Computational Neuroscience

AY 2022-23

Laboratory Assignment 1 (LAB1)
Implementing Spiking Neurons using Izhikevich's Model

General Information

Solve the following assignment, whose completion is required to access the oral examination. Upload the assignments all-together in the Moodle platform of the course (once you have completed all the labs, not only this single one) as a compressed folder including one subfolder for each laboratory.

The subfolder for this lab should be called "LAB1" and should include the scripts and the other files as requested in the assignment below. You can organize the code as you wish, implementing all the helper functions that you need, provided that these are included in the subfolder and are appropriately called in the scripts.

Bonus track assignments are meant to be for those who finish early, but they are not formally required for completing the Lab Assignment.

Detailed instructions for submissions are given in the lecture note "Intro to the course".

The recommended programming language is MATLAB, but you are allowed to use Python (e.g., with NumPy, or TensorFlow).
If you use MATLAB, you will provide:

- the source files as a collection of the scripts (.m files) used to solve the assignment, or as a live script (.mlx file) with all the necessary code.
- the output data as a collection of binary .mat files, or in a single .mat file.

If you use Python, you will provide:

- the source files in one of these forms:
    - a collection of the scripts (.py files) used to solve the assignment, with a main script that calls all the necessary other scripts;
    - a Jupyter nootebook (.ipynb file) with all the necessary code.
- the output data as a collection of pickle or json files, or in a single pickle/json file
    - in this case it is required to include a script to load the saved data in the chosen format.

In both cases, the required figures can be provided in .pdf files or in a graphics format (e.g., png, jpg). When multiple images are required, you are allowed to generate a single file including multiple subplots (or pages, if appropriate).

Supporting Material

Papers on the Izhikevich's Model

[1] E.M. Izhikevich, "Simple model of spiking neurons." IEEE Transactions on neural networks 14.6 (2003): 1569-1572.
Available online at: http://izhikevich.org/publications/spikes.pdf
[2] E.M. Izhikevich, "Which model to use for cortical spiking neurons?." IEEE transactions on neural networks 15.5 (2004): 1063-1070.
Available online at: http://izhikevich.org/publications/whichmod.pdf
Web page: http://izhikevich.org/publications/whichmod.htm

Reference values of the model's parameters

The values of the Izhikevich's model parameters and the shape of the input in all the cases are provided in the following MATLAB .m file:
http://izhikevich.org/publications/figure1.m
You are invited to use the above file to generate your own *original* code.

Matlab documentation

Matlab User's Guide https://www.mathworks.com/help/index.html
Matlab documentation using the *help* command

Python documentation

https://www.learnpython.org/
https://numpy.org/
https://matplotlib.org/

Assignment: Implementation of the Izhikevich model

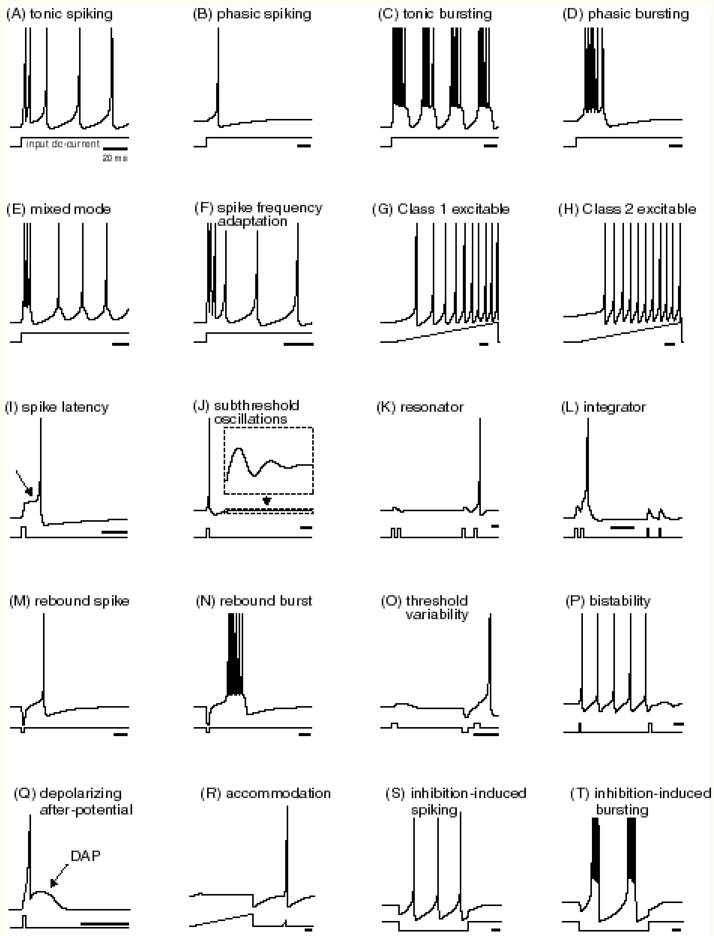
The assignment consists in the following points:

1) Implement the Izhikevich's model in Matlab
2) Develop all the 20 neuro-computational features of biological neurons using the model developed at point 1) and plot
   - o the resulting membrane potential's time courses into individual figures (one figure for each neuro-computational feature)
   - o the phase portraits that correspond to each of the neuro-computational features (one figure for each neuro-computational feature)

Recall that the Izhikevich's model is described by the following equations:

$$du/dt \ = \ 0.04\,u^2 \ + \ 5u \ + 140 \ - \ w \ + I$$
$$dw/dt \ = a(bu \ - \ w)$$
$$if\ (u \ \geq \ 30)$$
$$u \leftarrow c;\ w \leftarrow w \ + \ d$$

The system can be solved (simulated) by using the Euler's method or the leap frog method, analyzed in class.



The 20 neuro computational features to develop are described in the Izhikevich's paper [2]. They are summarized in the this figure, where the different features are obtained by using different values of the model's parameters (a, b, c and d) and different types of (externally applied) input.

The output of the assignment should then consist in the following

- The source code.
- The 20 images of the membrane potential time course for the 20 neuro computational features.
    - Note: use labels on X and Y axis (time, membrane potential). The name of each figure should indicate the name of the corresponding neuro-computational feature.
- The 20 images of the phase portraits for the 20 neuro-computational features.
    - Note: use labels on X and Y axis (membrane potential variable, recovery variable). The name of each figure should indicate the name of the corresponding neuro-computational feature.

Bonus Track Assignment: In-depth analysis of particular cases

Focus (at least) on the following neuro-computational features: Resonator, Integrator, Bistability.

For each of the considered features, provide a data vector/array representing the input that led to the desired observed neuronal behavior and another vector/array that corresponds to a case in which the desired neuronal behavior does not emerge.

Moreover, for each of the considered features, also write a brief comment in which you explain why the neuronal behavior is not emerging in the second case.