Assignment 1: Spike propagation along cables

Neural Computation 2010-2011

21st October 2010

1 Unmyelinated axon

Building on our previous study of passive cables and single-compartment spike generation, this assignment combines the two to look at spike propagation in axons. Create a single axon with Hodgkin-Huxley channels. Parameters: 2000μm long, 1.5 μm diameter.

Question 1 (5 points) Use default HH parameters for the axial and membrane resistivity. What is the value of the space constant λ in this case? Show your calculation, and justify any assumptions you are making.

The value of `nseg` determines how many segments the cable is chopped into by the simulator. Each segment is considered iso-potential, that is, its voltage is the same everywhere. Choose `nseg` such that each segment is $\lambda/20$, which is usually a decent choice.

Insert an IClamp electrode at x=0.

Question 1b (5 points). Show with a long-lasting, sub-threshold current injection that your result for λ was approximately correct.

Question 2 (10 points). Inject a brief supra-threshold current and measure the speed of propagation of the spike by measuring the peak voltage in space plots (`Shape Plot -> Space Plot`) at different times. You can use `Tstop` and the `Continue for` button on the `RunControl` window with a small time-step to make it easier to measure. Make a plot showing the relation between the speed and the diameter. How does the speed depend on the diameter? How does this compare to the dependence on the diameter of the "speed" of passive propagation?

Question 3 (10 points) How does the temperature change the HH equations? Plot the speed of propagation as a function of temperature. Briefly discuss the result.

2 Myelination

If a neuron projects to far-away regions either within the brain or to the spinal cord, it is usually myelinated. To model this we append a long myelinated portion to the axon from part 1, treating the `axon` section now as an initial (unmyelinated) segment. A myelinated axon consists of long stretches of axon wrapped in layers of myelin, interleaved with Ranvier nodes with high channel densities. Create 10 nodes, and 10 myelinated stretches (e.g. `create node[10]`).

Node parameters: `L=0.5, diam=1.5, nseg=1.` The nodes have high channel densities, giving high specific conductances — Na: 1.2 S/cm^2, K: 0.36 S/cm^2, leak: 0.003 S/cm^2.

Myelinated sections are modelled as passive compartments with: `L=1000, diam=1.5, nseg=4`. Assume that myelination reduces both the specific leak conductance and the specific membrane capacitance by a factor of 200, compared to a typical passive compartment with specific leak conductance 0.001 S/cm^2. Adjust these parameters accordingly in the myelinated compartments. Note that we are thus modelling the effects of myelination, rather than having myelin as an actual component in the simulation.

Question 4 (5 points) What is the effect of myelination on the time constant of the myelinated compartments? And on the space constant λ?

Connect the compartments as: initial segment, myelinated segment, node, myelinated segment...
It is easiest to write a .hoc file. Neuron allows the use of `for` statements like:

```
for i=0,9 {connect myelin[i](1), node[i](0)}
```

Question 5 (5 points) Set the temperature of the cell to 20C. Measure the speed of propagation in the myelinated axon. Include a 'space plot' showing the spike. Estimate the propagation latency (based on overall speed of action potential propagation) from the eye to the primary visual cortex for myelinated and un-myelinated fibres, e.g. using your own head to determine a rough guess at the distance from a human eye to the rear of the brain.

Question 6 (5 points) Stimulate on the other end of axon, opposite from the initial segment. What happens? Explain the result.

In Multiple Sclerosis (MS) myelin coating is partly lost.

Question 7 (5 points) Simulate this effect by simultaneously increasing the specific capacitance and leak conductance in the myelinated compartments. After disrupting propagation in this manner, try to save it by changing the K conductance or the temperature (separately). How should they be changed? Explain your result, and speculate about what it might mean for potential MS treatments.

General issues

You will find that some questions are quite open-ended. A particularly well-researched answer can receive additional points, but core-dumping (just writing down all you can think of) will not. You should include enough information to show the reader how you obtained your result (e.g. showing the mathematical calculation or plots from a numerical simulation), and to convince the reader that your result is correct. To be fully convincing, sometimes additional simulations other than those explicitly mentioned may be appropriate, in which case you should explain clearly why those were needed and what insight they give.

All plots must include axis labels and units; they are nearly impossible for me to mark otherwise. Ideally, these will be shown directly on the plot; e.g. inkscape can be used to load just about any plot so that you can add arbitrary text.

Note that in many cases you will need to translate between quantities and variables mentioned in the lecture notes, those listed in the assignment, and those used by a specific simulator such as Neuron. For instance, the text might mention some value as a resistance, while Neuron uses a conductance. You will need to be able to convert between these representations as needed.

Plagiarism

Copying results obtained by others is forbidden, and can lead to severe punishment (including the loss of your degree, even retroactively). It's fine to ask for help from your friends on technical issues. However, this help must not extend to copying or sharing code, results, or written text, nor to writing code or text together with a friend. If any students are found to have shared or copied work in this way, the University rules on plagiarism will apply to all parties involved.

Submission

Your work must be submitted by the specified time on the due date using the `submit` command on Informatics DICE machines (type `man submit` for more details). Your work should be in the form of one PDF file for the assignment, plus separate .hoc files for each question. Each file *must* be named as in this example submit command:

```
submit msc nc 1 asst.pdf 1.hoc 2.hoc
```

Late submissions will be penalized according to the standard university policy (http://www.docs.sasg.ed.ac.uk/AcademicServices/Regulations/PGT_AssessmentRegulations.PDF, section 3.8) of 5% penalty per working day or part of a day, unless good reason is provided for the lateness. Good reason does not include working on other coursework, because managing such commitments is part of the standard university workload.

Getting a good mark

Be sure that you provide *evidence* that you did each part of this assignment. I can only judge what is actually submitted, so you should make sure that the files you submit make it clear that you have done everything requested, and thought about what each part means.

It should not be necessary to consult scientific literature to answer these questions. If you do use information from outside the course material or your own experience, you must cite it appropriately.

Please read and follow my list of writing tips (http://homepages.inf.ed.ac.uk/jbednar/writingtips.html).

Example .hoc file for myelinated axons

```
create axon, myelin[10], node[10]
axon {
   insert hh
   ....
}
for i=0,9 myelin[i] {
   L=1000
   ....
}
connect axon(1), myelin[0](0)

// axon - mye- node - mye -node....
for i=0,9 {
   connect myelin[i](1), node[i](0)
}
for i=0,8 {
   connect node[i](1), myelin[i+1](0)
}
celsius = 20
access axon
```