VS265: Neural Computation, Problem Set 1 - Threshold of Vision

Due date: September 12, 3:30pm

Fall 2024

General guidelines:

- We are grading problem sets anonymously. **Include your student ID in the submission, but do not include your name.**
- You may work in small groups of 2-3. Note that you are responsible for writing up and submitting your submission individually.
- You are expected to attach any code you used for this assignment but will be evaluated primarily on the writeup.

What determines the lowest light level you can reliably see? There are multiple factors responsible, but the principal biophysical limiting factor is the spontaneous activation of rhodopsin molecules that occur at 1 event per 160 seconds per rod in total darkness. This scintillating background of rod activity is also known as the Eigengrau, or 'dark light'. In order to reliably detect real light coming from the outside world, the arrival rate of photons must be sufficient to be statistically detectable above this background. For human observers, this has been measured to be at a rate of 1 photon catch per 5000 seconds per rod - i.e., only a 3% increase over the background rate. How does the brain achieve this?

As discussed in class, the psychophysical threshold for detection is defined as the stimulus level at which you are at 75% correct on a two-alternative forced-choice task (where 50% correct corresponds to pure guessing). This is the point at which $d' = 1$ for the signal vs. background distribution. (See Dayan & Abbott section 3.2 for further details.)

1. Given the above, and assuming both [background] and [background + photon] events are Poisson distributed, what rate parameter (in events/sec) would be needed in order to achieve $d' = 1$? (You may assume that the distributions for [background] and [background + photon] events have the same variance).
2. The above rate could be achieved by summing over some combination of space and time. What are some combinations of spatial area (in degrees^2 of visual space) and temporal duration that could meet the above rate? (you can assume a rod density of 10,000 rods/deg.^{2})
3. To get a visual feel for the problem the brain is solving, create a movie simulation of a 300 x 300 array of rods spontaneously activating in total darkness. To make it somewhat realistic, assume each rod response is a leaky integrator with $\tau = 0.5$ sec, so that the response to a photon lasts about half a second. (You can simulate a leaky integrator via $y_{t+1} = (1-\alpha)y_t + \alpha x_t$, where y_t is the rod response at time t and $x_t = \frac{1}{\Delta t}$ if a rhodopsin molecule is activated at time t and zero otherwise, and $\alpha = \Delta t/\tau$, with Δt being the step size of the simulation. It is most convenient to pick Δt according to the frame-rate you will use to play the movie - e.g., for 30 frames/sec use $\Delta t = 0.033$.)
4. Now create a second movie of a set of rods activating in response to photons only (assuming no spontaneous activity), at 1 photon catch/5000 sec/rod.
5. Next, create a third movie of this photon catch rate combined with the background spontaneous rate - i.e., [1/160 + 1/5000] events per second per rod. Place all three movies side by side so you can visually compare them as they play. Can you see any difference between movies 1 and 3?