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Dilawar Singh

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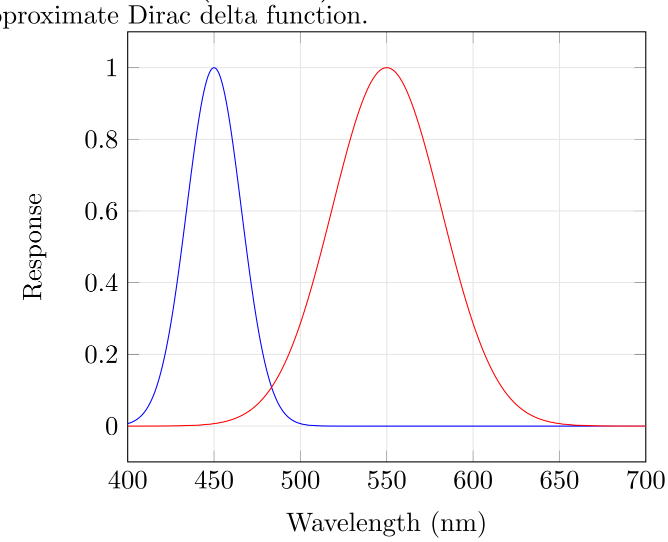
Problem 8.1, 5 Points Supposing you had just two opsins in your retina, for red and blue, that drive activity in red-selective and blue-selective neurons. Recall that the wavelength curve for these is quite broad, and let us say that the curves overlap. Draw a graph with response on the y axis, and stimulus wavelength on the x axis, for the two neurons.

Solution The response curve of these two neurons to the light is shown below. These are well approximated by following functions $blue(x) = \exp\left(\frac{-(x-450)^2}{500}\right)$, and $red(x) = \exp\left(\frac{-(x-550)^2}{2000}\right)$. Notice that these functions are also used to approximate Dirac delta function.

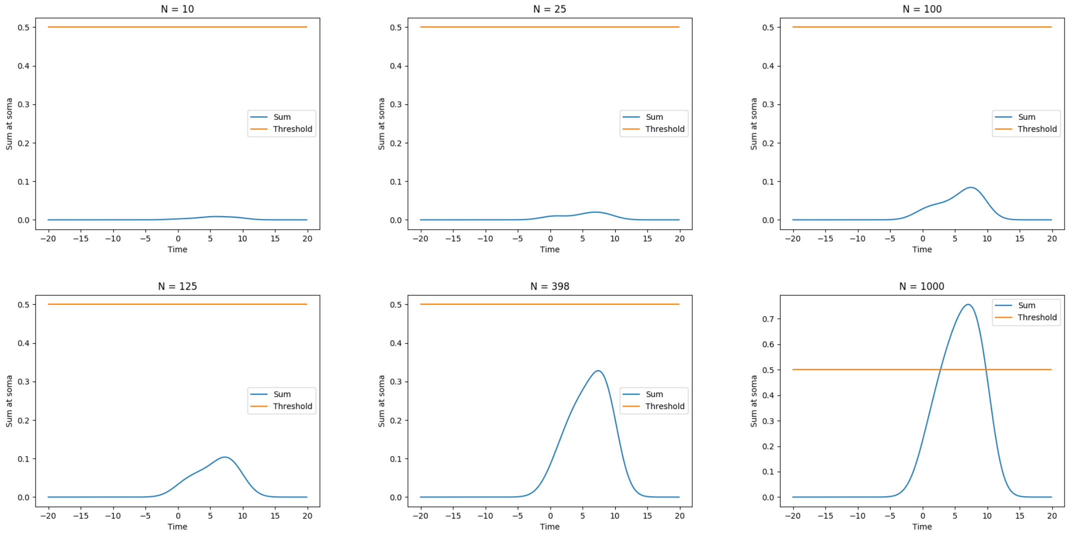


Problem 8.2, 3 Points Consider the response of the red and blue neurons to a monchromatic yellow stimulus, that has its wavelength 75% closer to red than to blue. Come up with a two-colour stimulus that would fool you into thinking it was the same colour as yellow.

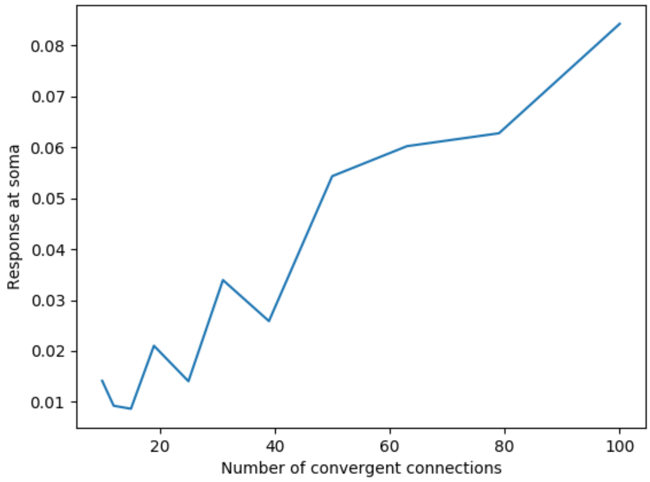
Solution With values in previous solution, the wavelength is 525 nm. At this wavelength the overall response is $blue(525) = 0.000013$ and $red(525) = 0.7316$. The combination of both is roughly 0.7316. The problem is to find x and y such that $blue(x) + red(x) + blue(y) + red(y) = 0.7316$. There are many solutions to this equation. One such solution is $x = 425$ and $y = 590$.

Problem 8.3, 5 Points Consider how inputs to a neuron sum, when they are located on an excitable dendrite. On the x axis draw the number of converging active inputs, and on the y axis draw the somatic excitation. Consider first summation if the inputs are far below dendritic action-potential threshold (relatively few inputs), and then draw what happens to somatic excitation as the number of inputs increases.

Solution I made a approximate model for this problem and computed the response at soma with varying N. Soma is far away from dendrite receiving inputs (50 a.u. away). All inputs are 60 +/- 10 a.u. away from soma. The time-difference between inputs are uniform random number 0 to 10 a.u. of time. For totally synchronous input, this time-difference should be 0. Some results are shown below.



If my model is correct, you were suppose to capture the following effect, qualitatively or quantitatively.



Problem 8.4, 5 Points Design receptors and thresholds, for a set of 5 single neurons that can do the logical operations AND, OR, NOR, NAND and XOR, respectively. Assume only two inputs in each case, A, and B. Explain how the last two work.

A $\xrightarrow{w_1}$, B $\xrightarrow{w_2}$ $\boxed{\theta = w_1 + w_2 - \epsilon}$ —— A `AND` B

Solution

A $\xrightarrow{w_1}$, B $\xrightarrow{w_2}$ $\boxed{\theta = min(w_1, w_2) - \epsilon}$ —— A `OR` B

A $\xrightarrow{-w_1}$, B $\xrightarrow{-w_2}$ $\boxed{\theta = -\epsilon}$ —— A `NOR` B

A $\xrightarrow{-w_1}$, B $\xrightarrow{-w_2}$ $\boxed{\theta = max(-w_1, -w_2) - \epsilon}$ —— A `NAND` B

This is bit odd!

A $\xrightarrow{w_1}$, B $\xrightarrow{-w_2}$ $\boxed{w_1 < \theta < -w_2 + \epsilon}$ —— A `XOR` B

Problem 9.1, 3 Points Read up how dopamine encodes reward expectation. In which of the situations will you get the highest peak of dopamine? Explain why.

1. Passing your course.
2. Passing your course if you didnt even study.
3. Passing your course on the second attempt.
4. Discovering that you had forgotten to register for the course so you dont even have to sit for the exam.

Solution Dopamine is released when there is an unexpected reward or when one is thinking of reward in future. Essentially if you get a reward without doing anything (or much), dopamine is released. I think 2 and 4 falls into this category.

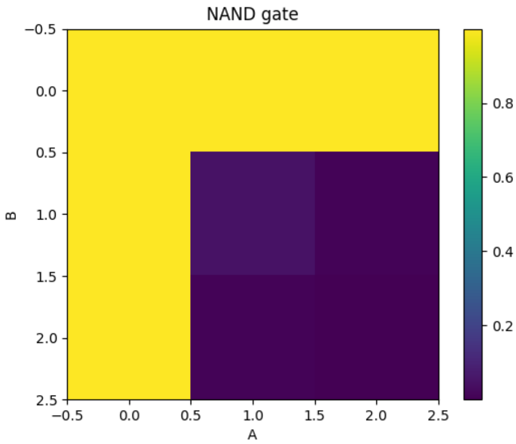
Problem 9.1, 5 Points Put together a few (named) signaling pathways to perform the operation of a NAND gate, triggered by receptor activation, and using the activity of a kinase as output. Which rate constants would you change to make it a NOR gate?

Solution Recall that a NAND gate with inputs A and B, is ON when at most 1 of the inputs is ON. Or in other words, if both A and B are ON, the output is OFF, otherwise it is ON. The kinase has to be OFF when both signal are high, and ON otherwise.

Let's say we have chemical species A and B (as input to gate), receptor R to activate kinase X. Following is one solution:

$$\mathrm{A} + \mathrm{B} \xrightarrow{k_1} \mathrm{AB}$$
$$\mathrm{R} + \mathrm{X} \xrightarrow{k_2} X^* + \mathrm{R}$$
$$X^* + \mathrm{AB} \underset{k_b}{\overset{k_f}{\rightleftharpoons}} \mathrm{XAB}$$

You need to find a signaling pathway which can do the above computation. Here is the simulation of this scheme. When both A and B are zero, the system is high (yellow).



In this reaction scheme, we can not convert this gate to NOR gate by merely changing the reaction rate.