Assignment 1: Interaction of synaptic input

Neural Computation 2014-2015. Mark van Rossum

10th October 2014

Practical info

Organize your answers according to the questions; don't merge them. Plots should include axis labels and units (either on the plot, or mentioned in the text), see link on the course website.

There will be a to-be-determined normalization factor between the number of points scored and the resulting percentage mark.

You will find that some questions are quite open-ended. In order to receive full marks for those questions, your answers need to go beyond running a simulation and making a plot. Instead, you should substantiate your explanations and claims, for instance by doing additional simulations or mathematical analysis. In particular for discussion questions core-dumping (just writing down all you can think of) is discouraged, and incorrect claims can reduce marks. It should not be necessary to consult scientific literature, but if you do use additional literature, cite it.

Copying results is absolutely not allowed and can lead to severe punishment. It's OK to ask for help from your friends. However, this help must not extend to copying code, results, or written text that your friend has written, or that you and your friend have written together. I assess you on the basis of what you are able to do by yourself. Similarly, it's OK to help a friend. However, this help must not extend to providing your friend with code or written text. If you are found to have done so, a penalty will be assessed against you as well.

Deadline will be announced via email and the website. Hand in a paper copy to ITO (if you are out of town an email with a PDF to me is fine, and I will confirm receipts). Late policies are strict and are stated at `www.inf.ed.ac.uk/student-services/teaching-organisation/for-taught-students/coursework-and-projects`.

Model

In this assignment we look at the effect of synaptic location on synaptic interaction between two synaptic inputs in a highly simplified, passive neuron model.

First, create a neuron model with a soma (cylinder with $10\mu m$ length and $10\mu m$ diameter) from which a single dendrite sprouts ($1000\mu m$ length and $1\mu m$ diameter).

Both soma and dendrite are passive; use `g_pas=0.0005` and NEURON's default value for r_i (called Ra in NEURON). Choose `nseg` such that each segment is $\lambda/20$, where λ is the electrotonic length. This is usually a decent choice to get sufficient numerical accuracy.

Now we create a synapses on the dendrite.

```
// exponential synapse
objref esyn1
```

```
dend esyn1 = new ExpSyn(0.5) // locate synapse halfway along dendrite
esyn1.tau=5 // time-constant in ms
esyn1.e=0 // reversal potential of synapse

objref nil, nc1
nc1= new NetCon(nil, esyn1)
nc1.delay=0
nc1.weight = 0.002 // weight in μS
```

The weight of the synapse is in this case set to 2nS, but you can change it using `nc1.weight = xxx`.

We set the time of synaptic input using the following construction:

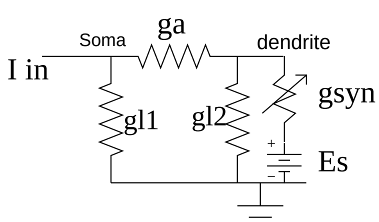
```
objref syntimes1
syntimes1 = new Vector(1)
syntimes1.x[0]= 10 // event at 10ms

objref fih
fih = new FInitializeHandler("loadqueue()")
proc loadqueue() { local ii
for ii=0, syntimes1.size()-1{
nc1.event(syntimes1.x[ii]) }
}
```

Question 1 (5 points) Create a synapse at various locations along the dendrite and of various strengths/weights. Plot the voltage excursion in the soma in response to a single synaptic event. What is the maximal excursion you can reach as a function of position? Explain the findings.

Question 2 (5 points) Try various values of the synaptic time-constant and again research the maximal obtainable voltage excursion. Explain the result.

Question 2 (5 points) One can define the (apparent) synaptic reversal potential as the potential of the soma at which activation of the synapse has no effect. When the synapse is not at the soma, this apparent reversal potential will be different from its true value (0mV). Measure and explain the apparent reversal potential as a function of the position of the synapse.

Question 3 (5 points) To further analyze the answer to the above question, consider the following circuit. Here g_{l1} is the leak in the soma, g_{l2} is the leak in the dendrite, and g_{syn} is the synaptic conductance (with reversal potential E_s). We use conductances instead of resistances to simplify expressions. Note 1) that the capacitance has been removed to mimic steady state conditions, 2) that the cable has been replaced by a single conductance g_a, 3) that V_{rest} is defined as zero. Thus, in contrast to the simulation, the results are relative to the resting voltage.
Use Kirchoff's law (in both the soma and the dendrite) to calculate the voltage in the soma. Furthermore, calculate the somatic input resistance, that is the relation between the current injected in the soma and the resulting change in somatic voltage: $R_{in} = \Delta V_{soma}/I_{in}$. How does the input resistance vary with g_{syn}?

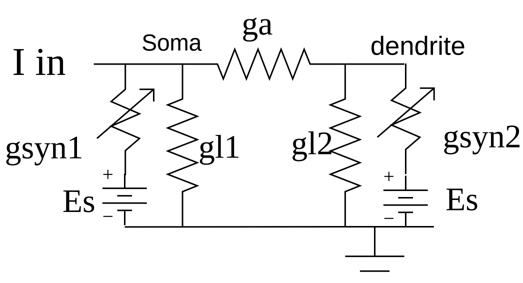


Question 4 (5 points) Calculate the apparent synaptic reversal potential using the results from the previous question.

Next, we compare the interaction of one synaptic input with another. Create a neuron model with a soma (cylinder with $10\mu m$ length and $10\mu m$ diameter) from which now two dendrites sprout (both have $1000\mu m$ length and $1\mu m$ diameter). The first input is on the first dendrite and is either halfway the dendrite, or very close to the soma.

Question 5 (5 points) Calibrate the synaptic strengths (separately for both locations of the synapse) such that the maximum excursion in the soma due to activation of the synapse is about 15 mV, no matter if the synapse is at the soma or along the dendrite. Use a time-constant of 100ms, and make sure the events are well separated in the simulation. State the conductance values used. Now add a strong 'test' synaptic input halfway the second dendrite. Plot the somatic voltage excursion when this test input is co-activated with the first synapse at the soma and when activated with the first synapse along the dendrite. Explain the result.

Question 6 (5 points) To further explore the effect of synapse location consider the following simplified circuit. The synaptic conductance can be set to either somatically ($g_{syn1} = g_s$; $g_{syn2} = 0$) or dendritically ($g_{syn1} = 0$; $g_{syn2} = g_s$). Compare the somatic input impedance when the synapses lead to the same voltage in the soma. How does this explain the findings of Question 5?



Question 7 (5 points) Comment on the relevance of the findings of Question 5+6 to biological neurons.

Remarks:

1. For systematic exploration of the role of a (synaptic) parameter, it is annoying to run, edit value, run, edit value, etc. Instead, it can be useful to create an array of synaptic inputs, each with different parameters and different activation times. This allows you to obtain all data for a plot in one simulation run. You can use constructions such as:
```
ns=20 //synapses 0...ns-1
objref syn[ns], netcon[ns]
for is=0,ns-1{
dend1 syn[is] = new ExpSyn(0.5)
syn[is].gmax = xx*is
....
```
2. Analysis of the simulation is easiest outside of NEURON, using matlab or similar. Voltage/current traces can be saved. For that use constructions like
```
objref data
data = new Vector();
data.record(&soma.v(0.5)) // this for voltage in soma
objref fout
fout= new File()
fout.wopen("out.dat")
```

```
data.printf(fout)
fout.close()
quit()
```