Quantitative Methods in Neuroscience
(NEU 466M)
Final Project
Due: Wednesday May 9 at 11 am in NHB 3.350

Switching during perceptual bistability. In this project, we will explore switching dynamics during perceptual bistability. We will build models, analyze data from the models, and perform psychophysics experiments to compare behavior with models. Team up with one classmate so you can do the project in groups of two.

Consider a pair of neurons in a circuit:

$$\tau \frac{ds_1}{dt}(t) = -s_1(t) + f(-ws_2(t) - ga_1(t) + b_0(1 + n_1(t))) \,, \tag{1}$$

$$\tau \frac{ds_2}{dt}(t) = -s_2(t) + f(-ws_1(t) - ga_2(t) + b_0(1 + n_2(t))) \,, \tag{2}$$

where s_1 and s_2 are the time-varying synaptic activation variables, w is a synaptic inhibitory weight, τ is the synaptic time-constant, and b is the strength of the feedforward input. Let the $f - I$ (transfer) function of each neuron be the sigmoid $f(x) = e^x/(1 + e^x)$. There are two sets of new variables. The first set of variables comprises the noise terms n_1 and n_2, which are independent for each neuron and can be assumed to be Gaussian with zero mean and standard deviation σ. The second set of new variables, a_1 and a_2, represents the level of *adaptation* in the two neurons. The more a neuron fires, the more adapted it becomes, driving the variable from unadapted ($a_i = 0$) to an increasingly adapted value (larger a_i) that acts like a negative drive to the neuron. The strength of the adaptation effect on a neuron's response is controlled by the parameter g.

The adaptation variables obey a simple differential equation in vectorial form:

$$\tau_a \frac{d\mathbf{a}}{dt} = -\mathbf{a}(t) + \mathbf{f} \tag{3}$$

where $\tau_a >> \tau$ is the slow synaptic adaptation time-constant, and $\mathbf{f}$ is the 2×1 vector of firing rates of the neurons, as given in Equation (1). The noise variables are simply linearly low-pass filtered versions of random Gaussian noise:

$$\tau_n \frac{d\mathbf{n}}{dt} = -\mathbf{n}(t) + \sigma\sqrt{2\tau_n}\xi \tag{4}$$

where $\tau_n << \tau$ and ξ is a 2×1 vector of two independent zero-mean Gaussian random variables of unit variance (`randn` in Matlab).

In your simulation, use $\tau = 20$ ms, $\tau_a = 200$ ms, $\tau_n = 4$ ms, $dt = 0.1$ ms, $w = 12$, $b_0 = w/2$.

We will study the psychophysical phenomenon of perceptual bistability and use the equations above to model it. Our goal is to get some understanding of the mechanisms that lead to switching in perceptual bistability.

a. **Primary literature and report.** Read the following paper: R. Moreno-Bote, J. Rinzel, and N. Rubin. Noise-induced alternations in an attractor network model of perceptual bistability. *J. Neurophysiol* 98: 1125-1139. Write a $\approx$ 2-page summary/report about it. Include a discussion of your own findings in it as much as possible.

b. **Psychophysics.** In a quiet room with no other distractions, view the Necker cube stimulus (enclosed file) and log the times of switches on Matlab using the enclosed code `switch_time_recording.m`. Collect as much data as you can tolerate, in several sessions that each last as long as possible, with both members of your team as subjects. Tabulate your data in the form of two tables, one for each subject. For each subject, report in column 1 the ISIs (the time-intervals between switches). In column 2 note the session number in which that switch interval was taken. **All groups: send me your data by Friday, May 9.**

c. **Modeling I.** Switching driven by adaptation only (zero noise, $\sigma = 0$): Code your simulations and plot s_1, s_2 versus time. You have built an oscillator – there is perfectly periodic switching between the two percepts. How does the period of oscillation vary with g? Plot. For a fixed g, how does the switching period depend on b, the strength of the ff input? Does period go up or down as the strength of the input drive (the contrast of the stimulus) is increased?

d. **Modeling II.** Switching driven by noise only (zero effect of adaptation, $g = 0$): Fix the noise standard deviation σ to some appropriately large value to drive noise-induced switching, and plot s_1, s_2 versus time. Plot the ISI distribution (defined as distribution of time-intervals between adjacent switches). For different values of the noise standard deviation σ, plot ISI distributions: how does the ISI mean (average switching time) vary with σ?

e. **Analsysis I.** For the purely noise-driven model in d., compute the *switch-triggered average* (STA) of the stimulus (i.e., the input b, including the constant component and the noise component) for just the in-to-out direction switches. For the same switch direction, compute the STA for each neuron separately. Plot and interpret your result. Do the same for the other switch direction.

f. **Analsysis II.** Model with both adaptation and noise: Fix an adaptation strength g, then plot ISI distributions for a few (4-5) different but well-spaced values of noise variance. Get all ISI distributions on same plot, including the zero-adaptation case. Interpret.