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HW3 – CS346

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1. In Exercise 1, we were tasked with implementing the HH model without the Na-K Pump. To do so, we started by initializing all the variables given to us in the tables along with a large number of anonymous functions. The first of the anonymous functions were the opening and closing constants for m, n, and h, the probabilities of gates for Na, K, and Leakage being open.

Each of these functions was a function of the current voltage, as a greater voltage meant a greater opening rate constant for Na, and leakage, but less for K. Moving forward, each of these six opening and closing rate constants were used when calculating the anonymous function derivatives for n, m, and h for the RK4 approximation. Of the three anonymous functions, none of them took more than 2 variables, but for the sake of alignment and debugging, the function was created to take V, n, m, and h so that in our RK4 approximations, each would be in line.

Next, we created anonymous functions to compute the currents through the K, Na, and Leakage channels. Unlike the derivative functions above, none of these were programmed to input all the same variables as they do not need to line up in the simulation loop. These equations were implemented exactly as described in the textbook.

The last anonymous function is by far the most interesting as it is the derivative calculation for voltage. In addition to V, n, m, and h, it also takes parameters for I, the current inputted current, and Na\_O and K\_O, flags for if the Na and K channels are open or closed. The model gives the derivative of voltage as a function of the inputted current and the currents of each channels, however the channels are not always open, so voltage gating needed to be implemented.

To do so, the current of K was multiplied by K\_O as K\_O was either 1 (open) or 0 (closed), effectively controlling the role of the current of K in the calculating for the equation for voltage. The same was done for the current of Na.

To calculate the value of Na\_O, additional constants were created for the threshold for when the Na gate open and closed. Using a logical operator, the Na\_O variable was equal to 1 if the voltage was above -55mV and below 49.3mV, and if the K\_O was 0, meaning that the K gate was closed. This mean that after the K gate opened, the Na gate had to close as required in the model and could not open again until the K gate was shut. The K gate opens if the voltage is above 49.3mV and closes during repolarization, as soon as the derivative of voltage is no longer 0. Thus, using a logical operator again, K\_O was 1 if the voltage was greater than 49.3 or if the derivative was negative. This ensured that the gate opened at the threshold, closing the sodium gate, and stayed open until the voltage reached its minimum.

These variables were calculated every loop and put into the dVdt anonymous function to calculate the change in voltage as a function of the current. To finish off the model, an initial current of 15mV was applied .5 seconds into the simulation. This .5 second offset was calculated based on the time step, and so the applied current calculated with another logical operator. If the loop was between the calculated time step in terms of iterations, the logical operator would return 1 and be multiplied by the applied current, otherwise it would return 0 meaning that the current was shut off.

![A screenshot of a cell phone

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As we can see from the above simulation, the graph is a way off from the expected HH graph in the textbook. Immediately we see that the voltage climbs slowly off the start. This is because although the K and Na gates are closed, the Leakage gate is open. Without the pump to counteract the flow of K ions out of the interior through the Leakage channel, the mV difference rises slowly until the initial current is applied at .5 seconds.

The spike appears relatively normal in the voltage graph, and the graph of n, m, and h look appropriate. However, as the simulation continues, we see the importance of the pump to maintain equilibrium. Without the pump, the Leakage will continue until the mV is above -55mV meaning the Na gates open again causing another action potential. Interestingly, without any more voltage being applied, the mV threshold doesn’t quite reach high enough meaning the K gates never open and so the voltage never drops.

2. In Exercise 2, we were tasked with implementing the Na-K pump. The role of the Na-K pump is to counteract the effect of the Leakage channel during the resting phase to keep the potential at equilibrium. Thus, the only way to cause an action potential is with external stimulus.

Using the code from Exercise 1, we added a new constant I\_P for the current of the pump. However, unlike the other currents, the pump current is constant and is therefore not a function of voltage. The only job of the pump is to cancel out the Leakage, so the pump constant was the negative of the initial leakage value. This constant was then added into the anonymous function for voltage calculation. Otherwise, nothing else was changed, but the results are impressively different.

![A screenshot of a social media post

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Here we finally see the importance of the pump. Unlike in Exercise 1, before the initial stimulus, the voltage stayed perfectly constant, showing the pump’s role in maintaining equilibrium. Then, after the action potential, the voltage steadily climbs back to -65mV before levelling off. We see the corresponding changes in the graph of n, m, and h in that they there is one action potential before they start to return to their normal values.

Currently, the only difference is the drop at the top of is later and less immediate, and the rebound of the voltage suddenly jumps up once the K channel closes as opposed to being a smooth line. On the other graph of m, n, and h, we see that n and h cross each other when they shouldn’t in the graph shown in the textbook. We believe that this is due to the fact that the Na-K pump is always on in this simulation whereas it is not always in real life. Thus, assuming it shuts off as the Na concentration approaches 0 inside and K concentration approaches 0 outside, its shutting off during the simulation may impact the peak of the graph and how it rebounds.