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Models of Neural Systems I, WS 2007/08
Project Assignment

To hand in on Feb 11th 2008

Bursting

Many neurons can produce brief trains of spikes interspersed with long quiescent periods. This phenomenon called bursting was found in many brain areas such as thalamus and cortex and may play an important role in information transmission and encoding.
The aim of the project is to study burst generation in pancreatic β-cells. The membrane dynamics of the cells can be described by a simplified system of 3 differential equations:

$$C_m \frac{dV}{dt} = -I_{\mathrm{Ca}}(V) - \left(\bar{g}_{\mathrm{K}} n^4 + \frac{\bar{g}_{\mathrm{K,Ca}} c}{K_d + c}\right)(V - V_{\mathrm{K}}) - \bar{g}_{\mathrm{L}}(V - V_{\mathrm{L}}), \tag{1}$$

$$\tau_n(V)\frac{dn}{dt} = n_\infty(V) - n, \tag{2}$$

$$\frac{dc}{dt} = f(-k_1 I_{\mathrm{Ca}}(V) - k_c c), \tag{3}$$

where V is a membrane potential, n is a Hodgkin-Huxley type activation variable and c is a slow variable describing the intracellular concentration of calcium.
The Ca^{2+}current flows through a voltage-gated channel and thus:

$$I_{\mathrm{Ca}}(V) = \bar{g}_{\mathrm{Ca}} m_\infty^3(V) h_\infty(V)(V - V_{\mathrm{Ca}}) \tag{4}$$

The steady state activation and time constant of m and h variables are the same as in the Hodgkin-Huxley model, except that the voltage is shifted by $V^\star = -15\,\mathrm{mV}$ so that V is replaced by $V + V^\star$. Similarly, n satisfies Hodgkin-Huxley type differential equation, shifted along the voltage axis by an amount $V^+ = -35\,\mathrm{mV}$.
The remaining parameters of the model are: $C_m = 1\,\mu\mathrm{F/cm}^2$, $\bar{g}_{\mathrm{K}} = 5.5\,\mathrm{mS/cm}^2$, $\bar{g}_{\mathrm{L}} = 0.03\,\mathrm{mS/cm}^2$, $V_{\mathrm{Ca}} = 100\,\mathrm{mV}$, $K_d = 1\,\mu\mathrm{M}$, $k_1 = 0.0275\,\mu\mathrm{M\,cm}^2/\mathrm{nC}$, $\bar{g}_{\mathrm{K,Ca}} = 0.05\,\mathrm{mS/cm}^2$, $\bar{g}_{\mathrm{Ca}} = 8\,\mathrm{mS/cm}^2$, $V_{\mathrm{K}} = -75\,\mathrm{mV}$, $V_{\mathrm{L}} = -40\,\mathrm{mV}$, $f = 0.007$, $k_c = 0.02\,\mathrm{ms}^{-1}$.

Problems

1. Simulate the model of a pancreatic β-cell given by equations (**??**)-(**??**). Show the bursting phenomenon.

2. Plot the histogram of interspike intervals (ISI). Find the modes of the histogram relating to within burst intervals (WBI) and interburst intervals (IBI). Plot the WBI lengths as the function of the spike position in the burst.

3. Treating c as a constant parameter, consider the phase-plane structure of fast subsystem consisting of equations (**??**)-(**??**). Try to find the values of parameter c for which a stable point and a limit cycle exists.

4. Plot the bifurcation diagram of the fast subsystem varying parameter c. Plot the stable/unstable fixed points and stable limit cycles. Identify the bifurcation points.

5. Plot the nullcline of the slow variable on the bifurcation diagram. Can you explain the mechanism of the bursting using the diagram? Superimpose a (V, c)-projection of a burst cycle on the plot.

6. Using the bifurcation diagram predict which values of the k_c parameter will lead to bursting.

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