Tutorial 5.3: bistability and oscillations from two LIF neurons

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Part A: bistability with no synaptic depression

(i) - (ii) code: ‘tutorial5_3_parta.m’

Figure 1 below shows the plot of membrane potential against time and the synaptic gating variables against time for two, coupled neurons. Cell 1 had 3nA of current applied for the first 100ms before switching back to its baseline current of 2nA. Cell 2 had 3nA of applied current for 100ms after 3 seconds, but had a baseline current of 2nA everywhere else. It becomes evident that no oscillations are observed in the plot of the synaptic gating variable against time during the application of extra current pulse, while consistent, high-frequency oscillations are observed everywhere else. The plots of the membrane potential against time for the two cells show high-frequency oscillations of consistent frequencies, except during the time when extra current pulse is applied, during which the frequency of oscillations increases drastically. The increased frequency is evident from the plot looking much darker, like a dark bar, during the 100ms period when extra current was applied. This period of increased oscillations represents advancement in phase (a positive phase response) as a result of the voltage-dependent activation of calcium and potassium channels.

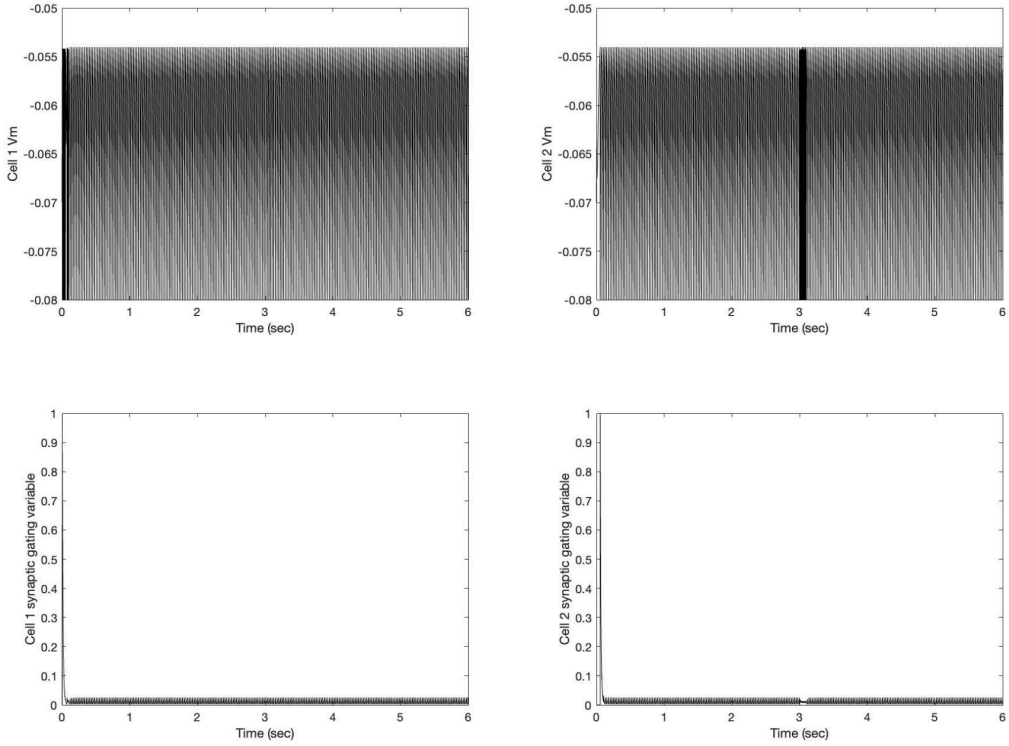


Figure 1: Membrane potentials and synaptic gating variables across time for a 6-second simulation of two coupled neurons, with 3nA of applied current injected to Cell 1 for the first 100ms and a pulse of 3nA applied to Cell 2 at the midpoint of the simulation. No noise was added.

(iii) code: ‘tutorial5_3_partaiii.m’
Figure 2 below shows the plot of membrane potential against time and the synaptic gating variables against time for two, coupled neurons, with the same conditions as used in part i to ii, but with noise added and no additional current added. The level of noise was specified as σ = $50pA.\ s^{-1/2}$. The both types of plots look more jagged, with the spikes having more variability in amplitudes.

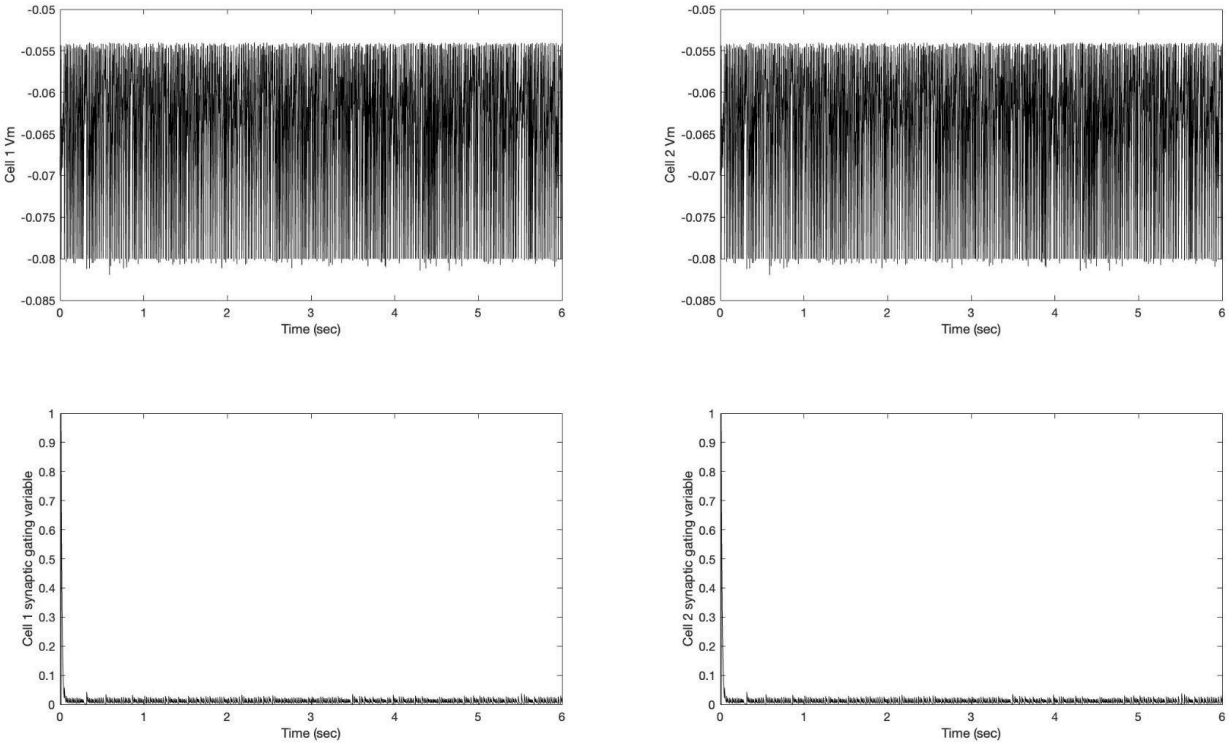


Figure 2: plots of membrane potential against time and the synaptic gating variables against time for two, coupled neurons, with the same conditions as used in part i to ii, but with noise added and no additional current added.

iv) code: ‘tutorial5_3_aiv.m’
The simulation from part (iii) ran for 13 seconds, which produced 1373 switches in states.

The plot of the membrane voltage and synaptic gating variables against time (Figure 3) closely resemble those from part (iii), though this one goes for a much longer period of time.

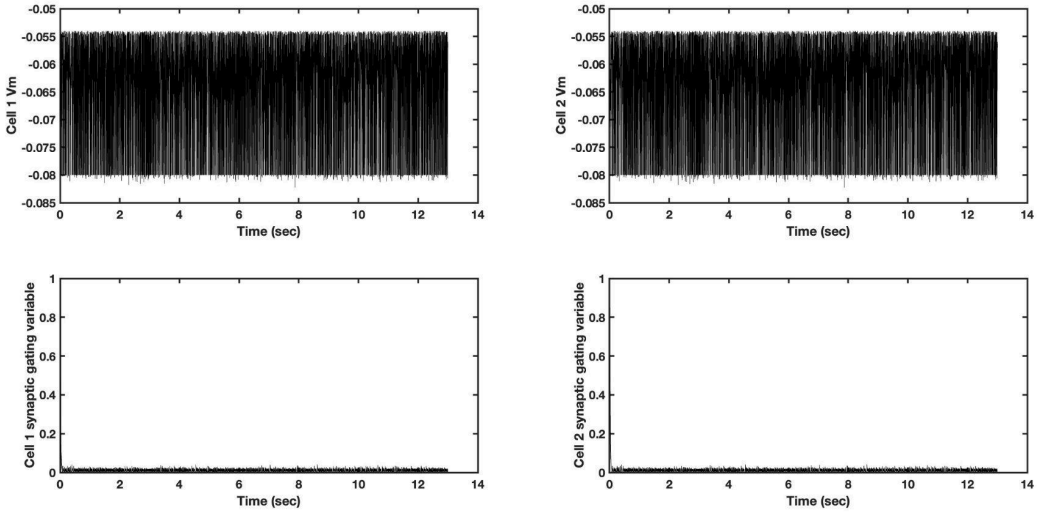
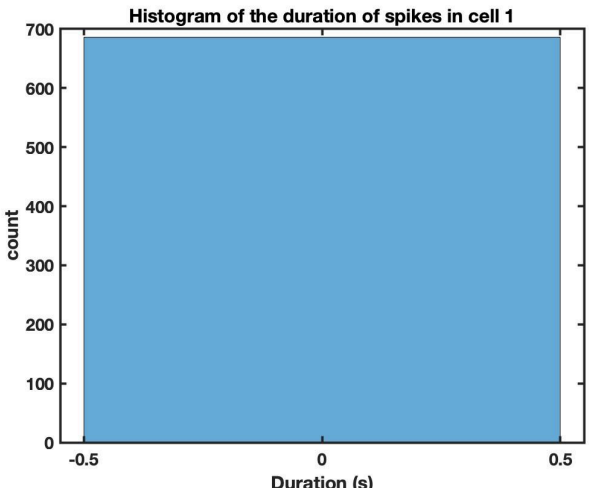


Figure 3: membrane voltages and synaptic gating variable values against time for cells 1 and 2 during a 13-second simulation.

Figure 4 and 5 below show the histogram of the duration in each activity state. It becomes evident that all of the spikes in cell 1 last between 0 and 0.5 seconds, while spikes in cell 2 follow a right-skewed distribution with a mode of around 0.015 seconds. Since cell 1 is almost never firing, it shows that the inhibition is strong enough that cell 2 suppresses all activity of cell 1 and cell2 becomes the only cell that could fire. When no noise was added to this model, all state durations in cell 2 are identical at a very small value, which reflects how the neuron always spikes at each dt regardless of the membrane potential values before that time. However, when noise is added, the distribution of the duration of spikes become wider and right-skewed as variable noise changes the membrane potential at each dt and increases the likelihood that the membrane voltage becomes sufficiently high enough for a spike to be generated in the next dt. Smaller state durations are observed more than higher state durations because the cell is more likely to switch states faster than it is to change states at a slow rate.



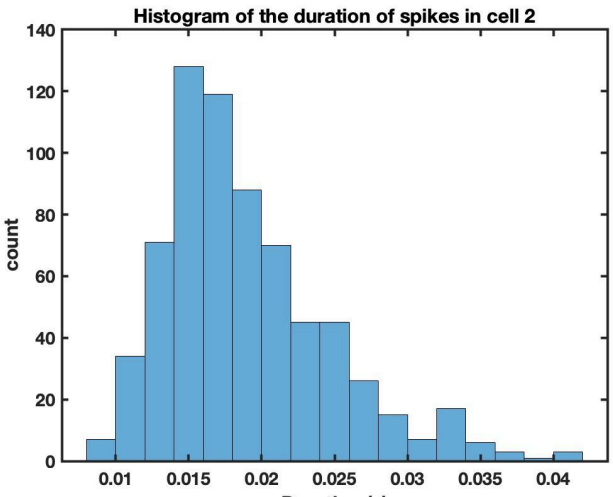


Figure 4(left) and 5 (right): histogram of the duration in each state for cell 1 and cell 2 respectively.

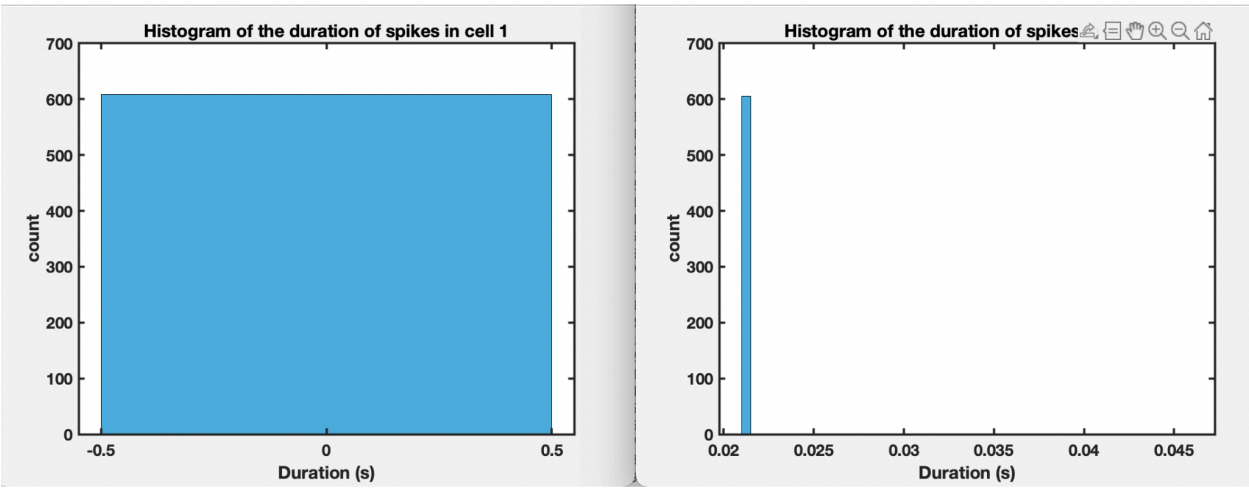
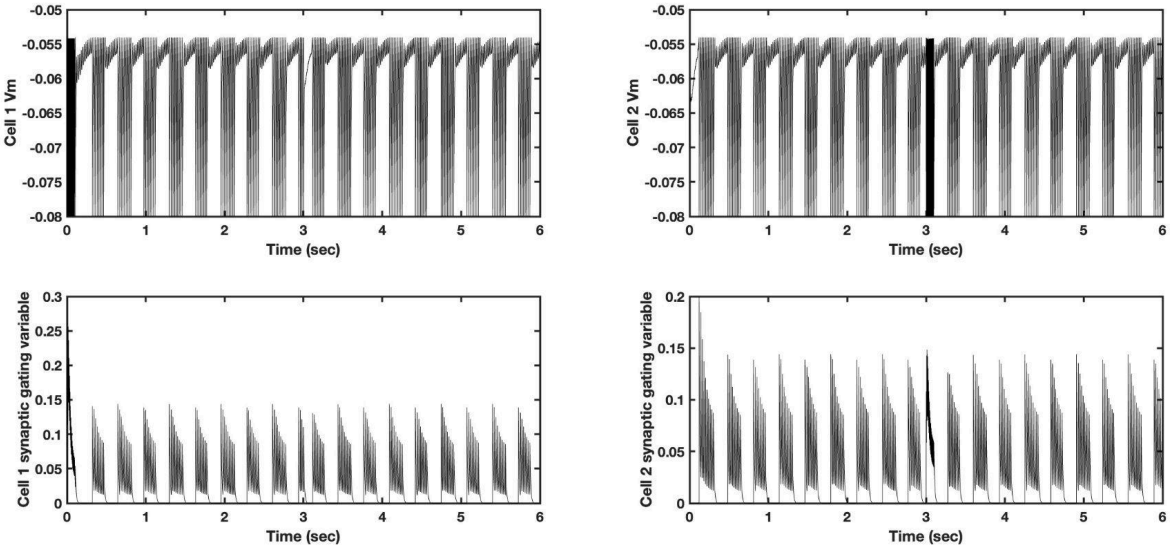


Figure 4.5 (left) and Figure 5.5 (right): histogram of the duration in each state for cell 1 and cell 2 respectively when no noise was added.

Part B:

v) code: tutorial5_3_partbv.m

The figure below shows the plots of membrane potential and synaptic gating variables against time for cells 1 and 2, which have synaptic depression with time constant for recovery of 0.2 seconds. The plots of the membrane potentials show that there is a high-frequency burst of oscillations when current pulse is applied, but otherwise follows a regular series of oscillations where each set of oscillations that extend from -0.08 to -0.055mV is followed by a period of oscillations of a much smaller amplitude, whose baseline gradually goes up from -0.058 to -0.055mV. The plots of the synaptic gating variables show a series of regularly-spaced bursts whose oscillations decay in amplitude from 0.15 to 0.09. Each burst is followed by a brief period of no activity, and when extra current is applied, the variability in amplitude of the oscillations become much smaller. The periods of inactivity in the synaptic gating variables and the periods of oscillations of reduced amplitude in the membrane potential indicate periods where the neuron is inhibited by its coupled neuron, during which its activity is suppressed.



vi)code: tutorial5_3_bvi.m

Figure 7 below shows the plots of membrane potentials and the synaptic gating variables against time when a noise level of sigma = 5pAs$^{-½}$ has been added, with other factors being kept the same from part iv. The plots do not look significantly different from the plots obtained in iv. 1221 switches in activity states were observed during the 13-second simulation period, which is markedly reduced from the number of transitions observed without synaptic depression. Also, when one cell is receiving extra current and is having oscillations of a higher-frequency, its coupled cell has a period of no oscillating activity. This is evident from the lack of oscillations at the 3-second mark for Cell 1 and during the first 100ms of Cell 2. It becomes evident that all of the oscillations in cell 1 last between 0 and 0.5 seconds, while oscillations in cell 2 follow a unimodal, Gaussian distribution with a mode of around 0.22 seconds. Since cell 1 is almost never firing, it shows that the inhibition is strong enough that cell 2 suppresses all activity of cell 1 and cell2 becomes the only cell that could fire. The distribution of state durations for cell 2 is not skewed, unlike in part iv when synaptic depression was not present. The gaussian distribution of the state durations reflect how synaptic inhibition causes more spikes to stay in a particular state for a longer period of time when it is inhibited, and shifts the mode duration to be around the middle of the range of possible durations.

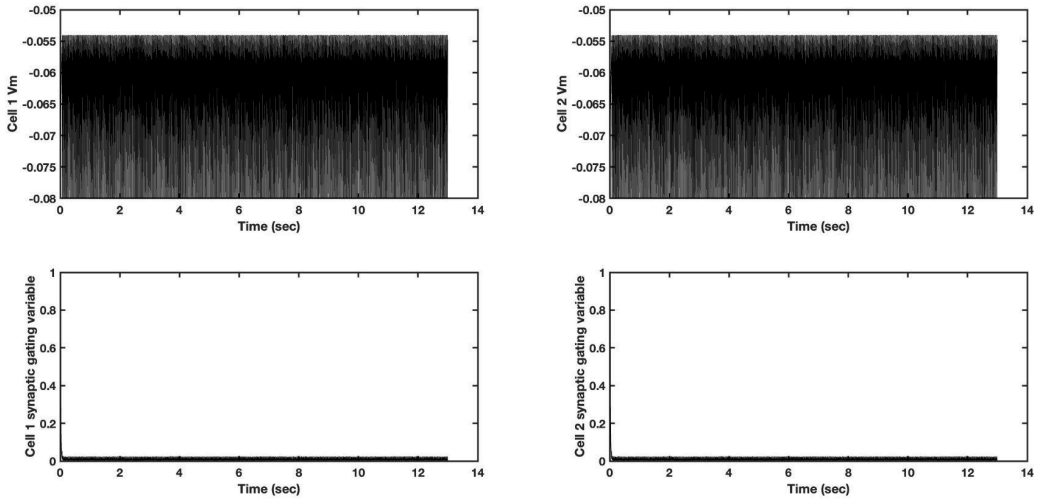


Figure 7: plots of membrane potentials and the synaptic gating variables against time when a noise level of sigma = $5pAs^{-½}$ has been added.

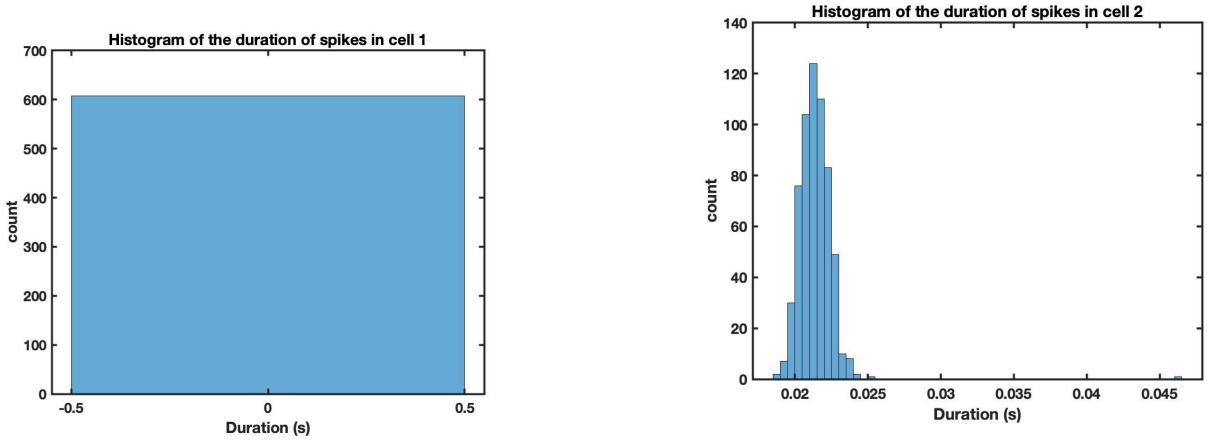


Figure 8 (left) and Figure 9 (right): histogram of the distribution of state durations for each cell when synaptic depression was applied.