Problem set 3

- Due at start of class, as announced.
- Working together is absolutely encouraged. While doing so, please write your own code and solutions – and make sure these codes and solutions reflect your own understanding of each part of the problem.
- Please do not refer to previous years' solutions.
- Turn in a write-up of your solutions including discussion/analysis AND plots, neatly organized together with all code you wrote/used for the assignment. Full points require that writeup be legible, understandably explained, and reasonably organized.

I **Filtering of inputs: what matters in driving the membrane response?** Let's say we know the voltage right now: at a time t_{now}. (For example, we could have just seen a spike, so we know $V(t_{now})$ has just risen above threshold.) And – we'd like to know what current $I(t)$, defined over a time interval $[0, t_{now}]$, could have driven the neuron to this voltage. For the current-driven (RC) circuit model studied in class,

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- Choose $t_{now} = 30ms$, $V(t_{now}) = 10mV$, and $R * C = 10ms$. Find two input currents $I_1(t)$ and $I_2(t)$, that look very different but produce the same value of $V_{t_{now}}$. For both cases demonstrate your results by plotting the relevant voltage and current traces using MATLAB (you may start with the relevant code provided / studied in class).
- Answer this question: what is it about the explicit solution for $V(t)$ from class that indicates (a) that you would be able to find more than one different current trace that leads to any $V(t_{now})$, and (b) why the two specific traces you took while different, both led to the same $V(t_{now})$.

II **Summation of simultaneous impulses: do impluses summate linearly, sublinearly, or superlinearly?**

IA(t)

superposition

I1 —> V1
I2 —> V2
I1 + I2 —> V1 + V2

- Consider the current-driven (RC) circuit, with $R * C = 10ms$. Consider an incoming current impulse, with magnitude $\bar{I}$ μA and width Δ_1 ms (choose whatever values you wish for these constants). Starting from $V(0) = 0$ mV, what is the peak voltage achieved over time in response to this impulse? If the threshold for spike generation is 10 mV, what fraction of the way to threshold does this impulse drive the voltage response (if your impulse take the cell over threshold, reduce $\bar{I}$ and repeat)? Call this fraction f. Next consider the case in which N such impulses arrive simultaneously (equivalent to taking the amplitude $\bar{I} \to N\bar{I}$). (NOTE: this is different from having two pulses arrive one after another in a temporal sequence, they should arrive at the same time.) What is the lowest value N that will drive the voltage over threshold? How are f and N related? Solve this question using BOTH MATLAB code, AND the explicit solution from in integral form from class (check your work, you should get the exact same results for both approaches)!

gA(t)

- Now study the same question, for a conductance-based input model. Now, the impulses should be in $g(t)$ conductance instead of the current $I(t)$, but otherwise be formed in the same way as for the previous problem. Choose $E = 11$ mV. First, using MATLAB only, experiment with a number of magnitudes $\bar{g}$ for the g1 + g2 NOT EQUAL to V1 + V2

conductance impulses and explain your findings for how pulses combine. Second, use the form of the explicit solution from class, or other arguments from class, to write down a two-sentence explanation of why you found what you did.

III **HH model**

Plot firing rate as a function of applied constant current (tuning curve)

- Use and / or modify the appropriate codes provided in the `HH` directory to plot the *firing rate - current* tuning curve for the Hodgkin Huxley model. That is: as a function of the constant value of applied current (i.e., $I_A(t) = \bar{I}$), plot the firing frequency in Hz. Hint: start at $\bar{I} = 0\ \mu A$ and gradually test more negative currents.
- Now repeat, but with a sinusoidal background current of frequency ω kHz. That is, plot firing frequency as a function of $\bar{I}$ for the applied current $I_A(t) = \bar{I} + \epsilon \sin(2\pi t\omega)$, where you choose values for ϵ and ω (try several different values). How does your *firing rate - current* tuning curve change? Can you provide a qualitative explanation? Hint: look for changes around the $\bar{I}$ value near the threshold for repetitive firing.
- Finally, think about how to add *noise* to your applied current. Next, implement this: include a noise term in your MATLAB code any way you wish (describe what you have done in a sentence or two!), and compute the *fano factor* – as defined in class. This will require repeating your simulation with multiple realizations of the noise current. For at least one value of $\bar{I}$, plot the fano factor vs. a measure of the noise amplitude.

NOTE! Those taking NBIO 301 will have the opportunity to do almost exactly the experiment above with the snail neuron in lab. The only difference is that the sin wave will be replaced by periodic pulses of frequency ω and strength ϵ (and some width Δ in time).