Course project (Progreso 3)

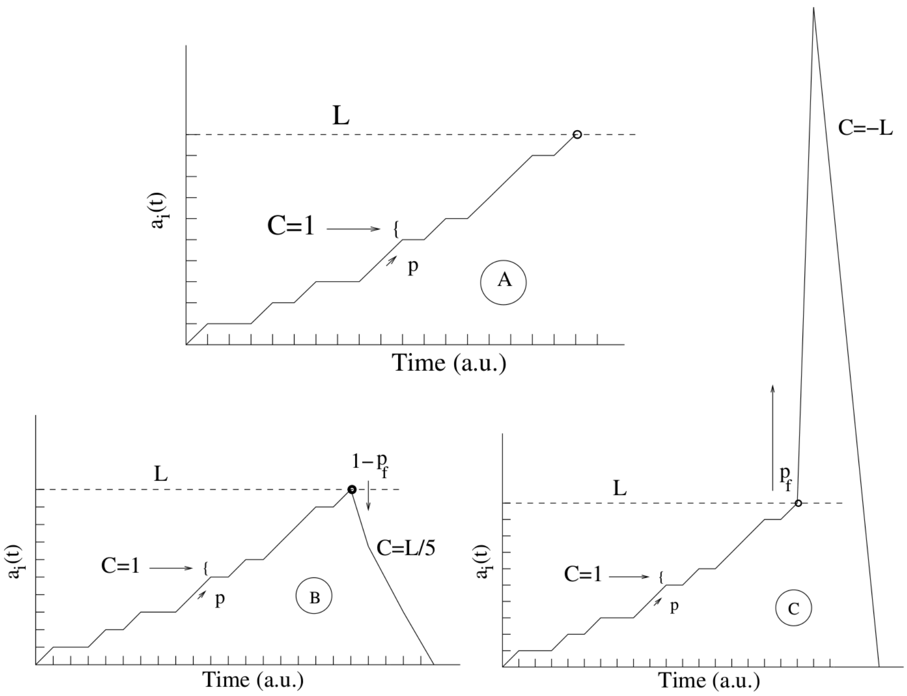
The Stochastic Neuron Model

Build a stochastic neural model with subthreshold oscillations and spiking activity. The spontaneous evolution of the activity of an isolated neuron follows a **1D random walk**. We have already implemented 1D random walks, remember our fly from the first class. The neuron activity is considered as a **discrete variable** and characterized in **time** by:

$$a_i(t+1) = \begin{cases} a_i(t) + C, \ \text{with probability } p \\ a_i(t), \ \text{otherwise,} \end{cases}$$

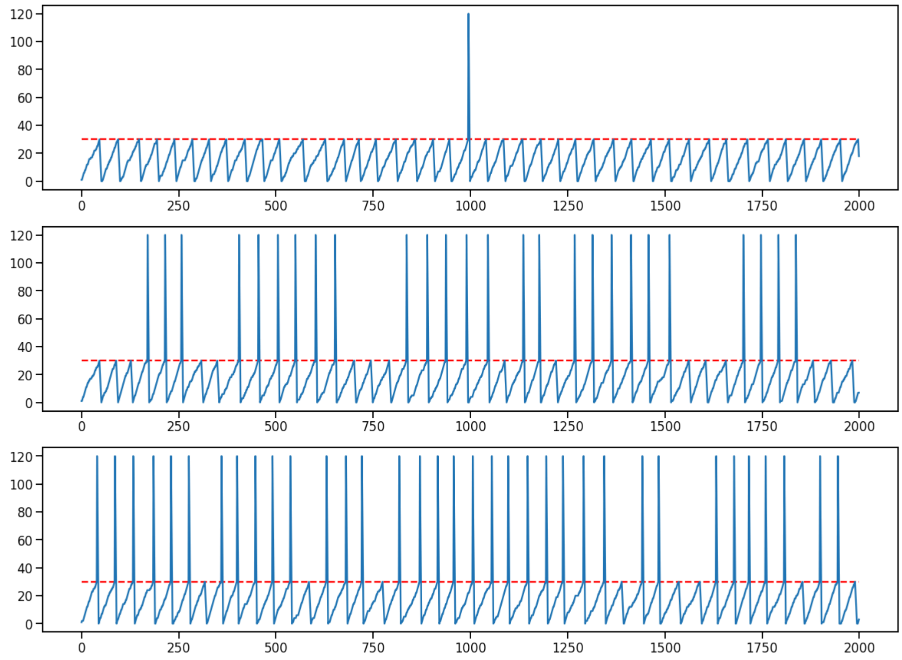
where p is the transit probability of its internal state per time step. Therefore $1-p$ is the probability of remaining in the current state. C is a parameter that depends on the temporal evolution of the unit activity. This parameter can have three different values. The neuron starts to increase its activity from an **initial state** $a_i = 0$, with probability p, using $C = 1$. If the neuron reaches its activation threshold, L, it produces a spike according to a firing probability p_f. The activity is incremented in $3L$ in order to model the spike event. After the spike, the neuron activity begins to decrease to the initial state following equation 1 with $C = -L, \ p = 1$ until it reaches the lower activity ($a_i^t = 0$). When the unit reaches the threshold and it does not fire, with probability $1 - p_f$, its activation begins to decrease again, but now $C = -L/5, \ p = 1$.

A schematic representation of this model is show below:

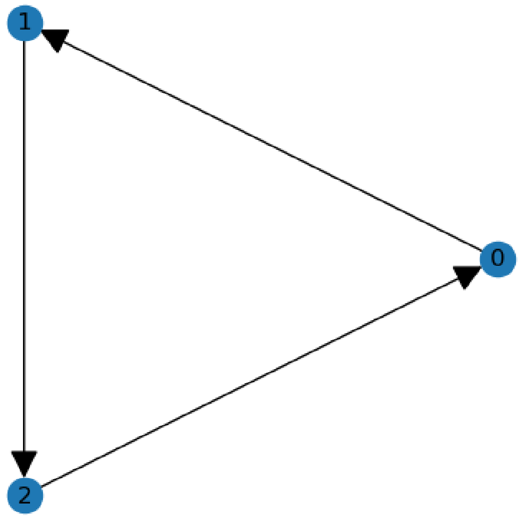


For the **neural model**, use a value of $p = 0.9$. That is 9 out of 10 steps will be up, for the **subthreshold oscillation state.**

- **(10%) The result for a single neuron should look like the following image**
  - From top to bottom $p_f \in \{0.1, 0.5, 0.9\}$, respectively.



- Construct a network, using difussive coupling among neighbor units. This means building a network of connected neurons.
- **(20%) Build a three neuron network connected as follows:**

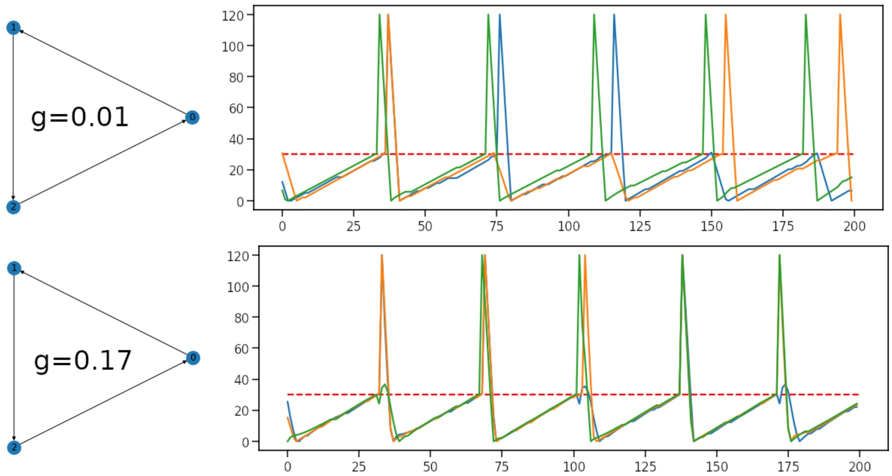


- The neurons are connected emulating electrical coupling, and the interchange rule between unit i and its neighbors j is defined by:

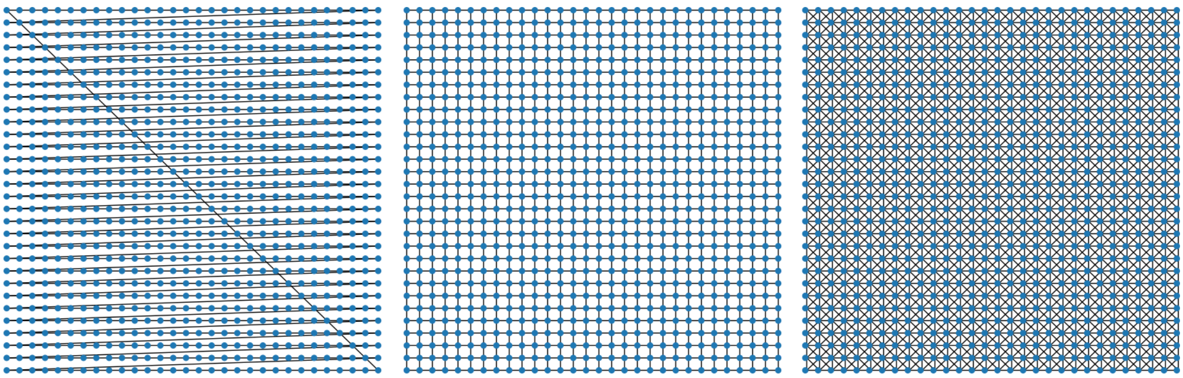
$$a_i(t) = a_i(t) + g \sum_{j=neighbors} [a_j(t-1) - a_i(t-1)]$$

where g is the electrical coupling conductance and $a_j(t)$ is the activity of its neighbor j. The value of the conductance g is the same in every connection. The electrical coupling induces a local synchronization in the network as a function of g.

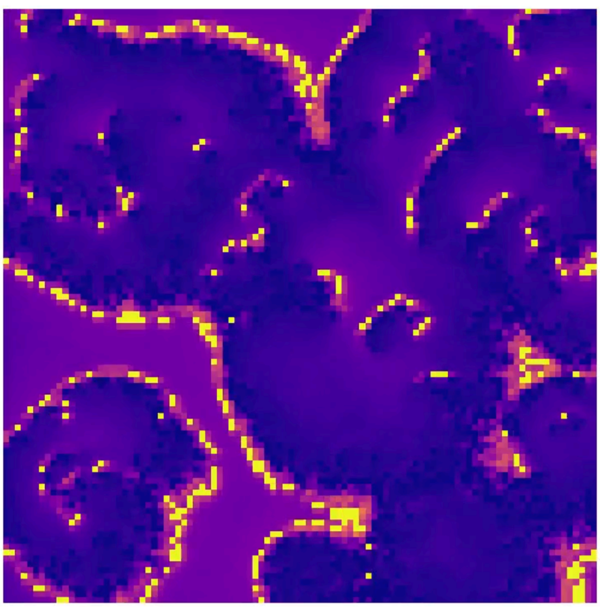
- See an example result for such network with $g = 0.01$ and $g = 0.17$ respectively:



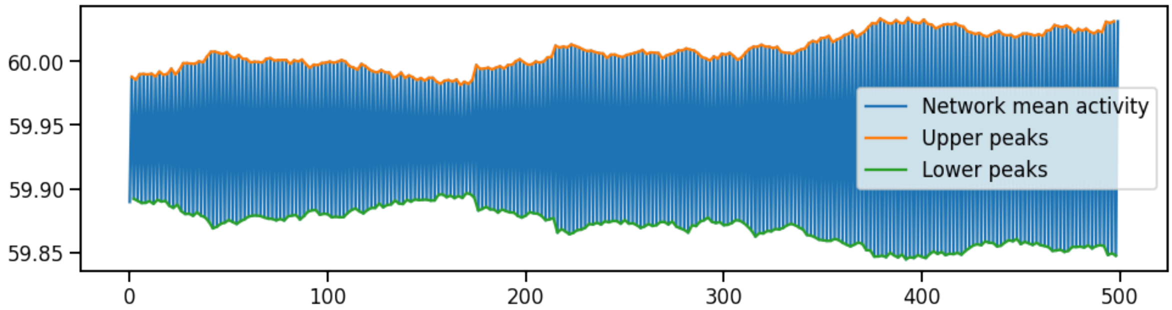
- Note in the figure above that the neuron activity is no longer discrete, owing to the electrical coupling interaction with its neighbors; now it is continuous.
  - Here, the activity is bounded between 0 and 120. You can no longer check if the activity is equal to a threshold.
  - Remember never to compare if two floats are equal. Instead, you want to check if the activity is within an interval, for example, between L and $2L$.
- **(10%) Build a 30x30 grid** of neurons (check the notebook game of life):
- Implement **3 types of neiborhoods**:
  - (Left) 2 nearest neighbors: 1 at left, 1 at right, with close conditions is simple (check small-world networkx).
  - (Center) 4 nearest neighbors: 1 left, 1 right, 1 up, 1 down, see https://en.wikipedia.org/wiki/Von_Neumann_neighborhood
  - (Right) 8 nearest neighbors: See https://en.wikipedia.org/wiki/Moore_neighborhood.
  - If you only implement 1 part, anticipate receiving 1/3 of the score from this point onward.



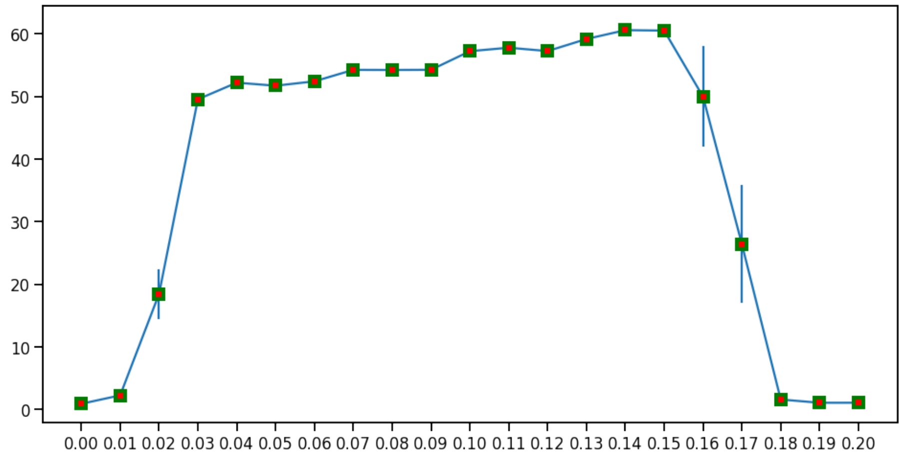
- The result of a simulation is as follows:



- **(10%)** Measure the global (mean) activity of the network in time $a_{Net} = \sum_i a_i/n$, where n is the number of neurons in the network:
  - Find minimum (lower/green) and maximum (upper/orange) peaks of a_{Net}.
    - Peak-to-peak amplitude, see: https://en.wikipedia.org/wiki/Amplitude
    - You can use find_peaks from scipy.signal.
    - Be careful, not always you will get the green and orange curves with the same length.
      - Solve this problem before going to the next step.



- Measure the average difference between peaks $\langle$orange curve $-$ green curve$\rangle$.
- **This is a global measure of the network behavior.** That is, the figure above is summarized in this single value ().
- **(10%)** Evaluate for different values of $g \in \{0.01, 0.02, \ldots, 0.20\}$. This is the x-axis, of the figure below. The y-axis corresponds to the mean peak-to-peak amplitude of the neural mean activity a_{Net}.
  - Below is the result for a grid network with Von Neumann neighborhood.
  - Check the results for **the 3 types of neighborhood (see the three grid structures above)**.
    - The values tested for g may vary for each type of neighborhood.
    - A number of 10 simulations were performed for each value of g, note the error bars.



- The figure above is a summary result, a phase transition occurs for g, the plateau in the figure above.
  - Study the simulations to discuss the figure above.
- **(40%) You must answer what is happening in the network.**
  - What is the behaviour you observe.
  - Run individual simulations of the grid network to interprete what you are seeing in the different regios of the phase transition above.
    - Check individual simulations examples: https://github.com/marsgr6/r-scripts/tree/master/vids
    - Here you want to observe some animations to understand what is happening, check https://github.com/marsgr6/r-scripts/blob/master/notebooks/game_of_life.py

Sources and resources:

- Stochastic Networks with Subthreshold Oscillations and Spiking Activity: https://link.springer.com/chapter/10.1007/3-540-44868-3_5
- Pdf file: https://github.com/marsgr6/r-scripts/blob/master/papers/castellanos2003.pdf

Deliver:

- **A report detailing your process and discussion of the results.**
- A notebook with results and notes (include .ipynb and .html files).
- A script with execution instructions (for the animation).

General recommendations

- (**-1 pts**) Specify the group members in the first cell of the notebook.
    - **Give an itemized list**: each member in a line.
- (**-1 pts**) Deliver a zip folder with the following name format:
    - **Final_Project_MS202320_II1II2II3[...].zip**: with **three files**: pdf, html and ipynb.
        - **Example:**
        - If the group members names are Jesus Nazareno and Maria Magdalena the file should be **Final_Project_MS202320_JNMM.zip**.
- (**-1 pts**) All members of the group should upload the file to the platform.
- The report (notebook) will be evaluated as:
    - **(-5 pts) Poor**: only code was delivered.
    - **(-4 pts) Fair**: commented code, with sections.
    - **(-2 pts) Good**: commented code, with sections and explanation of the each part of the process.
    - **(-0 pts) Excellent**: commented code, with sections and explanation of the each part of the process including formulas, research and explanation of what is being modeled.
    - Examples of items to research in order to build to your report:
        - What is computational neuroscience, models of spiking neurons, cellular automata, grid networks, small-world network. Syncornization, phase diagramas, to mention a few.
        - Again: **Research is an important part of your project report**, not just code.
    - Go to the first class slides. Identify input variables, output variables, type of model, what phases the model have, etc.