Dynamic Models in Biology, Computer Lab:

Action potential propagation

Propagation of action potentials underlie excitation along neurons, along skeletal muscle fibers, and throughout the heart. In this lab, you will investigate action potential propagation in a 1-dimensional spatial system.

Model

The action potential model used in this exercise is a generic neuronal-like model called the Morris-Lecar model. (The model was originally developed to mimic excitability in barnacle muscle). The model is implemented in the program `Morris_Lecar_cable.m`.

The model consists of a depolarizing Ca^{2+}-current and a repolarizing K^{+}-current. The model equations are

$$\frac{\partial V}{\partial t} = D\frac{\partial^2 V}{\partial x^2} + \frac{1}{C}\left(g_{Ca} m_\infty \left(E_{Ca} - V\right) + g_K w \left(E_K - V\right) + g_{leak}\left(E_{leak} - V\right)\right)$$

$$\frac{dw}{dt} = \frac{w_\infty - w}{\tau_w},$$

i.e., a reaction-diffusion system. Parameter values and the functions m_∞ and w_∞ are defined in the `Morris_Lecar_cable.m` file.

Baseline run

Simulate the system using the baseline parameter values. Note that the action potential was triggered by a narrowly peaked voltage pulse.

Excitability and propagation

Explore the dependence on initial conditions by simulating from initial voltage pulses of different amplitudes. Confirm that as long as the initial pulse triggers an action potential, the long-term shape of the action potential profile and the speed at which it propagates are independent of the initial condition. (Suggestion: estimate wave speed from the space-time plot in figure 1 by viewing it top down using the `view(2)` command.)

What is the minimum amplitude required to generate a propagating AP when the pulse is applied over the first 1 cm (i.e., `x_on` = 1 cm)? What is the minimum amplitude required to generate an AP in the un-coupled Morris-Lecar model? (Hint: this is the same value as that required to generate an AP by a pulse applied to all grid points along the cable). Why is a larger pulse amplitude required when delivered over a smaller region?

Wave speed and conductivity
How would you expect the wave speed to change if the diffusion coefficient D is increased? Verify your conjecture via simulation.

Wave speed and ionic conductances
Do you think an increase in one of the ionic conductances g_{Ca} or g_K could increase the wave speed? Run simulations to verify your expectations.

Two propagating APs
Modify `Morris_Lecar_cable.m` so that two action potentials are initiated — one from each end of the cable. What happens when the two action potentials collide? (You may need to increase the simulation time to see this.)