ESAM 495 Introduction to Computational Neuroscience

Fall Quarter 2008

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Problem Set 2 Due Thursday, October 23, 2008

1. **Connor-Stevens Model**
   Experimentally a very wide range of firing rates has been observed in neurons controling walking legs in crustaceans. In these neurons an additional K^+- conductance, I_A, has been identified, which is transient. In [1] the I_A-conductance is included in a Hodgkin-Huxley model with somewhat modified parameters. The model equations and parameters are given in detail in the appendix of the paper (some information is also given in Sec.6.6 of [2]). Implement this model, measure the firing rate as a function of injected current, and reproduce the essential features of Fig.13 in that paper[1].
   For the very low firing rates you will need integration times of the order of $t_{max} = 1500ms$ or more to obtain multiple spikes. With the forward-Euler scheme with fixed time step this will take relatively long. It is therefore better to use a numerical method with variable time step. Use the matlab function *ode15s*. Pay attention to the required order of the arguments of the function defining the differential equation: $F = F(time, Y)$, opposite to the order in the matlab template of the first homework. The function *ode15s* is specifically designed for stiff problems, i.e. problems with very disparate time scales. Try also the function *ode45*, which assumes the problem is not stiff. What happens?

2. **Izhikevich's Simple Model**
   (a) Use the GUI-version of the model available on Izhikevich's web site[2] to investigate the behavior of that model. Reproduce the two types of behaviors of thalamo-cortical neurons that were discussed in class as arising from I_{CaT}. Explain what happens. Suitable parameter values for this case can be found in [3].
   (b) Implement the Simple Model yourself using the forward Euler method; you can extract the relevant piece of code from the GUI-code. Implement a stimulating injection current consisting of two consecutive pulses of chosen duration and time separation. Investigate the two scenarios called 'resonator' and 'integrator' in [4] (K and L; parameters at the beginning of the GUI-code).
      i. In each case, first determine the fixed points analytically in the absence of a stimulus, $I_e = 0$. Find analytical expressions for the eigenvalues determining the stability of the fixed points. For the parameters of the cases K and L, which fixed points are stable/unstable? In the simulations below use the stable fixed point as initial condition.

[1] To find this and other papers it might be easiest to use pubmed at http://www.ncbi.nlm.nih.gov/sites/entrez?db=PubMed . It provides typically direct links to the journals, which are then accessible, at least when coming from a Northwestern IP address. Some journals/papers are not covered by pubmed but by Web of Knowledge at http://apps.isiknowledge.com/ , which is only accessible from Northwestern (or using vpn).

[2] http://vesicle.nsi.edu/users/izhikevich/publications/spikes.htm and http://vesicle.nsi.edu/users/izhikevich/publications/whichmod.htm

ii. **Integrator:**
For a single stimulus pulse of duration $T = 0.2$ determine the minimal injection current I_{th} (to three significant digits) that triggers a spike. Then apply two consecutive pulses of the same duration with strengths $0.8\, I_{th}$, separated by a time ΔT. For which range of ΔT do these double-pulses lead to a spike?

iii. **Resonator:**
Determine again for $T = 0.2$ the threshold injection current I_{th} (to three significant digits). Reduce the current to $0.9\, I_{th}$ and apply again two consecutive pulses separated by a time ΔT. For which values of ΔT in the range $0 \leq \Delta T \leq 110$ does this stimulation trigger a spike? How does the situation change if you increase I_e to $0.98\, I$?

iv. Explain the different outcomes in terms of the different *subthreshold* behavior of the model neurons for the two sets of parameters.

References

[1] J. A. Connor, D. Walter, and R. McKown. Neural repetitive firing - modifications of Hodgkin-Huxley axon suggested by experimental results from crustacean axons. *Biophys. J.*, 18(1):81–102, 1977.

[2] P. Dayan and L. F. Abbott. *Theoretical Neuroscience*. MIT Press, 2001.

[3] E. M. Izhikevich. Simple model of spiking neurons. *IEEE Trans. Neural Netw.*, 14(6):1569–1572, November 2003.

[4] E. M. Izhikevich. Which model to use for cortical spiking neurons? *IEEE Trans. Neural Netw.*, 15(5):1063–1070, September 2004.