaling. Specifically, we will simulate a Hodgkin-Huxley neuron in response to different current fluctuations (by varying the standard deviation of the injected current, just as we did in the integrate-and-fire neuron). We will then compute linear filters and nonlinearities (so, LN models) under these different conditions to see how they change.

You can use the provided `sta_hh.m` template as a guide.

#### Gain scaling in the Hodgkin-Huxley neuron

1. The template provided simulates a Hodgkin-Huxley neuron, and fits a linear-nonlinear model to the response of the simulated neuron. Choose a length of simulation ( $T$ ) and injected noise strength (standard deviation,  $I$  sigma) to use. The longer the simulation, the more time it will take to compute. Start small and increase the length depending on how long you want to wait—something in the range of 1000-100000 seconds should be good.
2. The code uses a loop to compute the spike-triggered average of the Hodgkin-Huxley neuron. For the integrate and fire neuron, spike times were well defined (by when the neuron crossed threshold). For the Hodgkin-Huxley neuron, you will need to identify spike times directly from the voltage trace (by identifying peaks in the voltage). To do this, use the provided `peakdet` function. The `peakdet` function identifies peaks in a provided signal that are larger than some  $\delta$ , which is a parameter you must provide to the function. Decide on a value for the  $\delta$  parameter that will robustly identify spikes. Verify that the spike detection is working properly.

3. **Question 1 [2 pts]:** The provided code will compute and plot the STA and nonlinearity (parts of the LN model). What is the shape (monophasic, biphasic or other) of the STA of the Hodgkin-Huxley model, and would this suggest a sustained or transient response to a step input (you don't have to simulate a step input) ? What is the qualitative shape of the nonlinearity?
4. **Question 2 [2 pts]:** Now, compute LN models again but this time in response to current injection with different standard deviation. Turn in two plots of LN models that you fit (filters and nonlinearities) one created using high standard deviation input and one created with low variance input. Did the linear filter or nonlinearity change? Describe these changes, if any, qualitatively. Do you see evidence for gain scaling as a possible feature of the HH equations?
5. **Question 3 [2 pts]:** What are the advantages and disadvantages of having individual neurons perform their own gain scaling (as opposed to it being a network phenomenon, which is how we implemented it last week)?

## REFERENCES

- [1] Blaise Aguerre y Arcas and Adrienne L Fairhall. What causes a neuron to spike? *Neural Computation*, 15(8):1789–1807, 2003.
- [2] Adrienne L Fairhall, William Bialek, et al. Computation in a single neuron: Hodgkin and huxley revisited. *Neural Computation*, 15(8):1715–1749, 2003.
- [3] Rebecca A Mease, Michael Famulare, Julijana Gjorgjieva, William J Moody, and Adrienne L Fairhall. Emergence of adaptive computation by single neurons in the developing cortex. *The Journal of Neuro- science*, 33(30):12154–12170, 2013.