Practice in groups

Action Potential propagation in purkinje fibers

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INTRODUCTION

In the second practice you developed a complete action potential (AP) model and, in this last practice, you will be able to implement a model of a purkinje fiber to analyze how the AP propagates through it.

> *Important*: *Remember that you are using a very simple model developed in the sixties. Be careful with the conclusions you obtain from your model to understand how these cells work.*

On the PDU you can find a file that simulates the Hodgkin and Huxley model in a 1-cm fiber of cells (HH_1D.R). You can use this model as start point for your model of a Purkinje fiber. The Action potential obtained with the model proposed by Hodgkin and Huxley is graphically represented in the file HH_1D.gif (you can find it on the PDU).

FIRST PART: SIMPLE FIBER MODEL (50%)

In this first part of the practice, you need to create the basic model. The membrane potential in a fiber is defined as follows:

$$C_m \frac{\partial V}{\partial t} = -I_{tot} + \sigma \frac{\partial^2 V}{\partial x^2}$$

Where C_m is the capacity of the cell, V is the membrane potential, I_{tot} is the addition of all the ionic currents, and σ is the diffusion coefficient of the tissue. The value of this coefficient in purkinje cells is approximately 0.08.

Following the example of the Hodgkin and Huxley model, you can obtain a new one with your model of the Purkinje cells. Remember that you do not have to stimulate the purkinje model.

You must use the same initial conditions in all the positions that in the original cellular model and, as border conditions, that the derivative of the membrane potential is 0 in the borders.

$$\frac{\partial V(0,t)}{\partial x} = \frac{\partial V(1,t)}{\partial x} = 0$$

You can see an example of the result you should get in the PDU (PK_1D.gif). Because the model is auto-excitable, and all the cells have the same initial conditions, the membrane potential in all the cells is the same all the time. This causes that the propagation of the AP is not seen: $\frac{\partial^2 V}{\partial x^2}$ is

always 0. To solve this problem, in the next sections of this practice, you will introduce new conditions to favor the conduction in the fiber.

SECOND PART: STIMULATED MODEL (20%)

One option to avoid the problem of the previous part is to stimulate the model in the first position. If you stimulate the fiber faster than the auto-generation of action potentials, you will be able to see the propagation of the AP.

Stimulate the first element of the fiber with a CL of 0.4 seconds for 2 seconds as in the HH example. After this, leave the fiber without stimulation for 8 seconds more.

You can see an example of the result you should get in the PDU (PK_1D_stim.gif).

THIRD PART: HETEROGENEOUS MODEL (30%)

The solution obtained in the previous section has a limitation: the fiber tends to balance, and the differences disappear.

As you saw in the first and the second practice, every cell could have a different value for the conductances (P1), and, depending on these values, the AP will be different (faster, longer, etc.) (P2). A realistic model of a purkinje fiber should add this characteristic.

To include this characteristic, each point of the fiber should have a different conductance for the currents. You can do this by modifying the conductances with a random factor between 0.95 and 1.05. This factor will remain constant during all the simulation. To calculate a vector of random numbers in an interval, you can use: `runif(n, min = 0, max = 1)`.

With this new configuration, the fastest cell will set the pace. You can see different examples of the result you could get in the PDU (PK_1D_rand_XX.gif). Remember that this simulation includes random numbers, so the solution changes in each execution.

PDE SOLVER

Depending on the PDE solver you use in this practice, the maximum grade will be:

- **ode.1d**: If you use the same solver than in the example, the maximum grade of the practice will be 7.

- **Explicit**: If you implement an explicit solver to calculate the result, the maximum grade of the practice will be 10.

- **Operator splitting**: If you implement an operator splitting, the maximum grade of the practice will be 13. To implement the operator splitting you can follow this scheme:

  - Obtain I_{tot} with an explicit solver

  - With the result of I_{tot}, calculate the membrane potential (V) with an implicit solver.

PRACTICE PRESENTATION

You must submit your codes to the PDU and to prepare a short document to explain your work and your results.

The final grade of this practice will be calculated as follows:

$$G_F = min(10; (0.5 \cdot G_1 + 0.2 \cdot G_2 + 0.3 \cdot G_3)(0.5 + 0.05 \cdot G_d) \cdot M_G)$$

G_1: Grade of the first part $(0 - 10)$

G_2: Grade of the second part $(0 - 10)$

G_3: Grade of the third part $(0 - 10)$

G_d: Grade of the document $(0 - 10)$

M_G: Maximum grade $\{7, 10, 13\}$