Equations for EPSP and IPSP model

The equations used in the EPSP and IPSP model are based off of Kohn and Worgotter's 1998 (kohn 1998) paper for employing a Z-transform to optimize the calculating of the synaptic conductance. The equation is designed for a NMDA synapse but has been adapted for both excitatory and inhibitory synapses. The computation of the model is based on one equation in the paper, equation 2.11. The model is broken up into two parts; the first part is to establish constants needed to compute the equation and the second is for the equation itself.

The constants only need to be establish once as long as the rise and fall times remain constant. The equations for the parameters c1,c2 and c3 are:

$$c1=\left[\frac{f\left(\tau_r,\tau_f\right)}{\tau_f-\tau_r}\right]\left[e^{\frac{-dt}{\tau_f}}-e^{\frac{-dt}{\tau_r}}\right] \quad (1.1)$$

where, taur is the rise time and tauf is the fall time. f(x,y) is a constant to represent the area under the conductance curve. In this model it is computed by the following equations:

$$max=\frac{\tau_f\tau_r}{\left(\tau_r-\tau_f\right)}\log\left(\frac{\tau_r}{\tau_f}\right) \quad (1.1a)$$

$$f\left(\tau_r,\tau_f\right)=\left(\tau_f-\tau_r\right)\left[\frac{1}{e^{\frac{-max}{\tau_f}}-e^{\frac{-max}{\tau_r}}}\right] \quad (1.1b)$$

The equations 1.1a and 1.1b do not work if taur and tauf are the same values. In the model if they are the same values a small value of 0.001 is added to the taur constant.

$$c2=e^{\frac{-dt}{\tau_f}}+e^{\frac{-dt}{\tau_r}} \quad (1.2)$$

$$c3=e^{\frac{-dt}{\tau_f}}e^{\frac{-dt}{\tau_r}} \quad (1.3)$$

The equation for the conductance is:

$$g_t=c1Ws_t+c2g_{t-1}+c3g_{t-2} \quad (2)$$

where, s is the input current at time t. In this model the input current is setup as a voltage clamp to represent a spike. The voltage clamp is set on for 1 millisecond and off the rest of the time. There are two different g (g^E,g^I) values to represent the epsp and ipsp. A spiking model should use separate conductances for each input. W is a weighted term that is can be adjusted in the model. It is a term that is often used by computational models to represent the synaptic efficacy. It can be thought of as the number of connections, the amount of ions released into the synaptic cleft or the distance the presynaptic connection on the dendrite from the soma. The weighted term is easier to monitor and it save computational time and complexity in the model. In the model the weights are multiplied by 0.001 to adjust the area under the curve of the voltage clamp to a more plausible spiking voltage. The weights for the EPSP and IPSP can be adjusted in the model.

The EPSP and IPSP are the current of each input in the postsynaptic cell. The equations for producing the EPSP and IPSP are:

$$EPSP = g^E (50 - V) \quad (3)$$

$$IPSP = g^I (-75 - V) \quad (4)$$

where 50 and -75 are constants to represent the membrane potentials of EPSPs and IPSPs. The currents are subjective to the is voltage membrane (V) of the postsynaptic cell. The voltage membrane changes and requires a spiking model to establish the voltage membrane based on the summations of all EPSPs and IPSPs at the axon hillock. For this model the Izhikevich spiking model (Izhikevich 2001) is used. The spiking neuron is computed by the equation:

$$\frac{v}{dt} = 0.04\mathrm{v}^2 + 5\mathrm{v} + 140 - u + [EPSP + IPSP] \quad (5.1)$$

$$\frac{u}{dt} = 0.02(0.2\mathrm{v} - u) \quad (5.2)$$

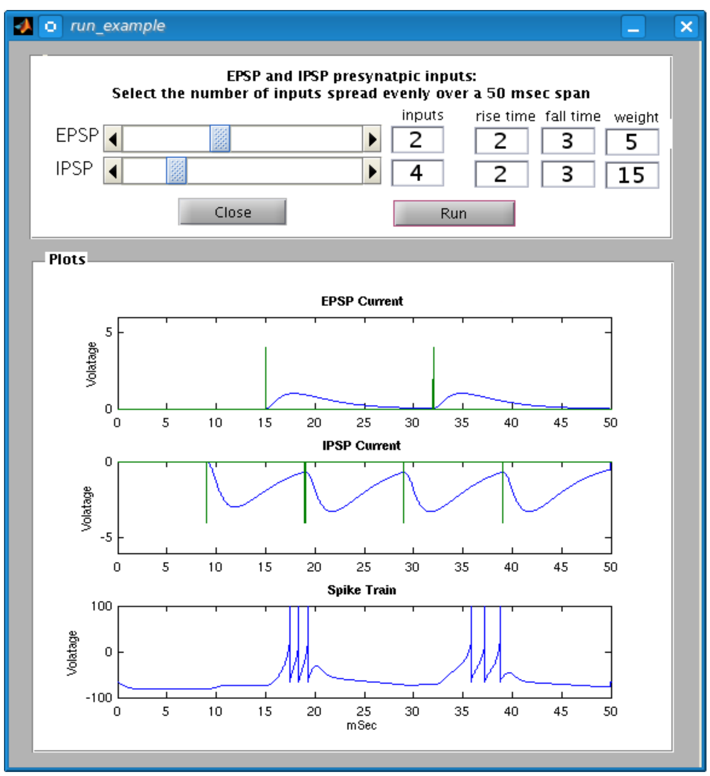

figure 1

The model produces three outputs. The EPSP current, the IPSP current and spiking voltage. Figure 1 shows the three outputs given 4 EPSP and 2 IPSP inputs. The green bars show the initiation of the voltage clamp. The voltage will increase to the cell's threshold and reset. The actual spike is not displayed.

Izhikevich, EM (2001). Resonate-and-fire neurons. Neural Networks 14: 883-894.

Kohn, J and Worgotter, F (1998). Employing the Z-transform to Optimize the calculation of the synaptic conductance of NMDA and other synaptic channels in network simulations. Neural Computation 10: 1639-1651.