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Models of Neural Systems I, WS 2008/09
Project Assignment

Synchronization

Similarly to other oscillating systems, neurons can synchronize their activity and exhibit a behaviour which is not intrinsic to any individual neuron. Synchrony plays an important role in locomotion and may be involved in neural computation. In this project you will study synchronous spiking in a simple network of model neurons connected mutually with inhibitory and excitatory synapses.

First, consider two synapticaly coupled integrate-and-fire neurons governed by the following equations:

$$\tau_m \frac{dV_i}{dt} = E_\text{L} - V_i - r_m \bar{g}_s P_{s,i}(t)(V_i - E_s) + r_m I_e, \quad i = 1, 2, \tag{1}$$

where $P_{s,i}(t)$ describes the activation of the synapse. When the membrane potential crosses a threshold V_th a spike is generated and the potential is reset to V_reset.

One way to describe the effect of a presynaptic spike on the postsynaptic conductance is to increase the activation $P_{s,i}(t)$ by a so-called alpha function. If a cell $j \neq i$ fires a spike at time t_j:

$$P_{s,i}(t) \to P_{s,i}(t) + \frac{P_\text{max} t}{\tau_s} \exp(1 - (t - t_j)/\tau_s). \tag{2}$$

In order to study synchronization between the two neurons, one can calculate the phase difference between the spikes. Suppose that both neurons fire periodically at times t_1 and t_2 respectively then the phase difference is:

$$\Phi = 2\pi(t_1 - t_2)/T \mod 2\pi \tag{3}$$

Problems

1. Construct a model of two coupled integrate-and-fire neurons obeying the equation (1) with $E_\text{L} = -70\,\text{mV}$, $V_\text{th} = -54\,\text{mV}$, $V_\text{reset} = -80\,\text{mV}$, $\tau_m = 20\,\text{ms}$, $r_m \bar{g}_s = 0.15$ and $r_m I_e = 18\,\text{mV}$. Both synapses should be described by the equation (2) with $P_\text{max} = 0.5$ and $\tau_s = 10\,\text{ms}$.

2. Simulate the model by setting different initial conditions to both neurons and running the simulation until a stable firing pattern is reached. What is the final value of Φ. Repeat the simulation using a few different random initial conditions.

3. Show how the pattern of firing for the network depends on the type (excitatory or inhibitory) connections. You can change the connection type by choosing positive or negative value of g_s.

4. Investigate the effect of the synapse time constant t_s on the phase difference Φ. Find out for which value of t_s the bifurcation occurs. Plot the bifurcation diagram.

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