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Models of Neural Systems I, WS 2007/08
Computer Practical 4

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Linear Membrane Models

Under normal physiological conditions the relation between the ion current flowing through a membrane I_i and the membrane potential V can be approximated by Ohm's law:

$$I_i = g_i(V - E_i), \tag{1}$$

where g_i is a conductance for a given ion and E_i is its reversal potential. In general the conductance can be time- and voltage-dependent. Here we will investigate how the membrane potential changes when subject to such a current flow.

Exercises

1. **Passive membrane**

   The following equation describes a passive membrane, which is subject to a current injection:

   $$\tau_m \frac{dV(t)}{dt} = -V(t) + E_m + R_m I(t) \tag{2}$$

   At time $t = 0$ membrane voltage is at rest $V(t = 0) = E_m$.

   (a) Build a model neuron from equation (**??**). Use $R_m = 10^7\,\Omega$, $I(t) = I_0 = 10^{-5}\,\text{mA}$, $\tau_m = 10\,\text{ms}$, $E = -80\,\text{mV}$. Using Euler method find $V(t)$ as a function of time.

   (b) Consider the following time-dependent current injection:

   $$I(t) = \begin{cases} 10^{-5}\,\text{mA} & \text{if } 100 \geq t \geq 10, \\ 0 & \text{otherwise.} \end{cases}$$

   Find a numerical solution for $V(t)$. Repeat the calculations for several values of the membrane time constant τ_m.

2. **Integrate-and-fire neuron** (Optional)

   Linear models are unable to produce realistic action potentials, but spikes can be simulated in such models with a simple reset mechanism.

   (a) Modify the Euler method so that every time when the membrane potential reaches the threshold $V_{th} = -54\,\mathrm{mV}$ a spike is generated and the potential is set to the value $V_{reset} = E_m$.

   (b) Using the integration with reset simulate the neuron from Exercise 1 with a constant current intensity I_0. Show the voltage traces for 500 ms. Compare the plots obtained with different stimulus intensities. How do you interpret the results?

3. **Synaptic current**

   Equation **??** can be also modified by including synaptic conductances in the membrane current:

$$\tau_m \frac{dV(t)}{dt} = -V(t) + E_m - r_m g_{syn}(t)(V - E_{syn}) \tag{3}$$

   where $g_{syn}(t)$ is a time-dependent conductance which can be approximated by:

$$g_{syn}(t) = \begin{cases} g_{max} t/\tau_{syn} \exp\left(-t/\tau_{syn}\right) & \text{if } t \geq 0, \\ 0 & \text{if } t < 0. \end{cases} \tag{4}$$

   Here take τ_{syn}=10 ms, $r_m = 1\,\Omega\mathrm{m}^2$, $g_{max} = 0.5\,\mathrm{S/m}^2$. Plot the following curves on one figure:

   - synaptic conductance $g_{syn}(t)$,
   - synaptic current $I_{syn}(t) = g_{syn}(t)(V - E_{syn})$, channel current $I_m(t) = 1/r_m(E_m - V(t))$ and their sum,
   - membrane potential $V(t)$.

   Consider inhibitory ($E_{syn} = -100\,\mathrm{mV}$) and excitatory ($E_{syn} = 0\,\mathrm{mV}$) synapses separately.

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