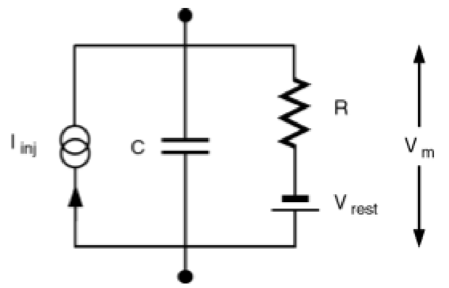
Solution 1: Integrate-and-fire neuron model

A. Constant spike rate

The model describes an Integrate-and-fire neuron, which is stimulated by an external current I_e. Such Integrate-and-fire neuron is modeled by an electrical circuit:



Caption:

- R = the resistance approximates the ion-transport over a channel
- C = the capacitor approximates the cell membran
- V_r or V_{rest} = the resting potential
- I_e = the external current to stimulate the neuron

So we can use the Kirchhoffs laws and the given equation.

1. Constant current

Using the constant current we make the following observations:

- The external current I_e charges the capacitor, so that the voltage increases up to an asymptotic value. The current determines the hight of the asymptote and also the slope.
- If $V_m > -54mV$, then the model creates a spike. The voltage increases very rapidly and goes down to $V_{reset} = -80mV$ one time step later.
- The hight of a spike is hard coded in the model. So the strength of the current determines the speed of the increase and thus, the firing rate. Figure 1 shows a current of $I_e = 1.7$nA (left side) and $I_e = 2.5$nA (right side).
- If the current is to low $I_e < 1.7nA$ to get the voltage above V_{th}= -54mV, the model doesn't fire a spike.

Methodology:

- The differential eq. were solved with Euler's method ($h = \tau/10 = 1$).
- For a detailed description of the simulation program, please look into the source file *lsg1a.m*

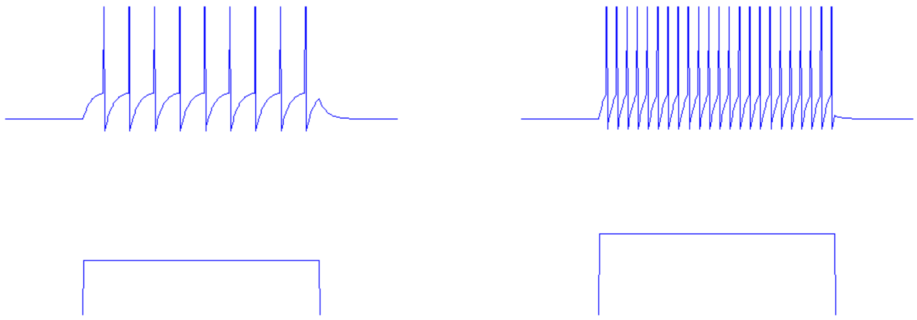


Figure 1: Spikes using constant currents $I_e = 1.7nA$ and $I_e = 2.5nA$

2. Variable current (from makeie.m)

The file *makeie.m* creates a variable current I_e for the neuron. This causes two effects (Fig. 2):

- Typically when the current is above 1.7nA, the membrane potential becomes sufficiently large ($V_m > -54$mV) to generate a spike.
- The hight of the current determines the firing rate (as explained before).

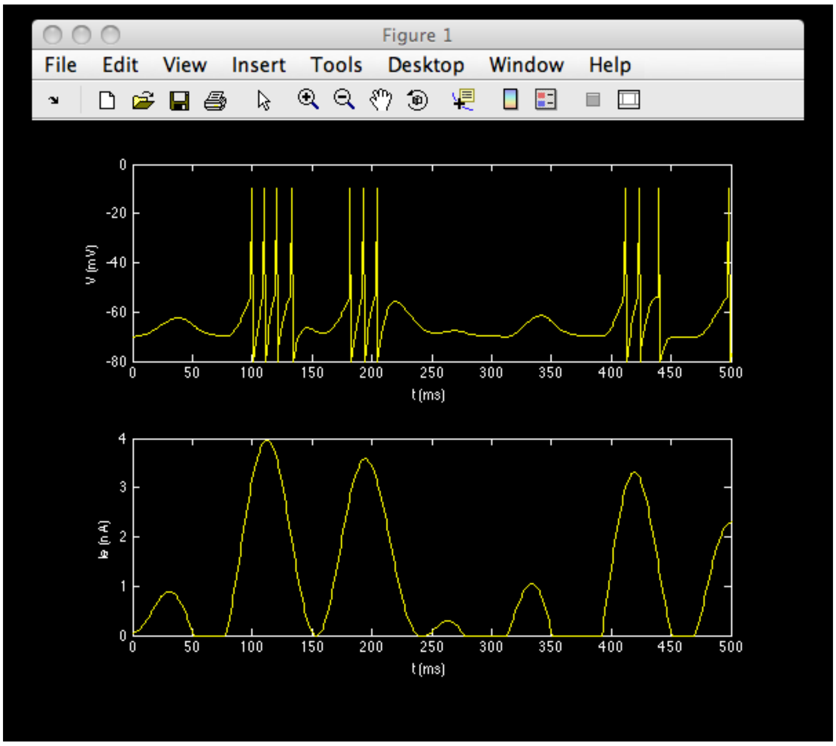


Figure 2: Spikes with variable current

B. Adaptive spike rate

The integrate-and-fire model has to be expanded with a method for spike rate adaption. So, we introduce an additional spike-rate-adaption conductance g_{sra}. g_{sra} increases at every spike with $\Delta g_{sra} = 0.06$ and decreases according to a differential equation. If the spikes follow each other closely, g_{sra} increases to higher values. This mechanism delayes the increase of the membrane potential V_m and so decreases the spike rate over time. Figure 3 shows the time-dependencies for the standard value of $\Delta g_{sra} = 0.06$ (left side) and for a better visualization value of $\Delta g_{sra} = 0.6$ (right side).

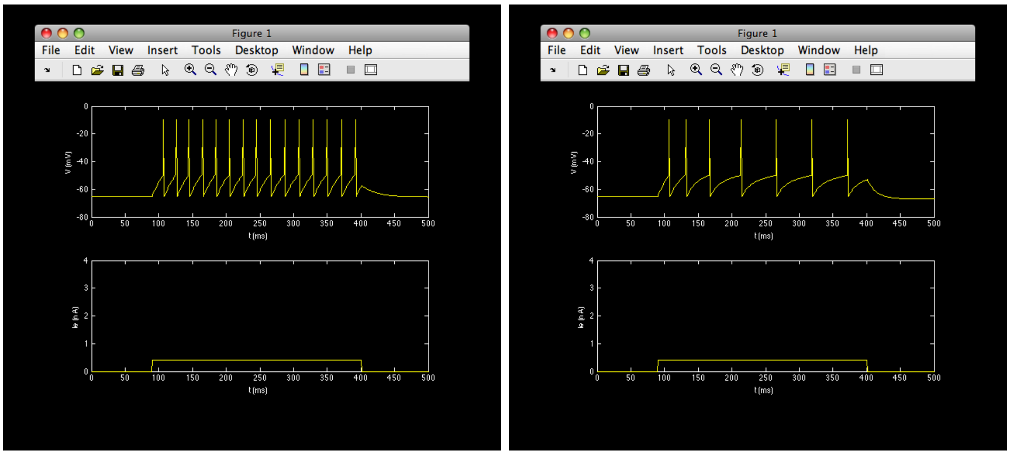


Figure 3: Adaptive spike rates

Methodology:

- The differential equations were solved with Euler's method, with $h = \tau/10 = 1$.
- For a detailed description of the simulation program, please look into the source file *lsg1b.m*.