Neuroprothetics Exercise 5
Multicompartment Model

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WS 2021/22

1. Create a Multicompartment Model

In order to simulate an unmyelinated axon, change the point neuron model from the last exercise to a multicompartment model consisting of $n = 100$ compartments. Modify the functions from the last exercise to work with arrays of dimension $n \times 1$ instead of scalar values. Implement the cable equation inside *hh_model*, have a look at the slides provided in moodle for more information. Use the implicit Euler method to solve the arising system of differential equations as described in the slides. The parameters are given in the Appendix. Use ρ_{axon}, r_{axon} and l_{comp} to compute R_a.
Tip1: If your code runs slow, use tic toc (Matlab) or timeit functions (Python) to determine which part takes most time to run.
Tip2: For debugging purposes, it might be useful to set the $\boldsymbol{C}$ *matrix to a zero matrix. This would lead to every compartment behaving as an isolated compartment, i.e. just as in exercise 4.*

2. Experiments

Run 100 ms long simulations ($\Delta t = 25\,\mu$s) at $6.3\,°C$ with the following settings.

1. Stimulate the axon at the first compartment with a rectangular 5 ms long pulse with an amplitude of 10 µA. Visualize how the action potential propagates along the axon. (You may use *imagesc* in Matlab)

2. Stimulate the axon with the same pulse as above but at compartment 20 and 80 simultaneously. Explain the resulting propagation profile (why does it stop in the middle?).

3. Explore the different parameters of the model, find out which affect the speed of action potential propagation and explain your findings (Not ion channel parameters. Keep in mind that ρ_{axon}, r_{axon} and l_{comp} result in a single parameter).

3. Solution

Here you can see how the resulting plots should look like. This is just to give you an idea if your results are valid.

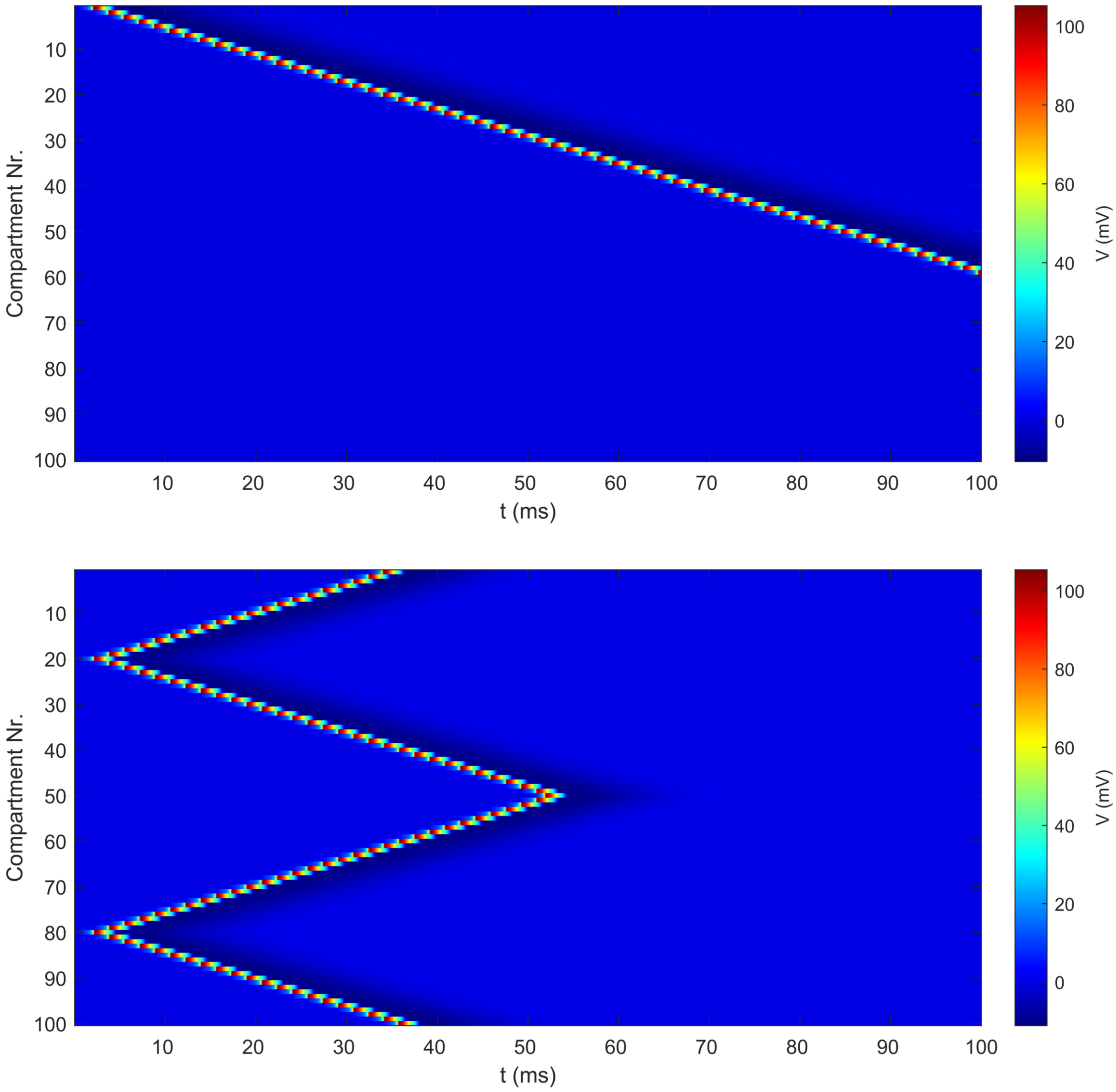

Abbildung 1: Top: Propagation of the action potential over the different compartments for stimulation at compartment 1. Bottom: Same for simultaneous stimulation at compartments 20 and 80. The colorbar shows the color coding of the potential values.

A. Equations and Constants

The original HH model was not fitted in respect to base SI units. In order for you to be able to use base SI units, the rate equations have been adapted. Furthermore, the original publications included area dependicies for most parameters (e.g. $\bar{g}_{Na} = 120 \frac{mS}{cm^2}$). These dependencies have been removed in this exercise for the sake of simplicity.

In the lecture the cell resting potential is given as $V_{rest} \approx -60mV$. The reason for $V_{rest} = 0mV$ here is that HH defined the resting potential to be zero. Therefore all voltage values are shifted compared to the lecture.

General equations:

$$i_{ion} = i_{Na} + i_K + i_L$$

Ionic currents:

$$i_{Na} = \bar{g}_{Na} m^3 h (V - V_{Na}) \qquad i_K = \bar{g}_K n^4 (V - V_K)$$

$$\frac{dm}{dt} = [\alpha_m (1 - m) - \beta_m m] k \qquad \frac{dn}{dt} = [\alpha_n (1 - n) - \beta_n n] k$$

$$\frac{dh}{dt} = [\alpha_h (1 - h) - \beta_h h] k \qquad i_L = \bar{g}_L (V - V_L)$$

Temperature correction (T in °C):

$$k = 3^{0.1(T-6.3)}$$

Rate equations:

$$\alpha_m = 1000 \cdot \frac{2.5 - 100 \cdot V}{e^{(2.5-100 \cdot V)} - 1} \qquad \beta_m = 4000 e^{-500 \cdot V/9}$$

$$\alpha_n = 1000 \cdot \frac{0.1 - 10 \cdot V}{e^{(1-100 \cdot V)} - 1} \qquad \beta_n = 125 e^{-25 \cdot V/2}$$

$$\alpha_h = 70 e^{-50 \cdot V} \qquad \beta_h = \frac{1000}{e^{(3-100 \cdot V)} + 1}$$

Constants

Conductances in mS			
$\bar{g}_{Na} = 120$	$\bar{g}_K = 36$	$\bar{g}_L = 0.3$	
Nernst/Resting potentials in mV			
$V_{Na} = 115$	$V_K = -12$	$V_L = 10.6$	$V_{rest} = 0$
Other constants			
$C_m = 1\,\mu\mathrm{F}$	$\rho_{axon} = 100\,\Omega\mathrm{cm}$	$r_{axon} = 2 \cdot 10^{-4}\,\mathrm{cm}$	$l_{comp} = 0.1 \cdot 10^{-4}\,\mathrm{cm}$

updated SS2019, Albert Croner, Korbinian Steger
updated SS2020, Albert Croner