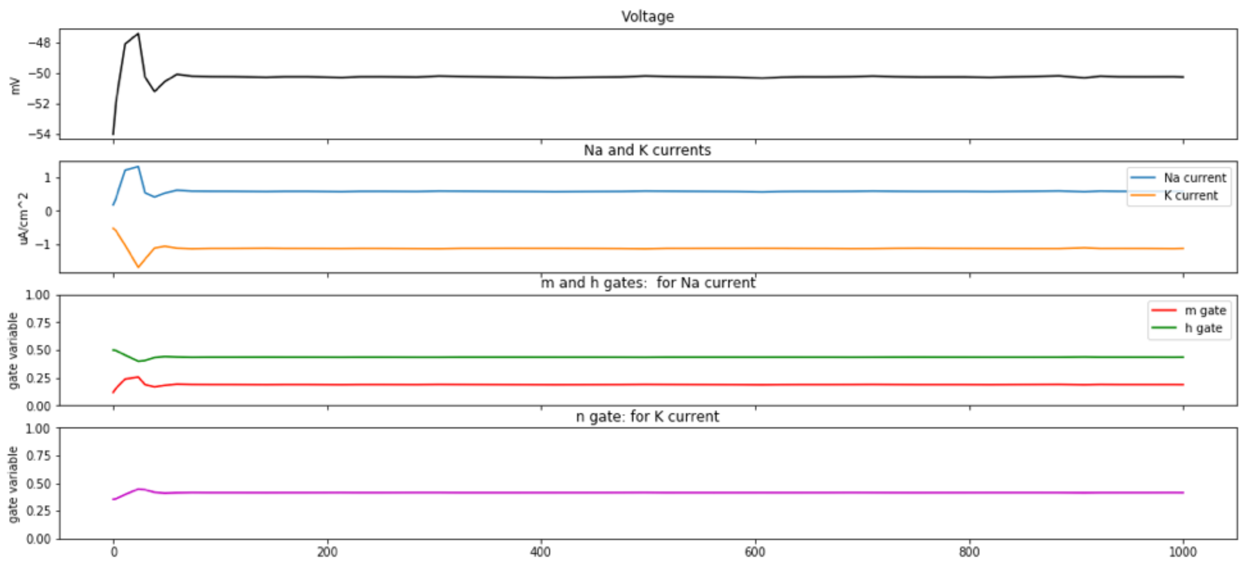
Part A)

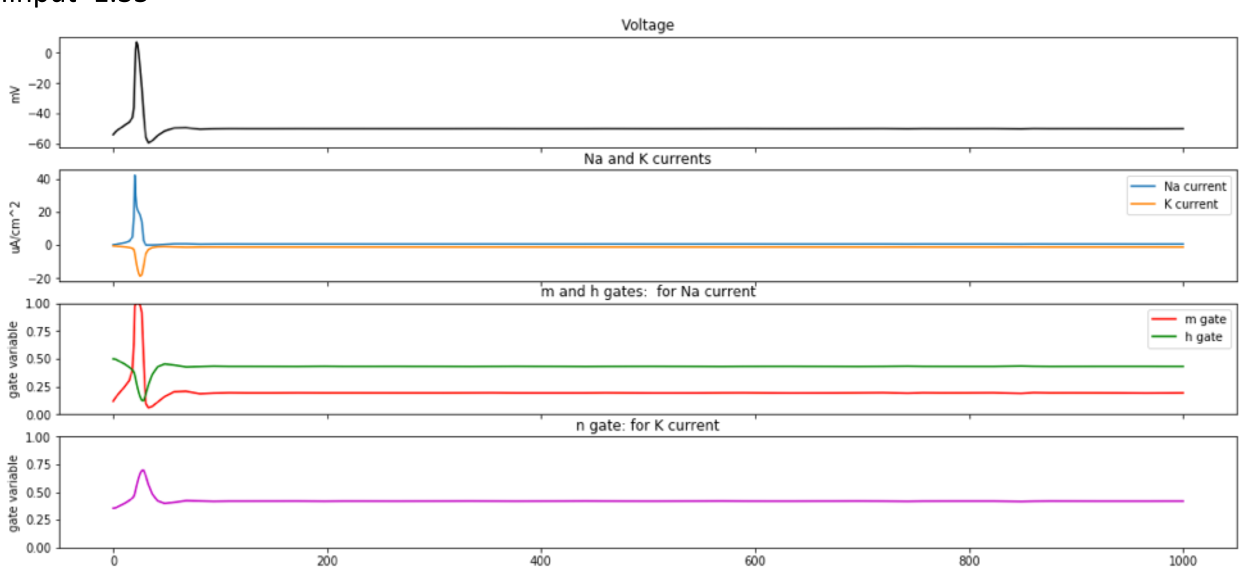
Parameter set 1

At Iinput~=1.35, it begins to fire a spike. But it only fires a single spike

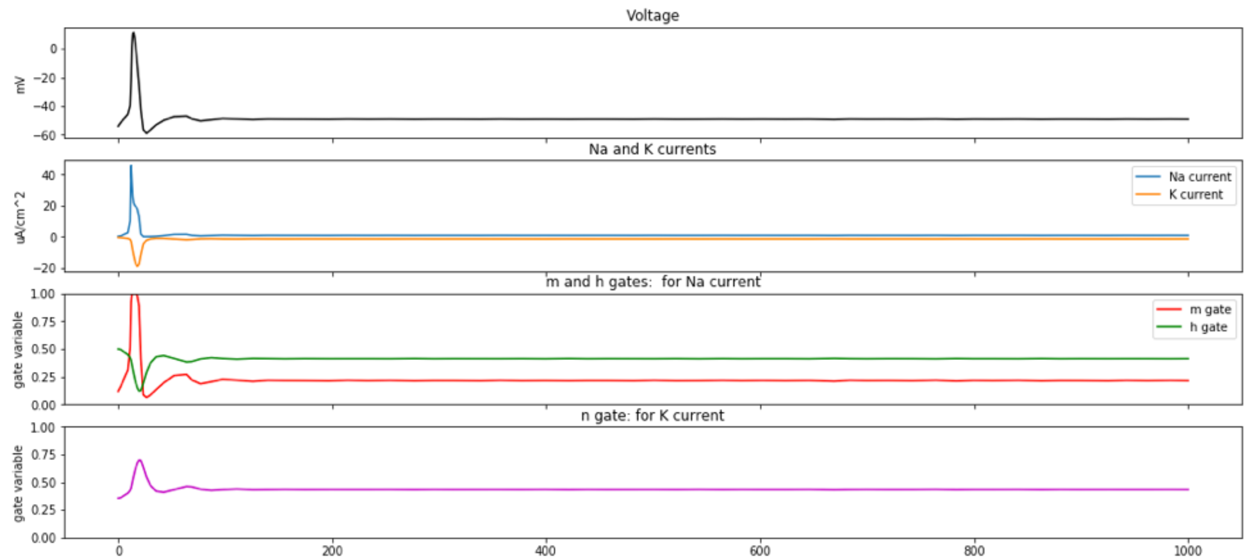
Iinput=1.30



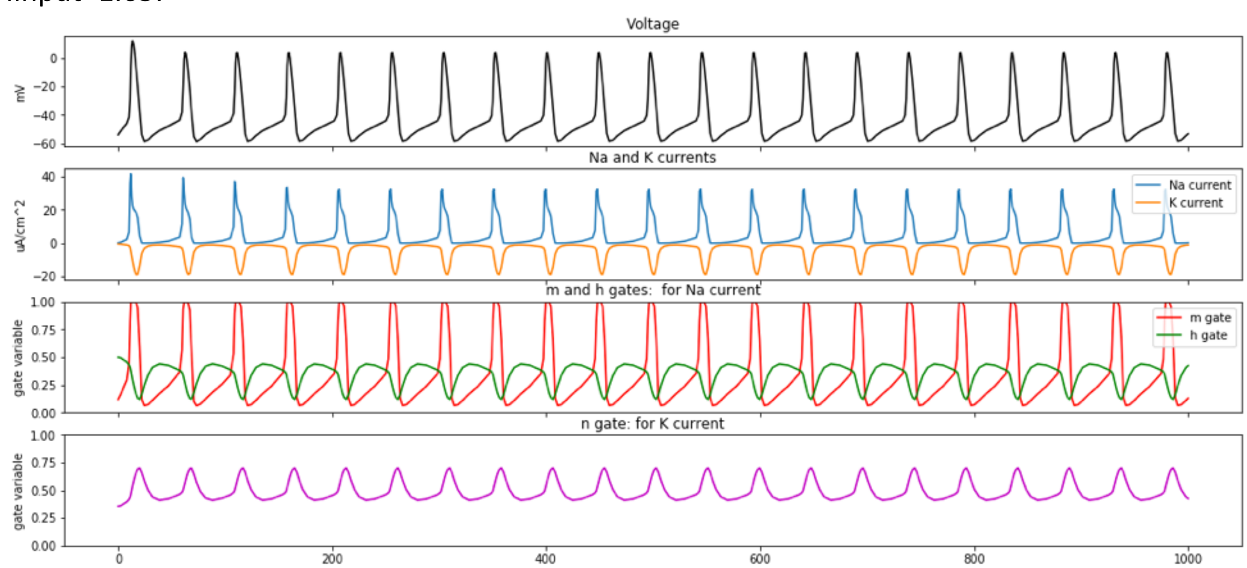
Iinput=1.35



Then, at Iinput=1.65, it starts to spike rapidly
Iinput=1.60:

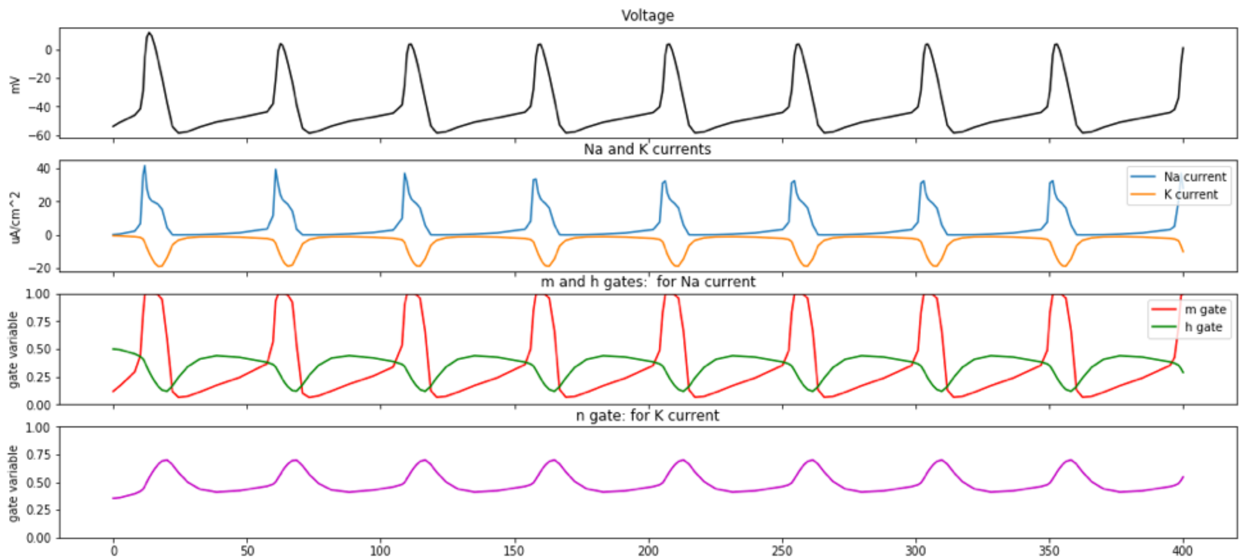


Iinput=1.65:

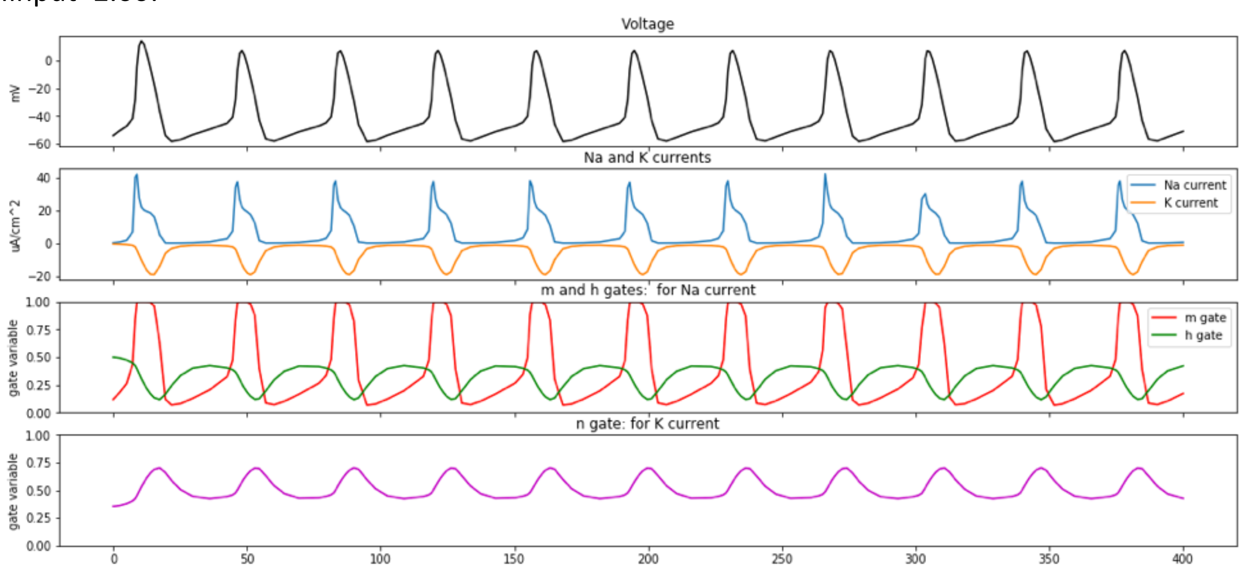


After this, the neuron only changes its response weakly to changes in input current. It does increase firing rate though:

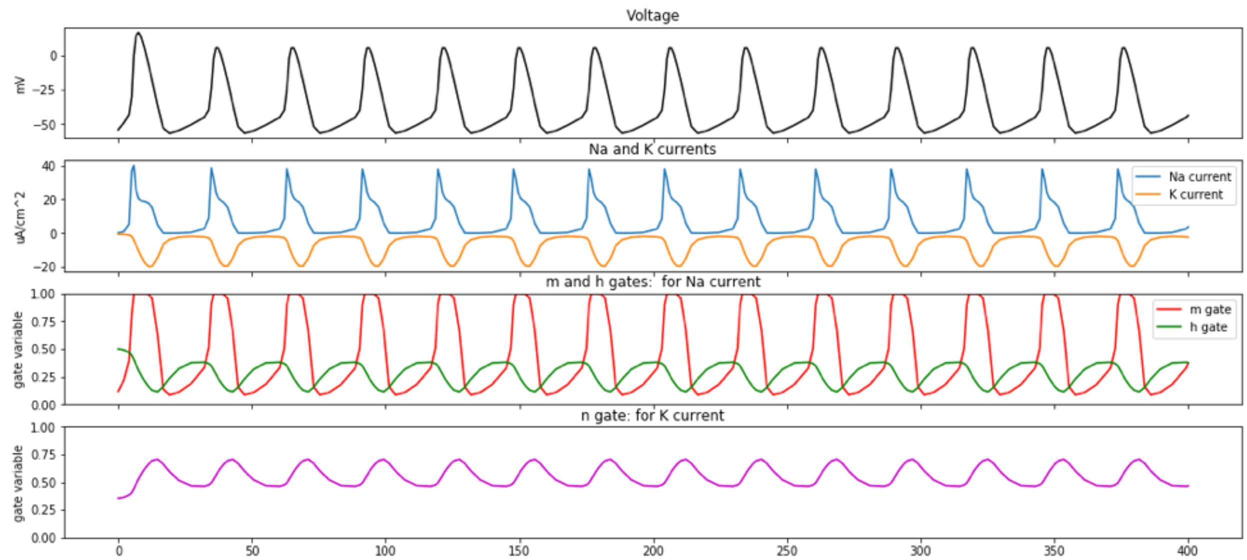
Iinput=1.65 (change simtime to only be 400 msec):



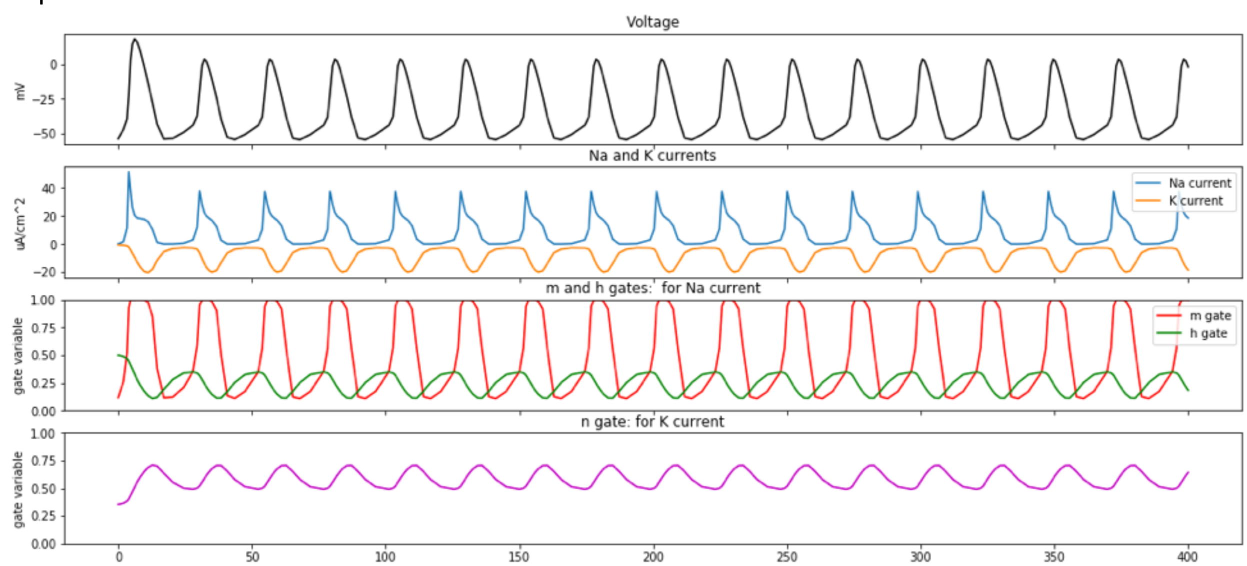
Iinput=2.00:



Iinput=3.00:

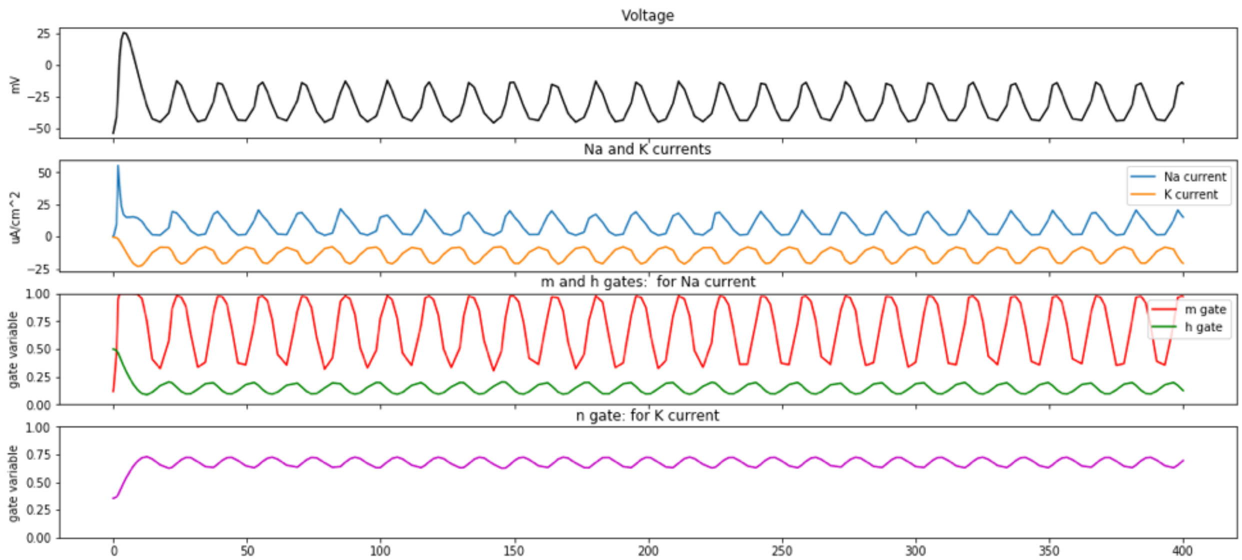


Iinput=4.00:

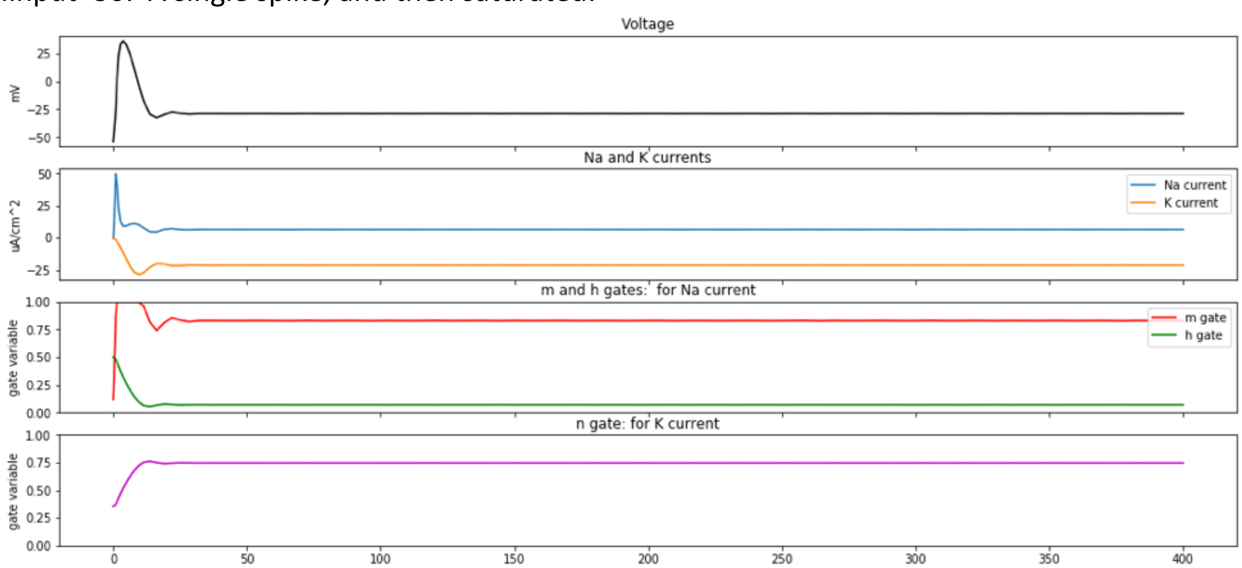


At very high values, the amplitude of the voltage spikes starts decreasing, until eventually it just saturates and doesn't spike

Iinput=10. Are these spikes, are subthreshold oscillations?



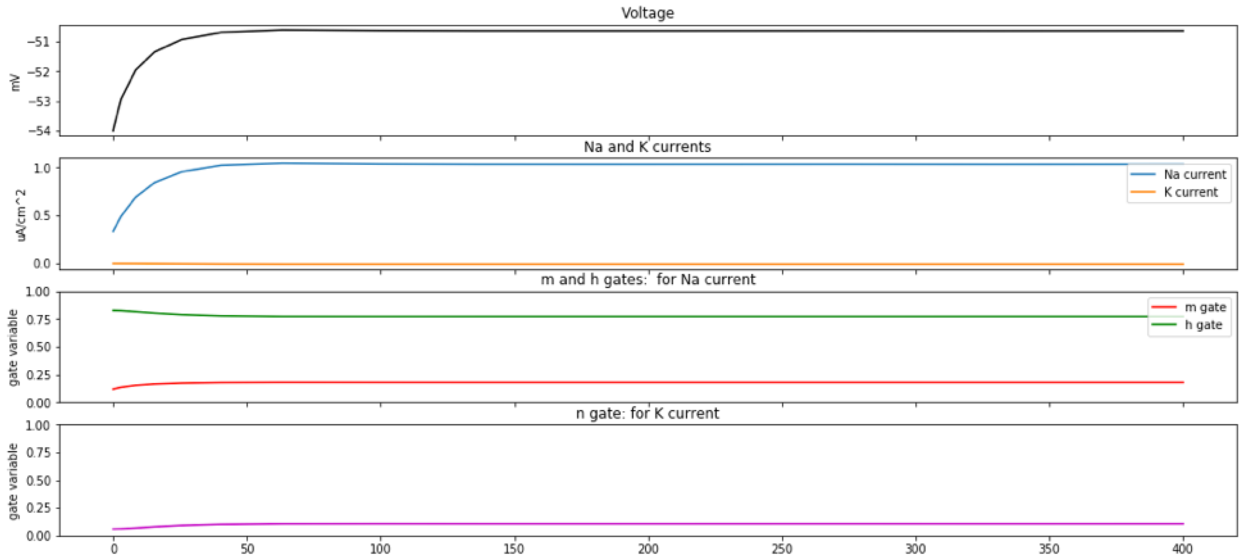
Iinput=30. A single spike, and then saturated:



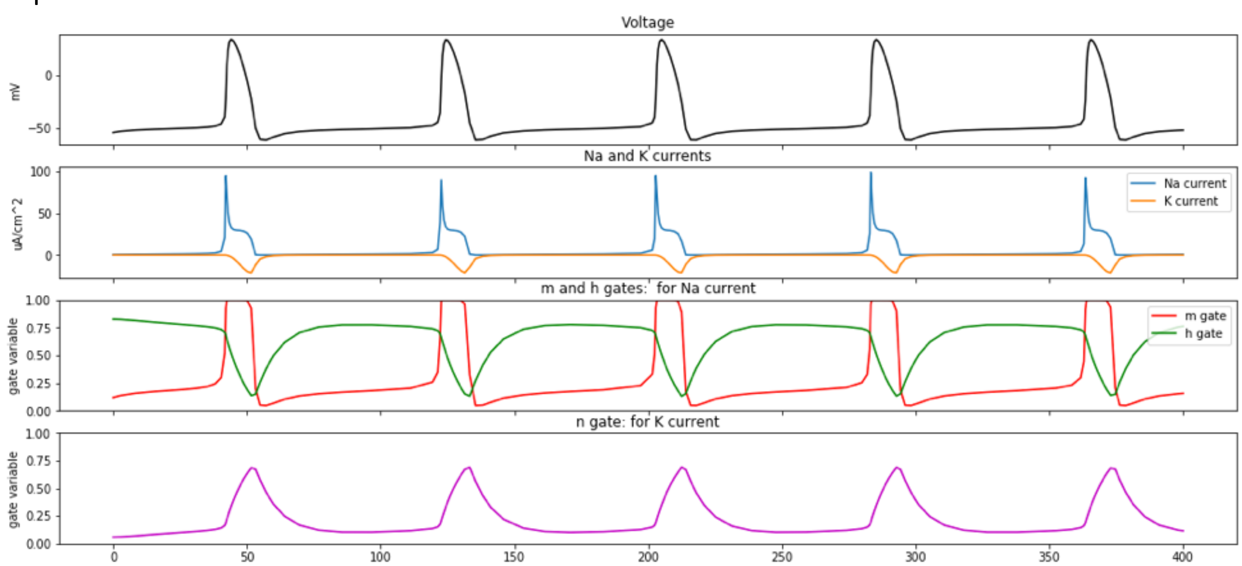
Parameter set 2

Between Iinput=0.15 and Iinput=0.20, it starts to fire spikes

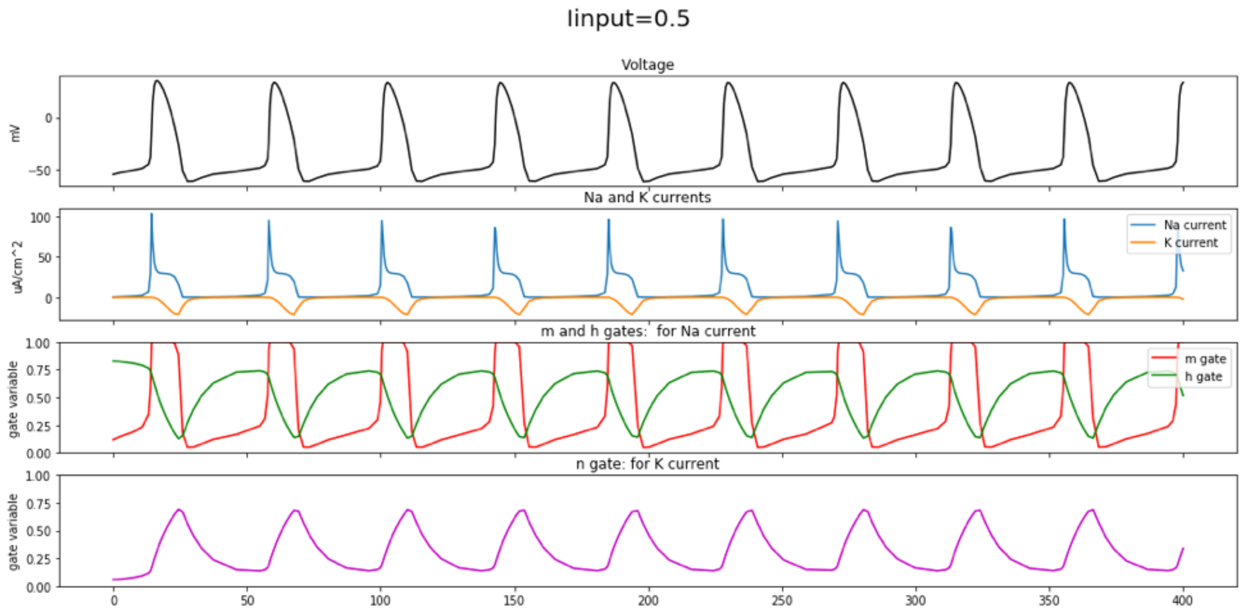
Iinput=0.15

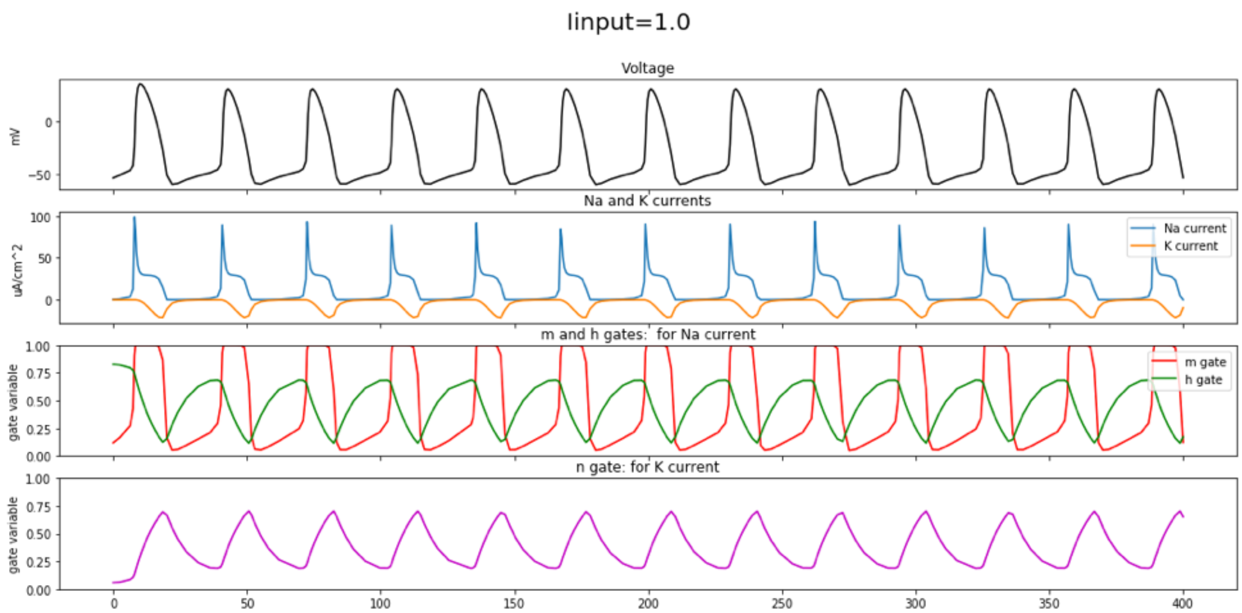


Iinput=0.20

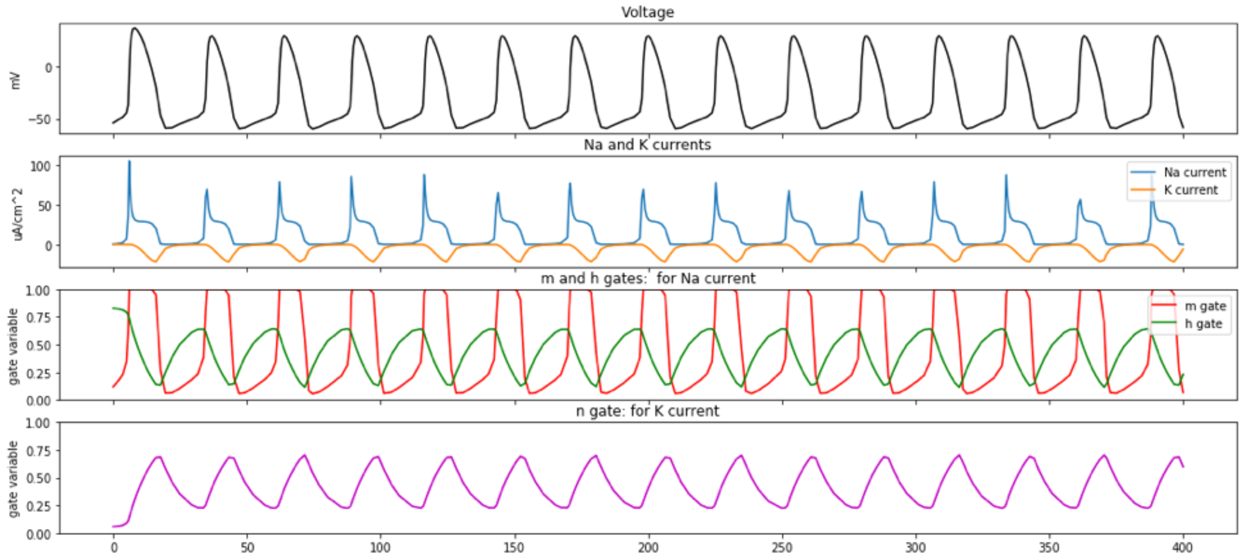


After this, the firing rate increases with Iinput:

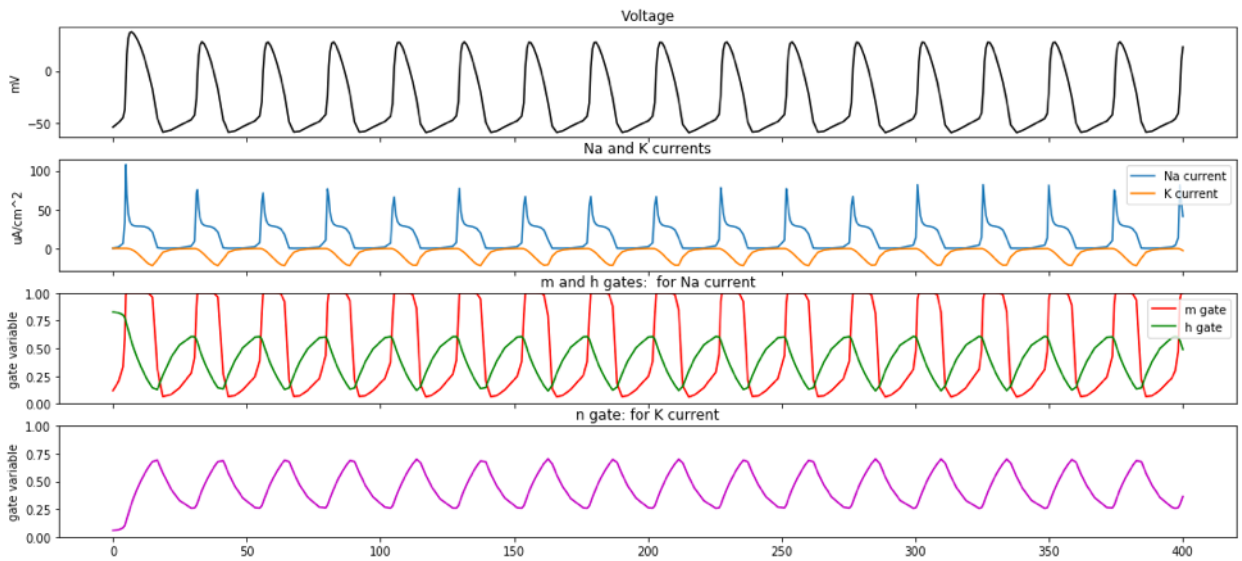

Iinput=0.5
Voltage
mV
0
−50
Na and K currents
uA/cm^2
100
50
0
Na current
K current
m and h gates: for Na current
gate variable
1.00
0.75
0.50
0.25
0.00
m gate
h gate
n gate: for K current
gate variable
1.00
0.75
0.50
0.25
0.00
0
50
100
150
200
250
300
350
400


Iinput=1.0
Voltage
mV
0
−50
Na and K currents
uA/cm^2
100
50
0
Na current
K current
m and h gates: for Na current
gate variable
1.00
0.75
0.50
0.25
0.00
m gate
h gate
n gate: for K current
gate variable
1.00
0.75
0.50
0.25
0.00
0
50
100
150
200
250
300
350
400

Iinput=1.5



Iinput=2.0



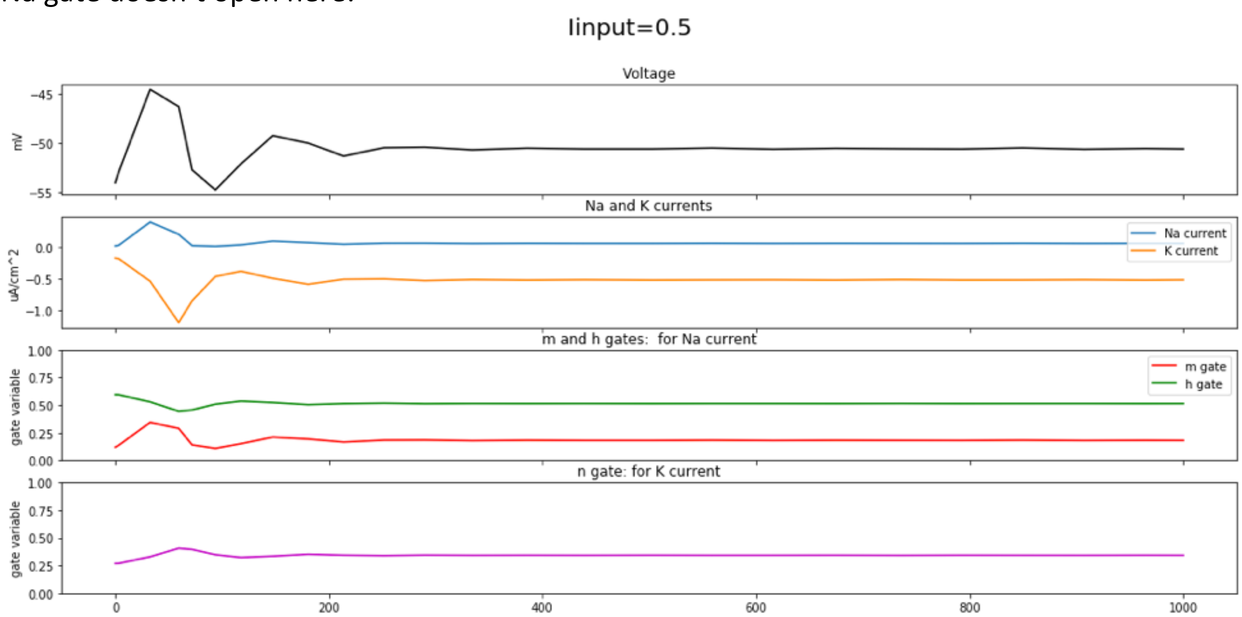
Past this, the firing rate continues increasing with current. Then, at even higher Input currents, it does the same things as neuron 1: it doesn't spike anymore and switches to subthreshold oscillations, after a single action potential.

Parameter set 3

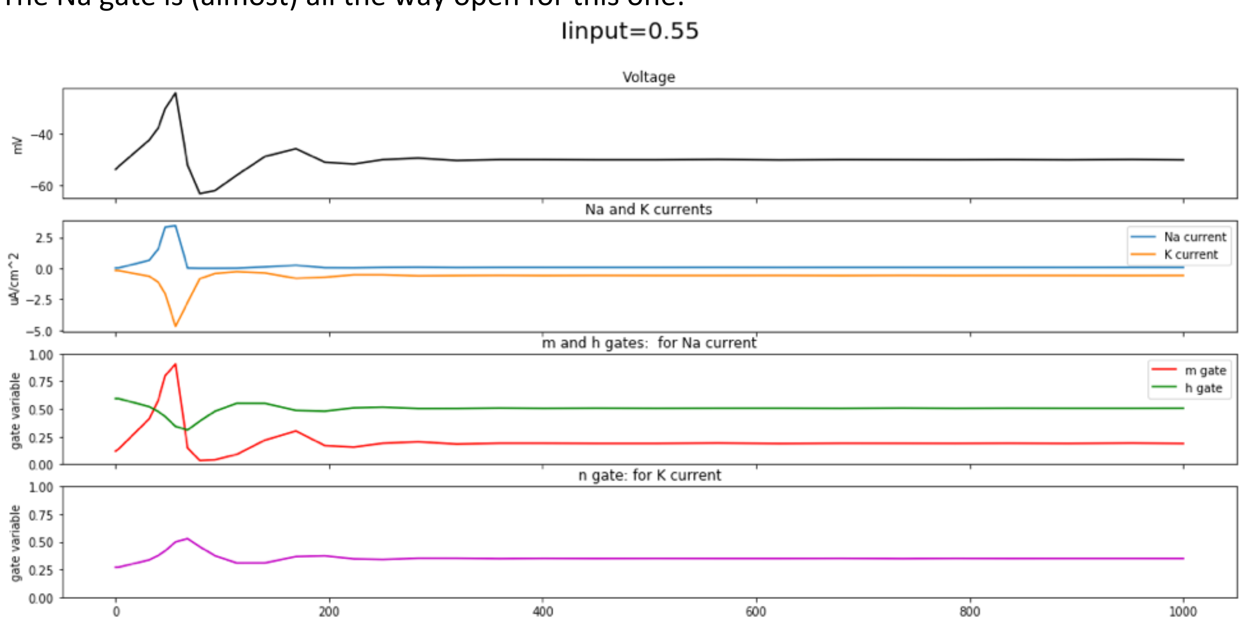
This neuron only ever fires a single spike. The amplitude of the peak voltage during the spike increases with the input current. Its hard to tell exactly where the 'threshold' is. But its somewhere between 0.5 and 0.65.

Note that the timescale (tau) for this neuron is much longer than neurons 1 and 2. This one has tau=50, while the other ones have tau=10. This can be seen in the plots below (but make sure to note the scale of the x-axis to make comparisons).

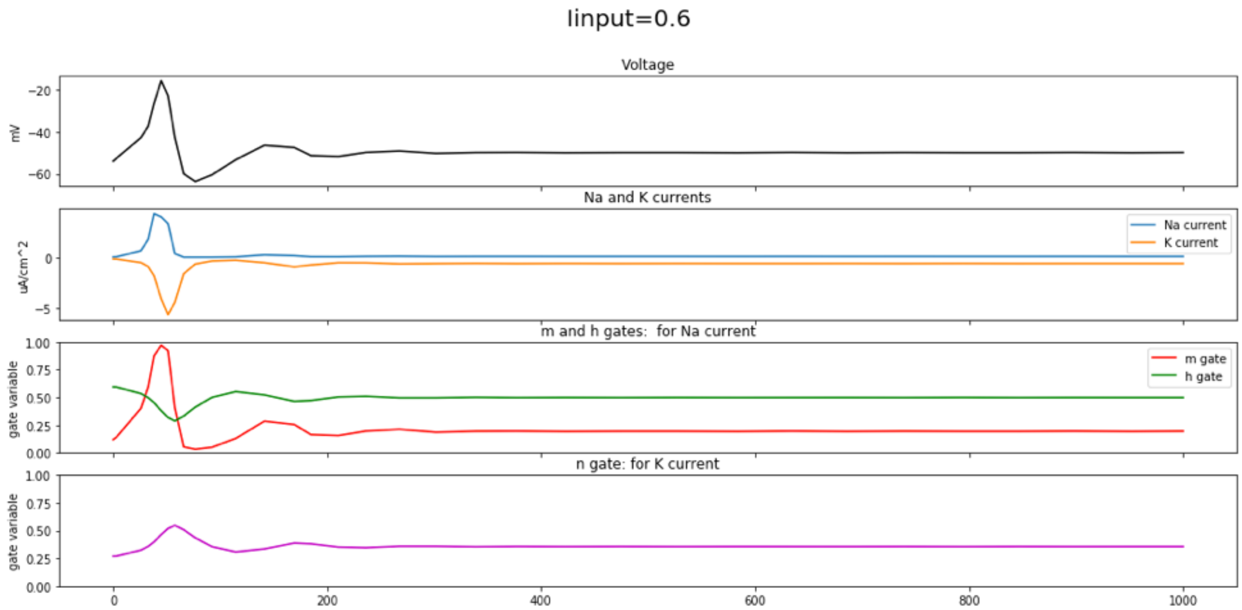
Na gate doesn't open here:



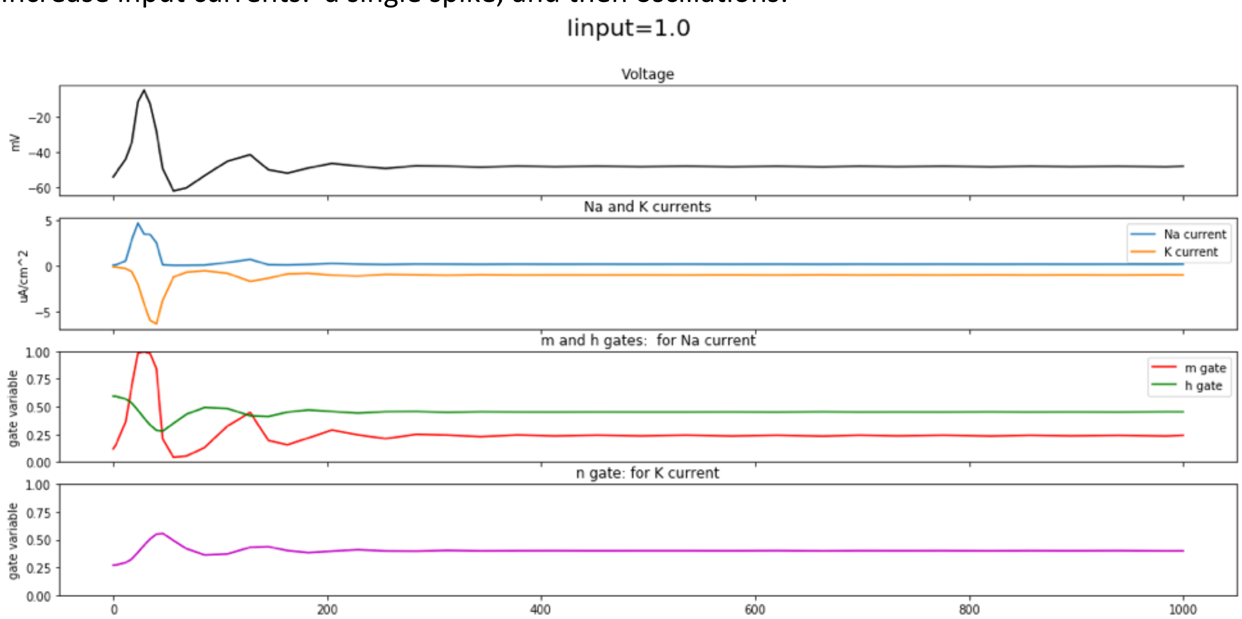
The Na gate is (almost) all the way open for this one:



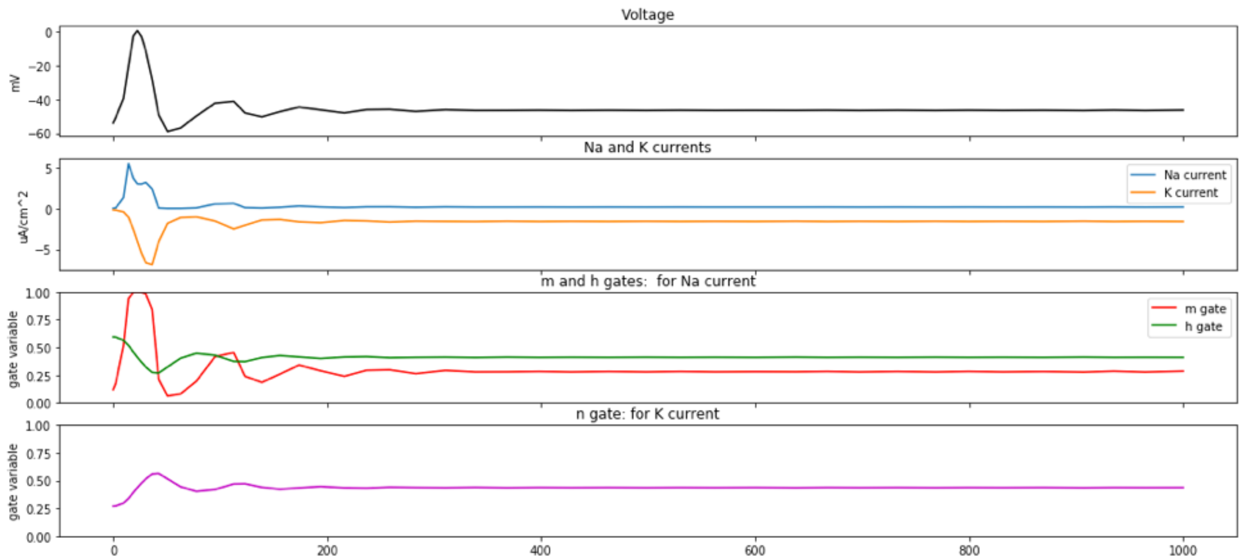
This looks like a spike:



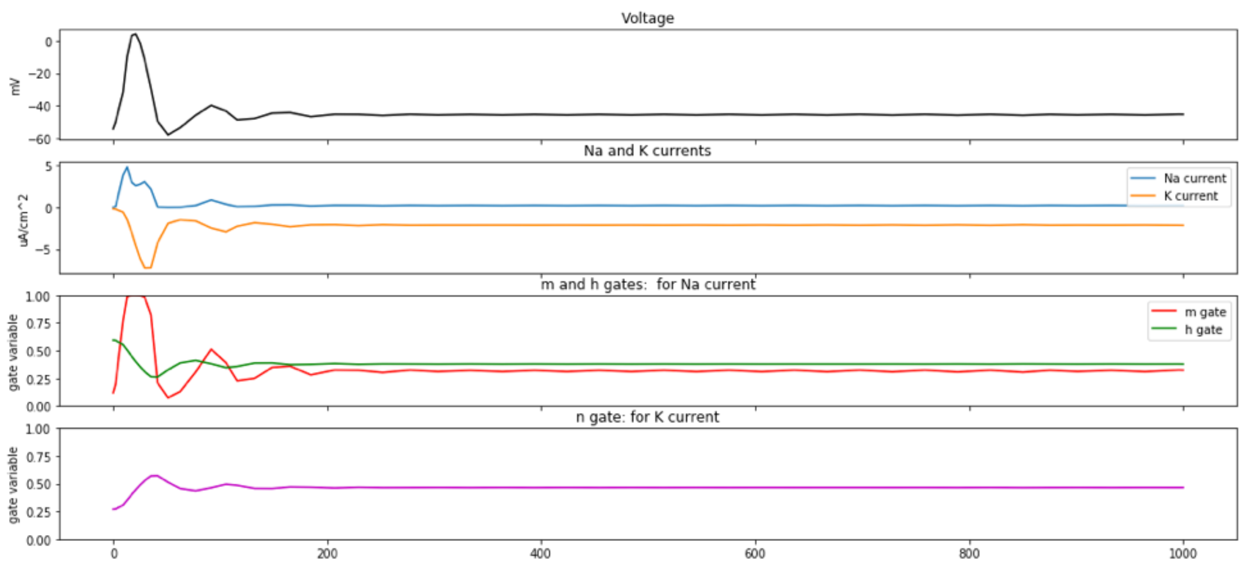
Increase input currents: a single spike, and then oscillations:

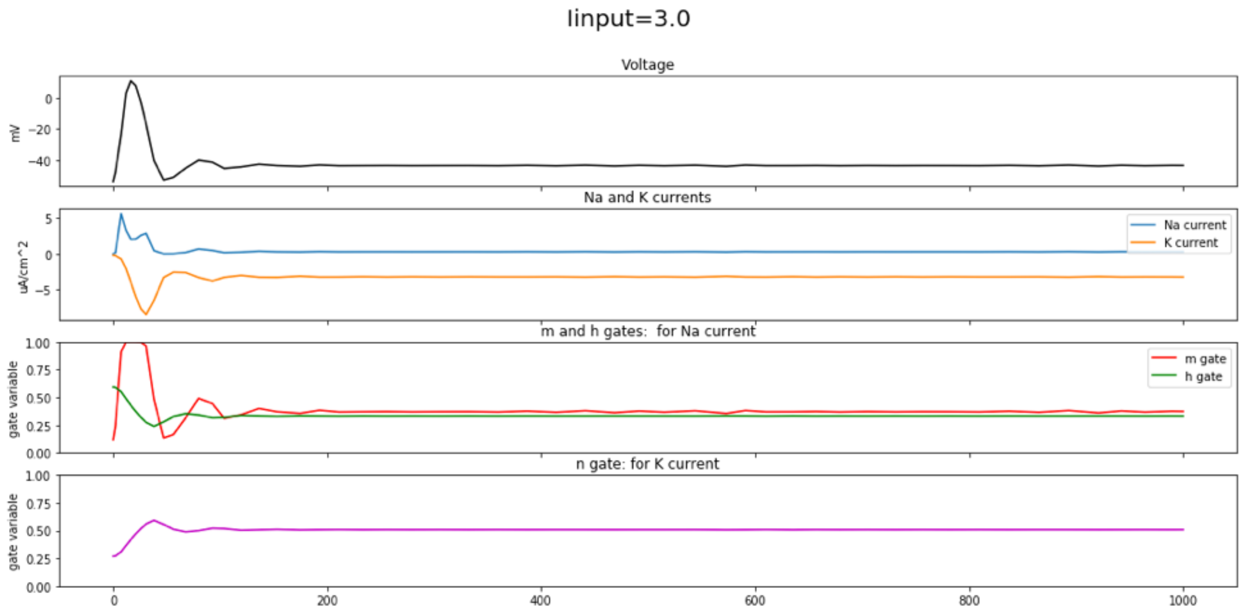


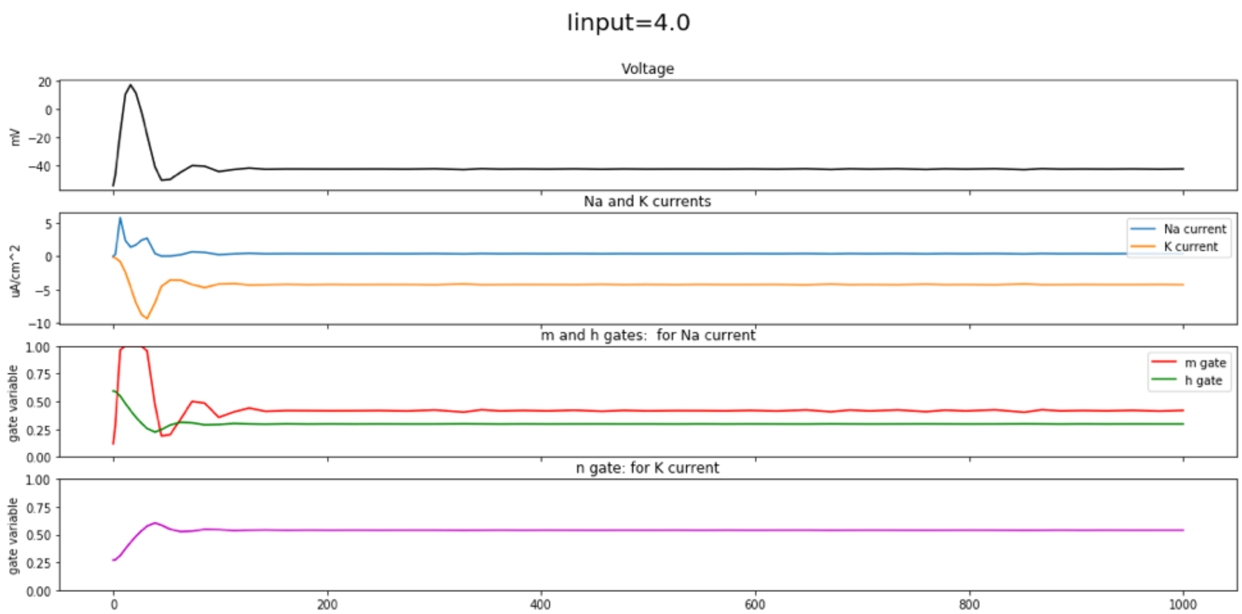
Iinput=1.5



Iinput=2.0

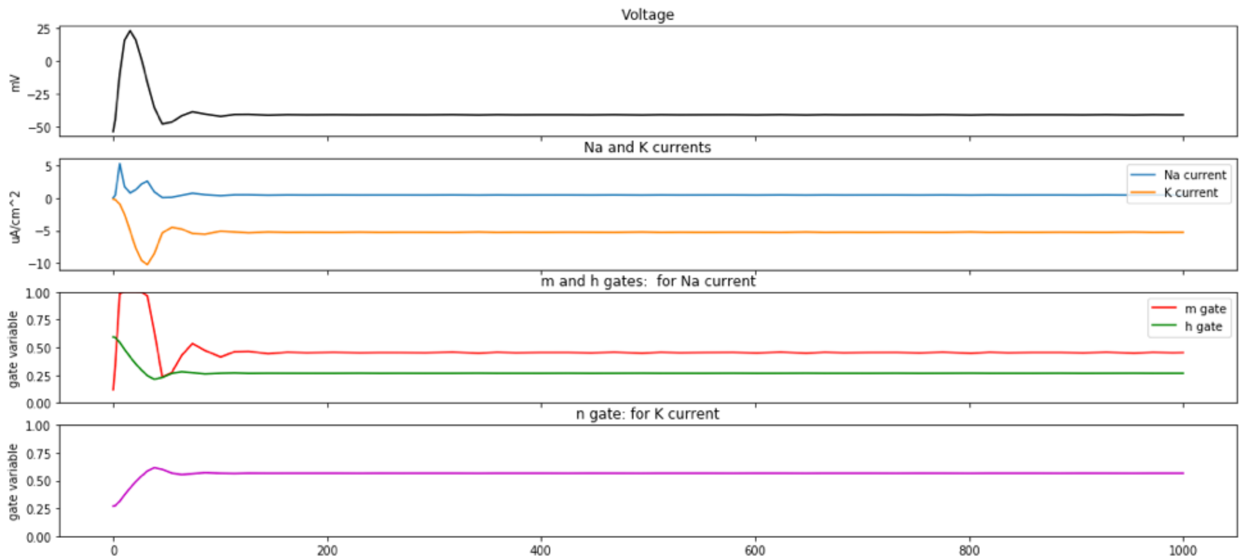




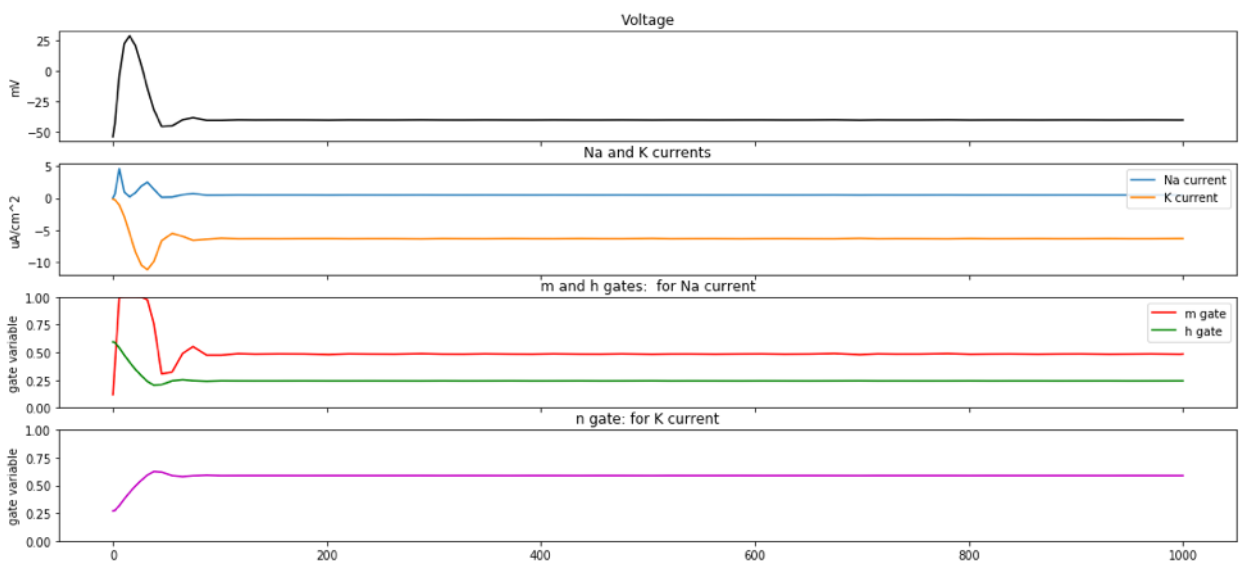


If keep increasing the input current, then the subthreshold oscillations decrease:

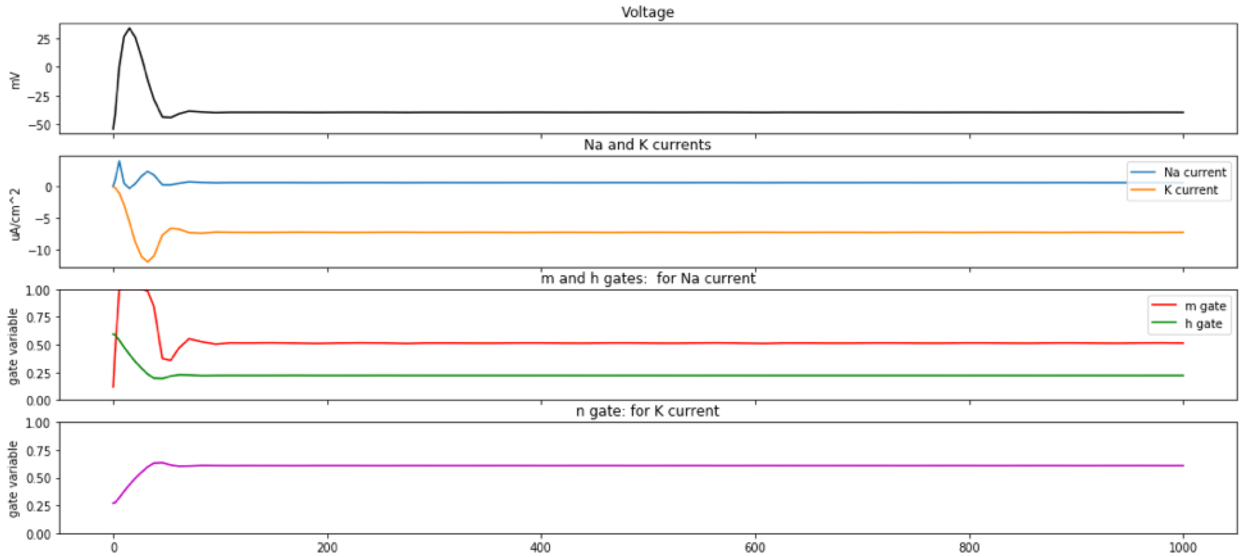
Iinput=5.0



Iinput=6.0



Iinput=7.0


Voltage
mV
Na and K currents
uA/cm^2
Na current
K current
m and h gates: for Na current
gate variable
m gate
h gate
n gate: for K current
gate variable
0
200
400
600
800
1000

ii) Which classification are these?

Copied from textbook:

The qualitative distinc- tion between the classes noticed by Hodgkin is that the frequency-current relation (the F-I curve in Fig. 7.3, bottom) starts from zero and continuously increases for Class 1 neurons, but discontinuous for Class 2 neurons.

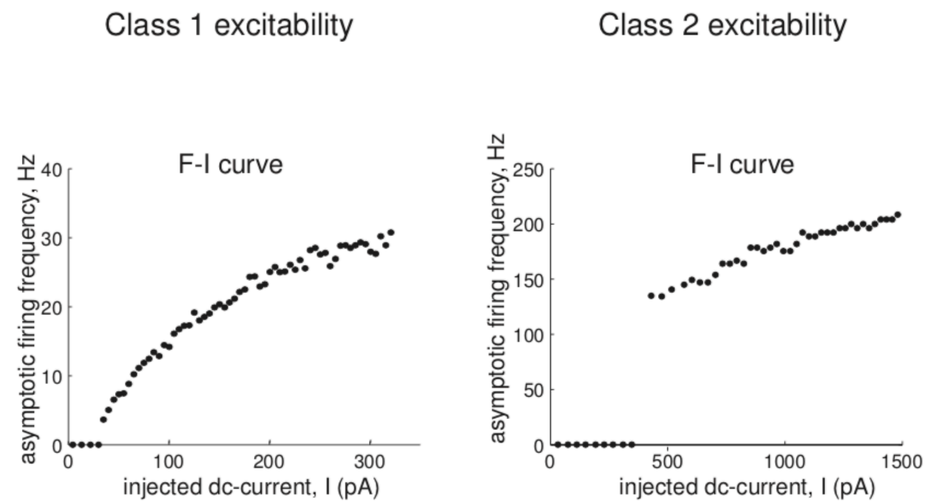


Figure 7.3: *Top:* Typical responses of membrane potentials of two neurons to steps of dc-current of various magnitudes I. *Bottom:* Corresponding frequency-current (F-I) relations are qualitatively different. Shown are recordings of layer 5 pyramidal neurons from rat's primary visual cortex (left) and mesV neuron from rat's brainstem (right). Asymptotic frequency is $1000/T_\infty$, where T_∞ is taken to be interval between the last two spikes in a long spike train.

Class 3 neural excitability. A single action potential is generated in re- sponse to a pulse of current. Repetitive (tonic) spiking can be generated only for extremely strong injected currents or not at all.

Using this, can say that:

Parameter set 1: Class 2 excitability (it jumps up rapidly in firing rate at Iinput=1.65)

Parameter set 2: Class 1 excitability (smooth increase in firing rate)

Parameter set 3: Class 3, because it only fires a single action potential, even at very high input currents

Part b)

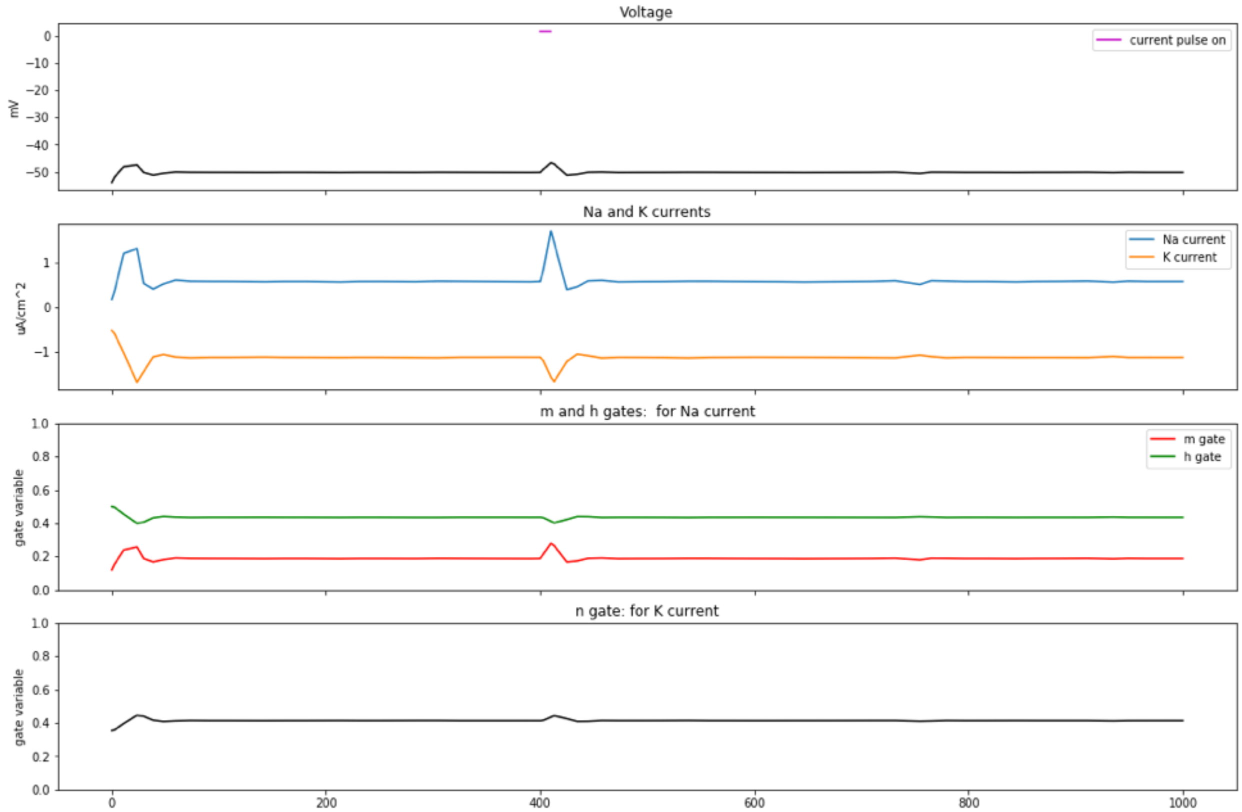
Study the response of each model neuron to small current impulses (both positive and negative deviations from a baseline current injection). For model neuron (1), use a baseline of Iin = 1.3μA/cm2, for (2) Iin = 0 and for (3) Iin = 0.5μA/cm2. Describe what happens to the voltage after a single short current injection.

Now make the pulse large enough to trigger a spike. What happens to the voltage after the spike? Does the neuron show any after-depolarization?

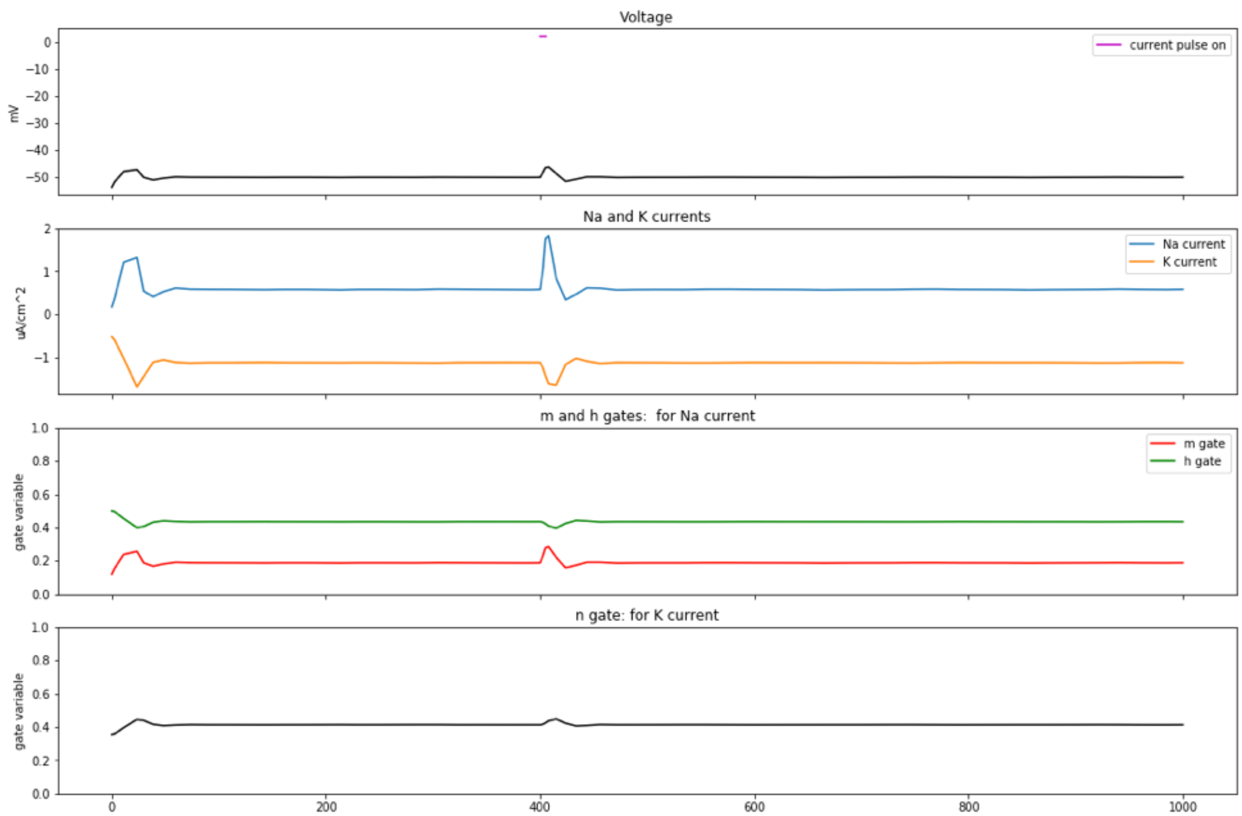
Study the response of the neuron to inhibitory inputs (with respect to the mean Iin above) of varying duration and amplitude. Can you get the neuron to show post- inhibitory (rebound) spiking?

Neuron 1.
After a short current injection, Both the Na current and K current turn on. There is slight oscillation, and then it goes back to baseline.

Neuron 1: t_pulse=10.0, I_pulse=0.4, I_base=1.3

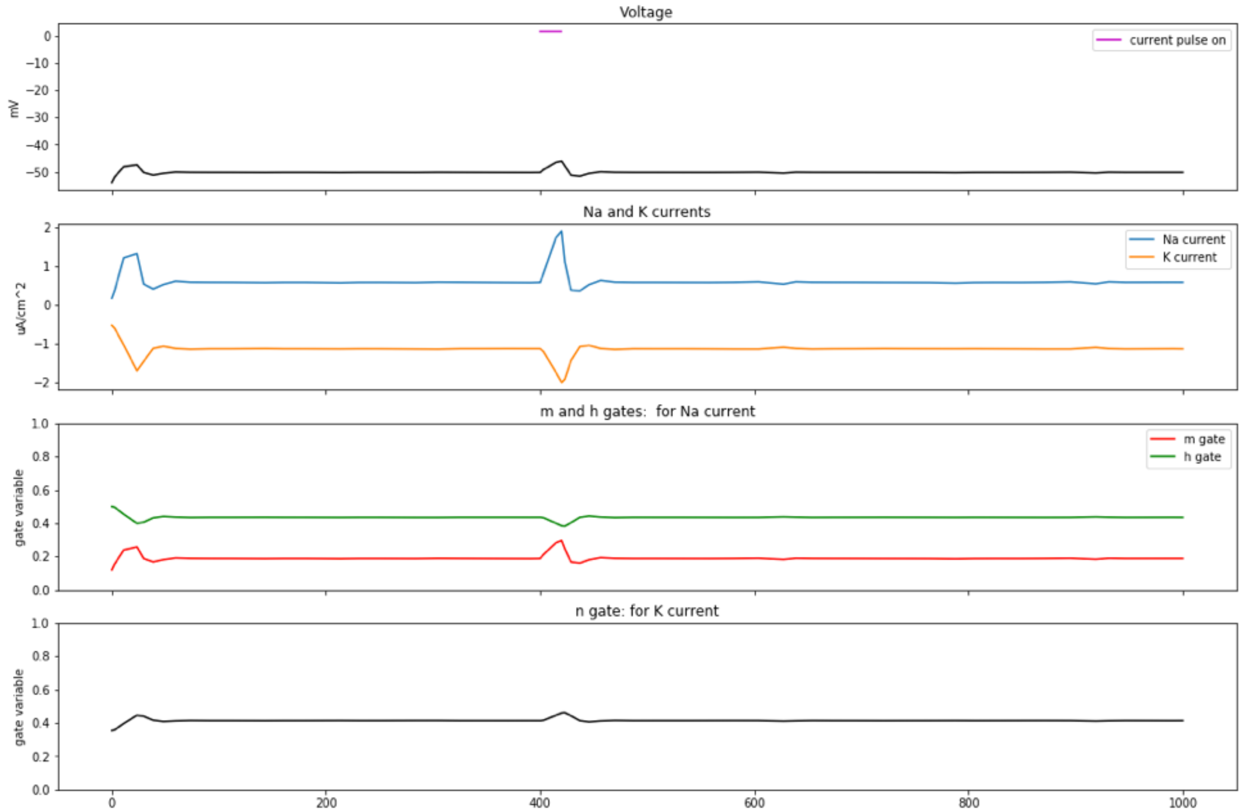


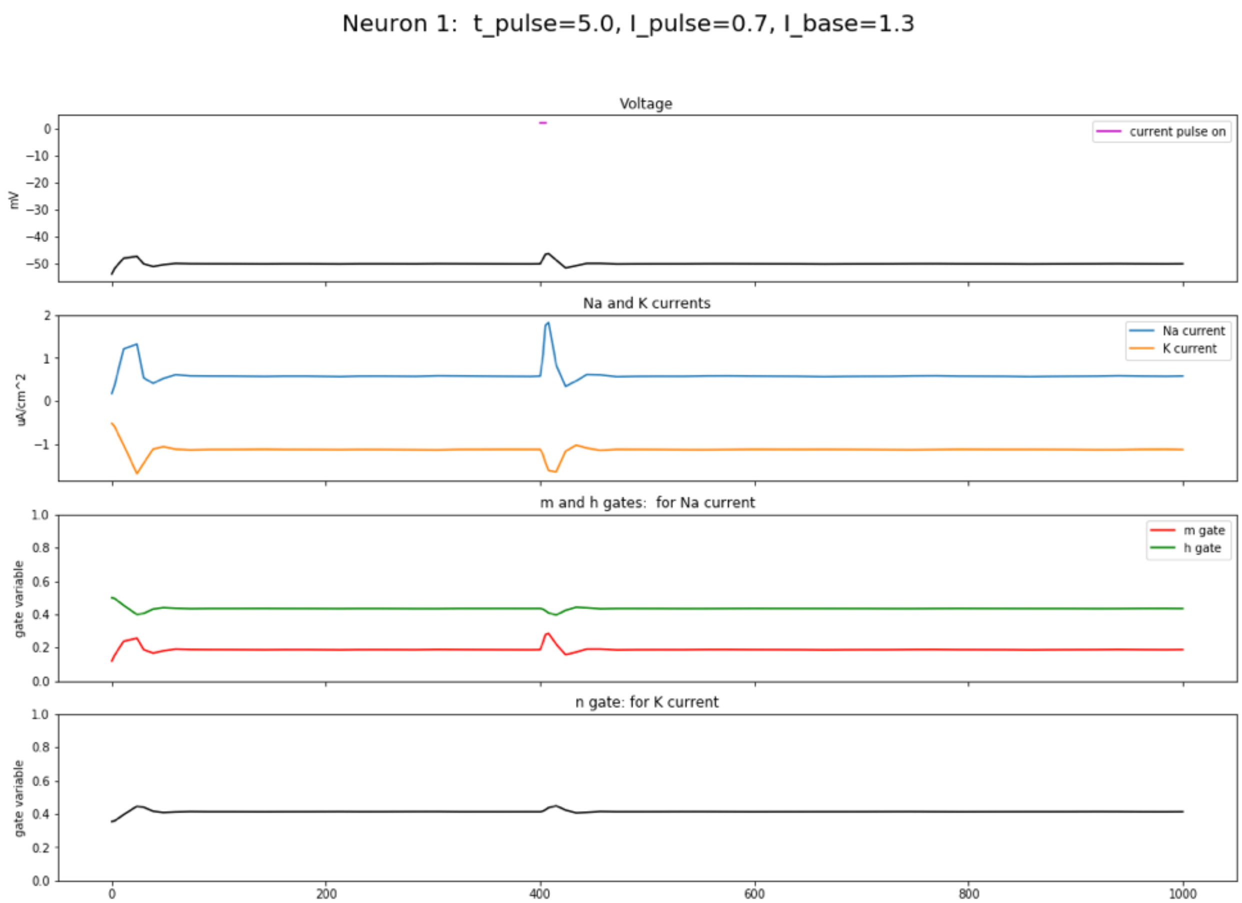
Neuron 1: t_pulse=5.0, I_pulse=0.7, I_base=1.3



Note that the response is qualitatively the same if we increase the duration of the pulse, but decrease the current injected, or decrease duration/increase current

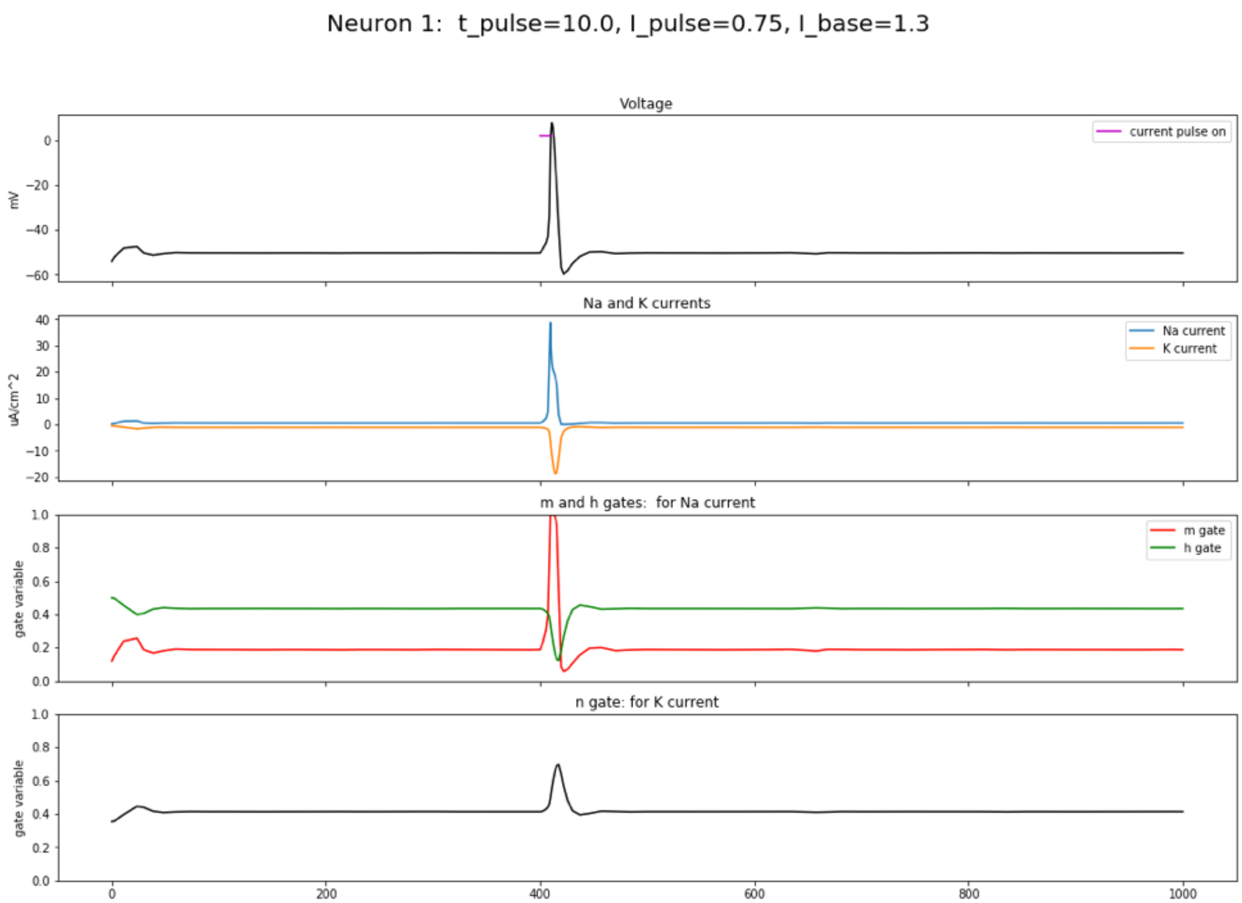
Neuron 1: t_pulse=20.0, I_pulse=0.35, I_base=1.3





Because of this, I'll just use a pulse input time of 10msec for all of the rest, and adjust the pulse current

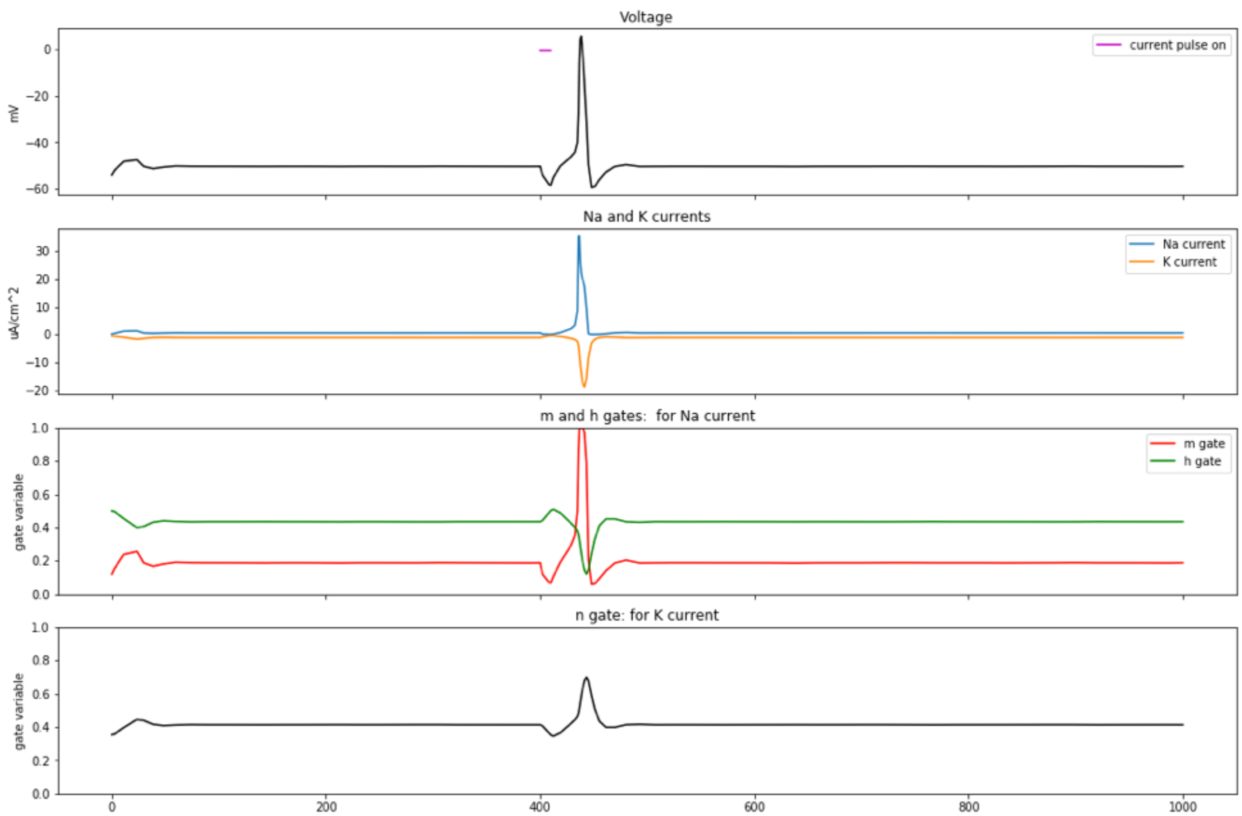
Here is large enough to trigger a spike:



After the spike, the voltage goes down, and then back to baseline, after a small oscillation upwards

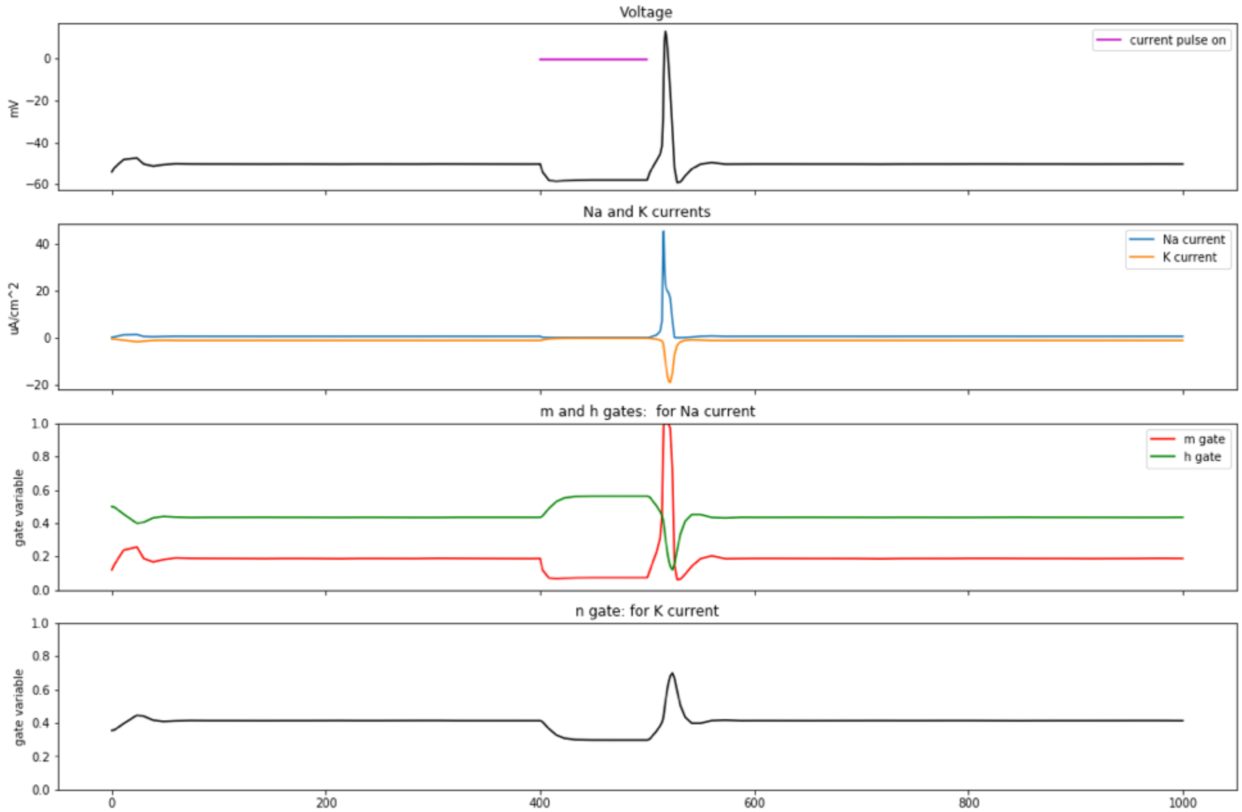
At negative pulse varies that are sufficiently low, can trigger a spike:

Neuron 1: t_pulse=10.0, I_pulse=-1.9, I_base=1.3



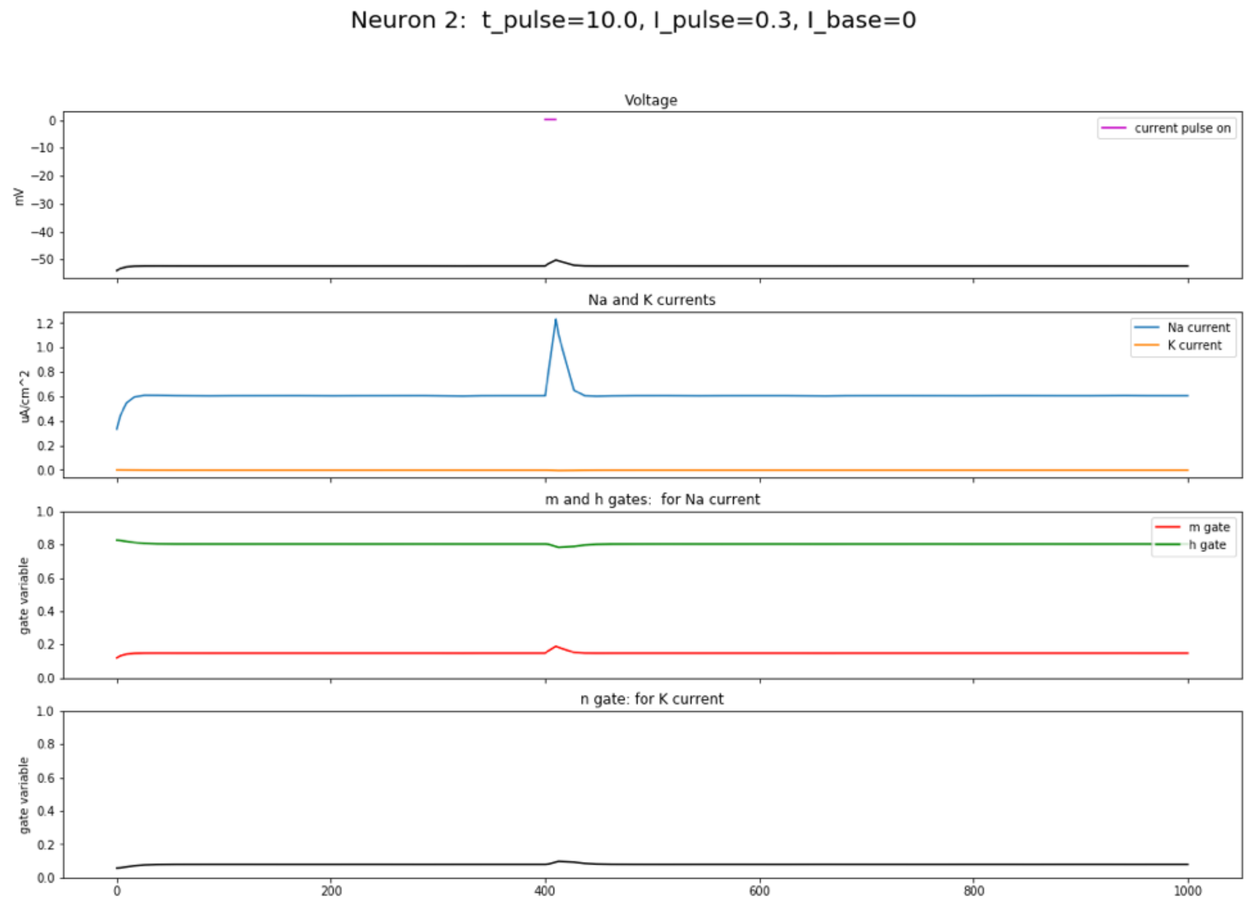
Note that here if we keep the negative pulse on for a longer time, it will polarize the neuron, and then there will be a rebound spike after release the current:

Neuron 1: t_pulse=100.0, I_pulse=-1.9, I_base=1.3

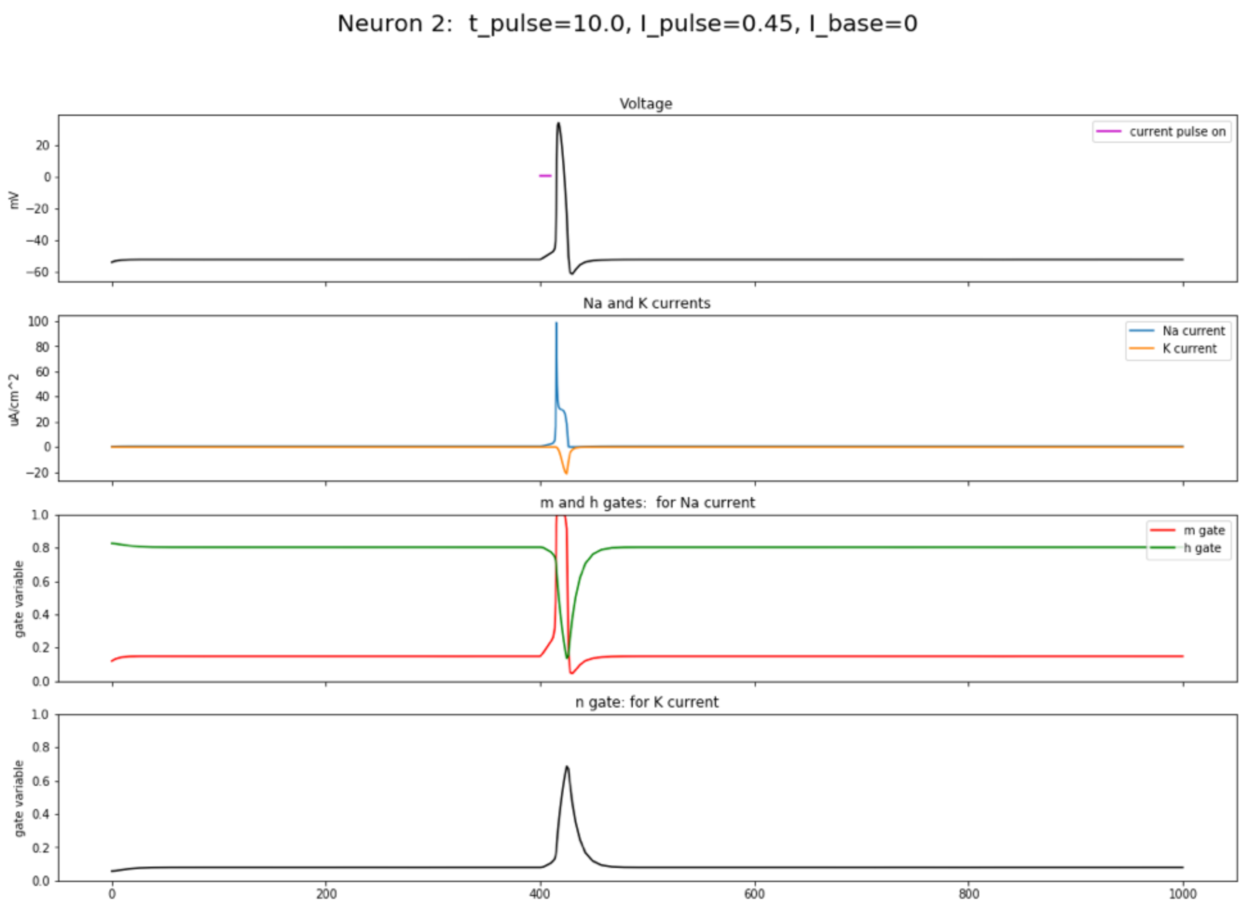


Neuron 2.

Small pulse that does not trigger an action potential:

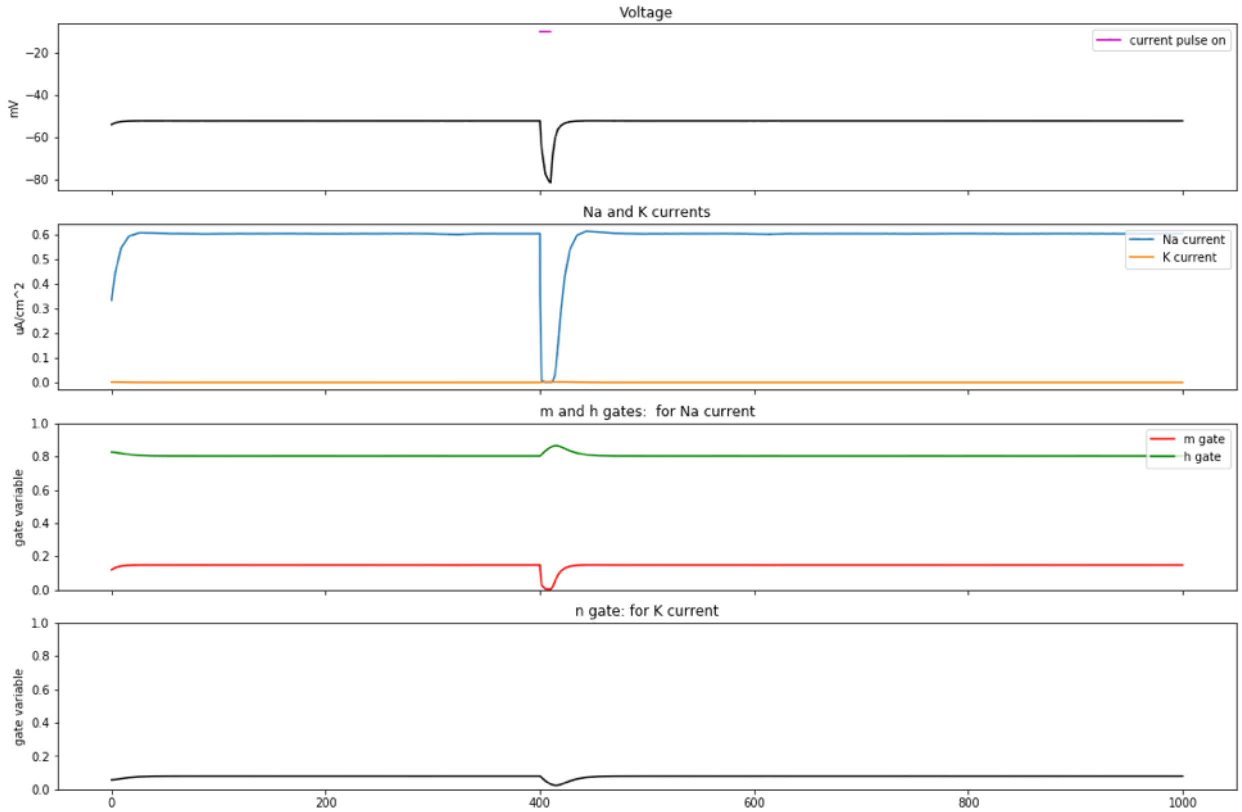


To trigger a spike. This looks qualitatively similar to neuron 1



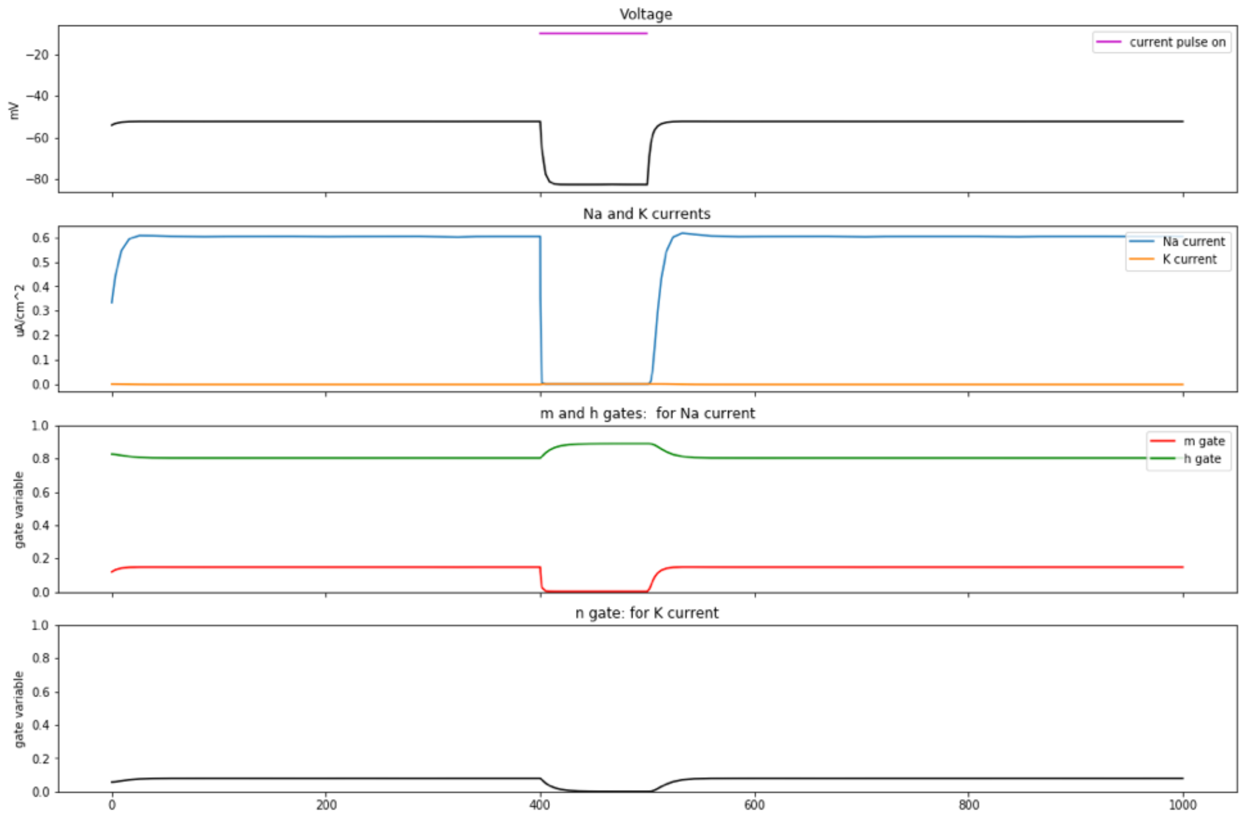
With negative input currents, even very large ones, cannot trigger a rebound spike:

Neuron 2: t_pulse=10.0, I_pulse=-10.0, I_base=0



Even if make the time for the injected current very long, can't trigger a rebound spike

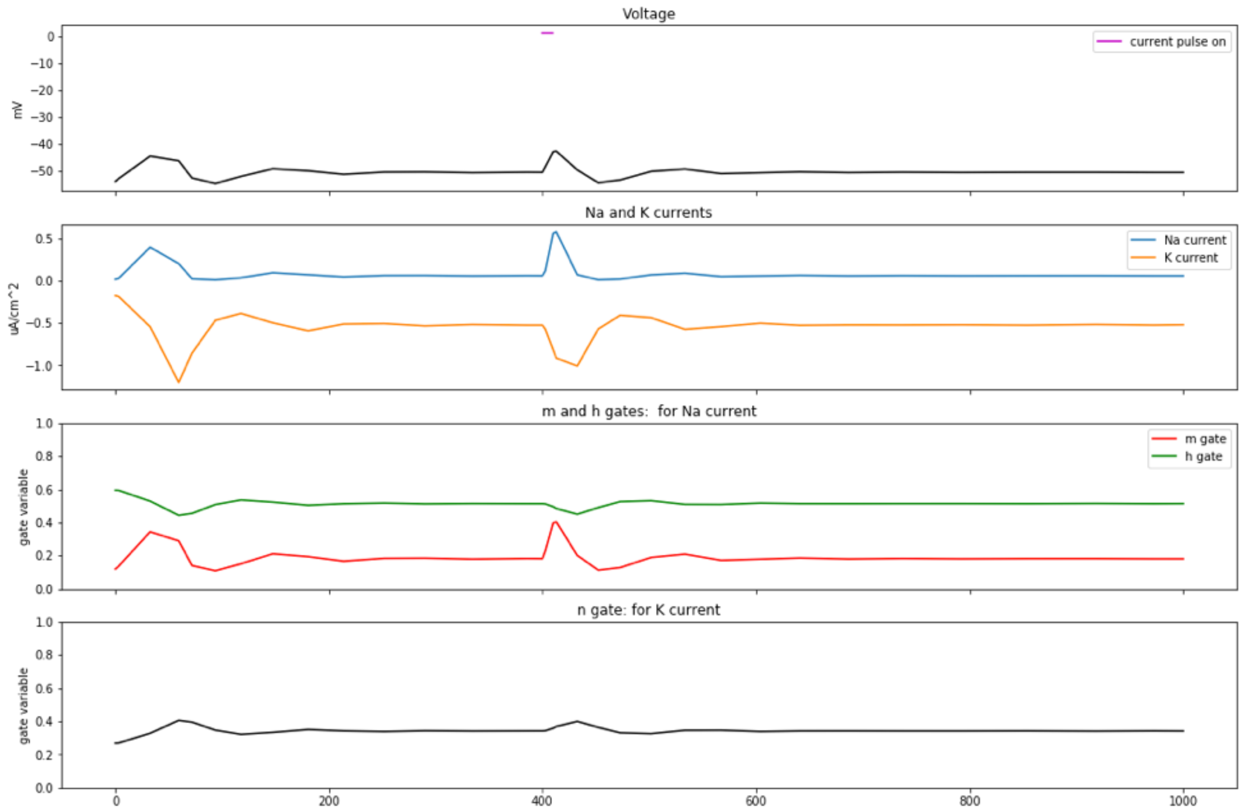
Neuron 2: t_pulse=100.0, I_pulse=-10.0, I_base=0



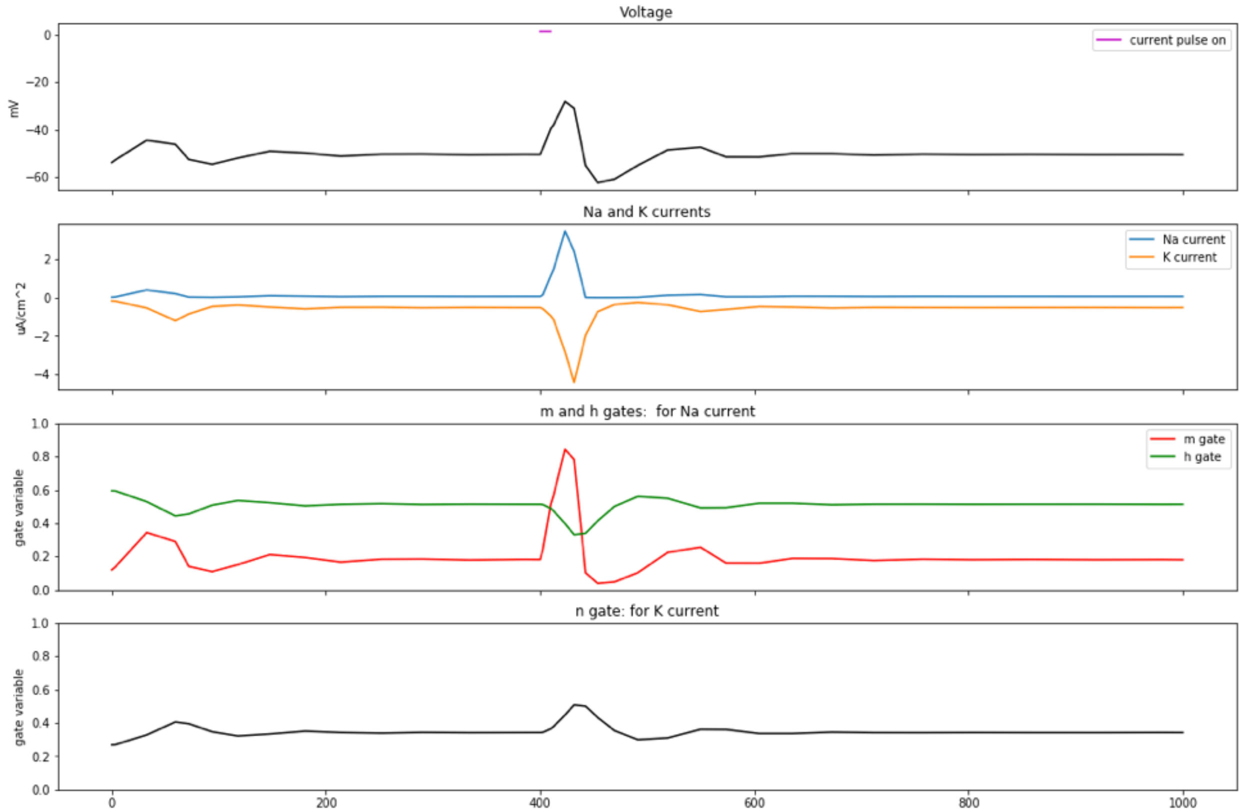
Neuron 3:

This neuron has a longer time constant. If inject current, then it oscillates. The amplitude of oscillation increases (nonlinearly) with the injected current, until the oscillation is large enough to be a ‘spike’.

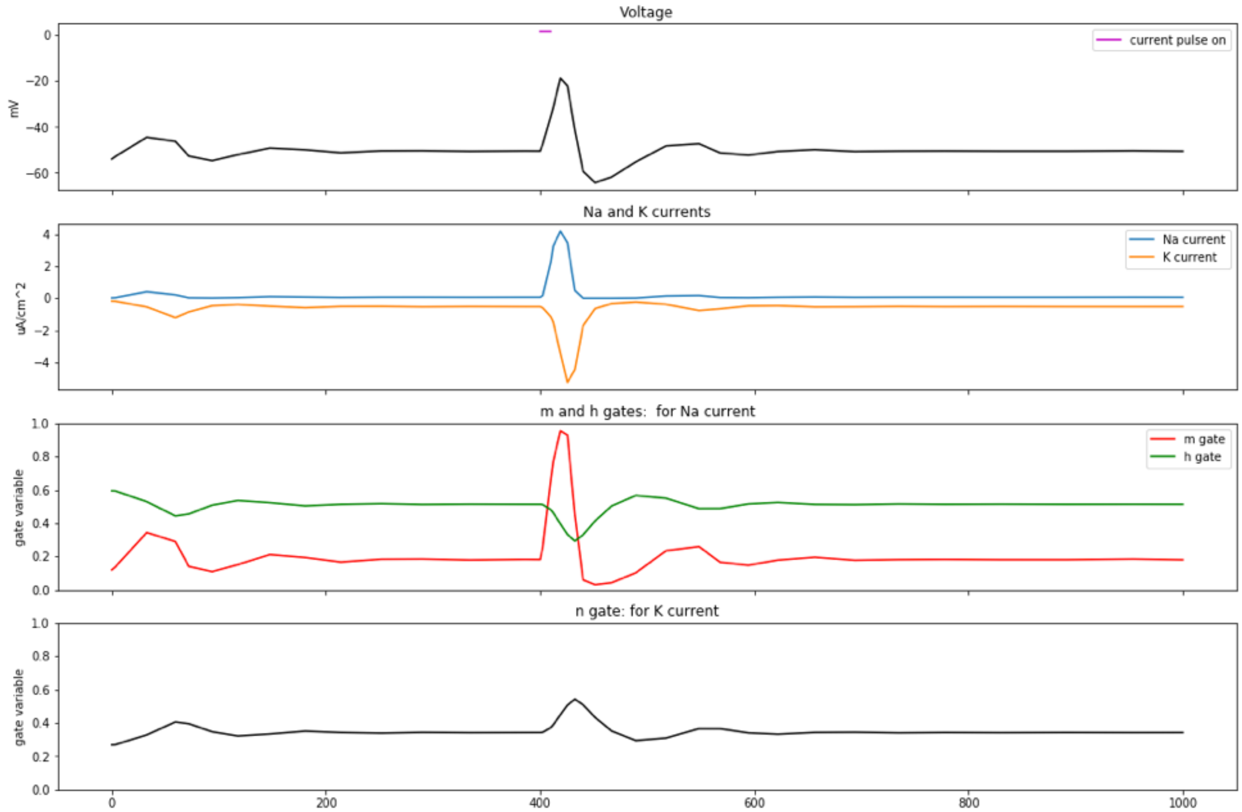
Neuron 3: t_pulse=10.0, I_pulse=0.75, I_base=0.5



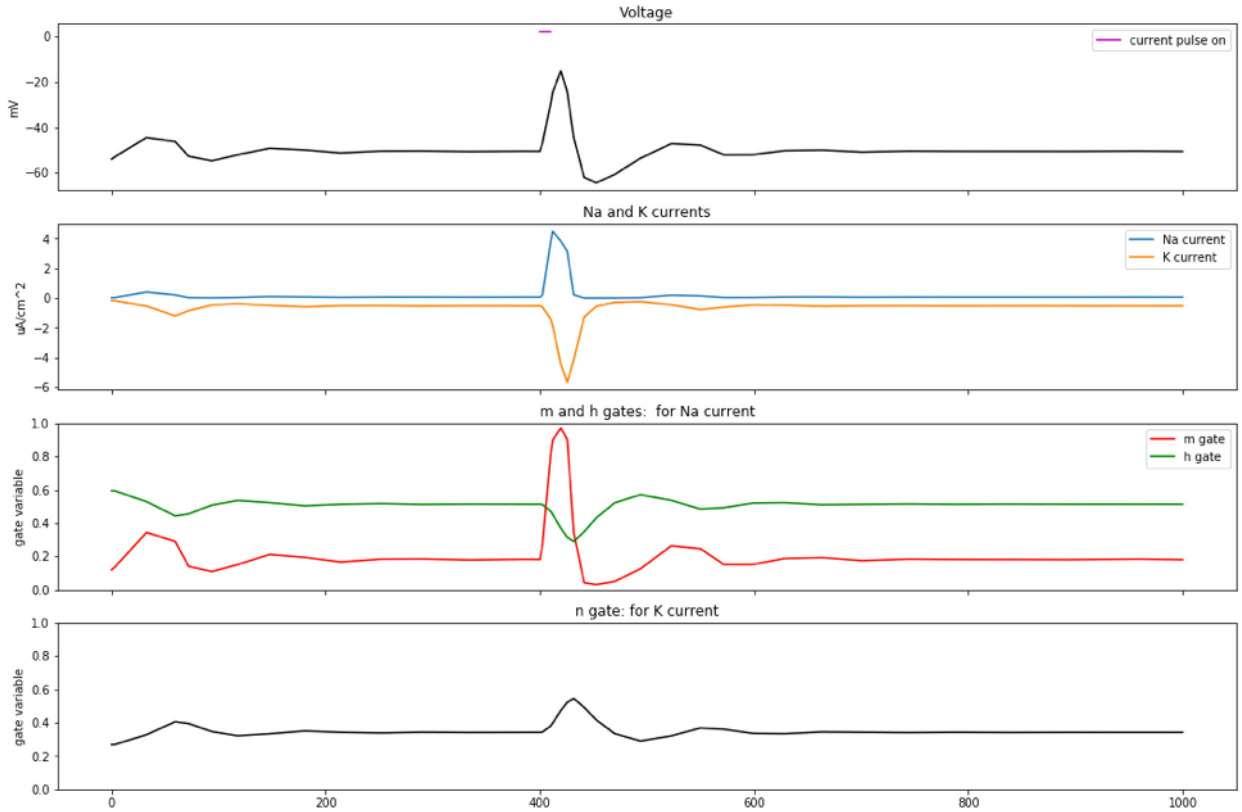
Neuron 3: t_pulse=10.0, I_pulse=1.0, I_base=0.5



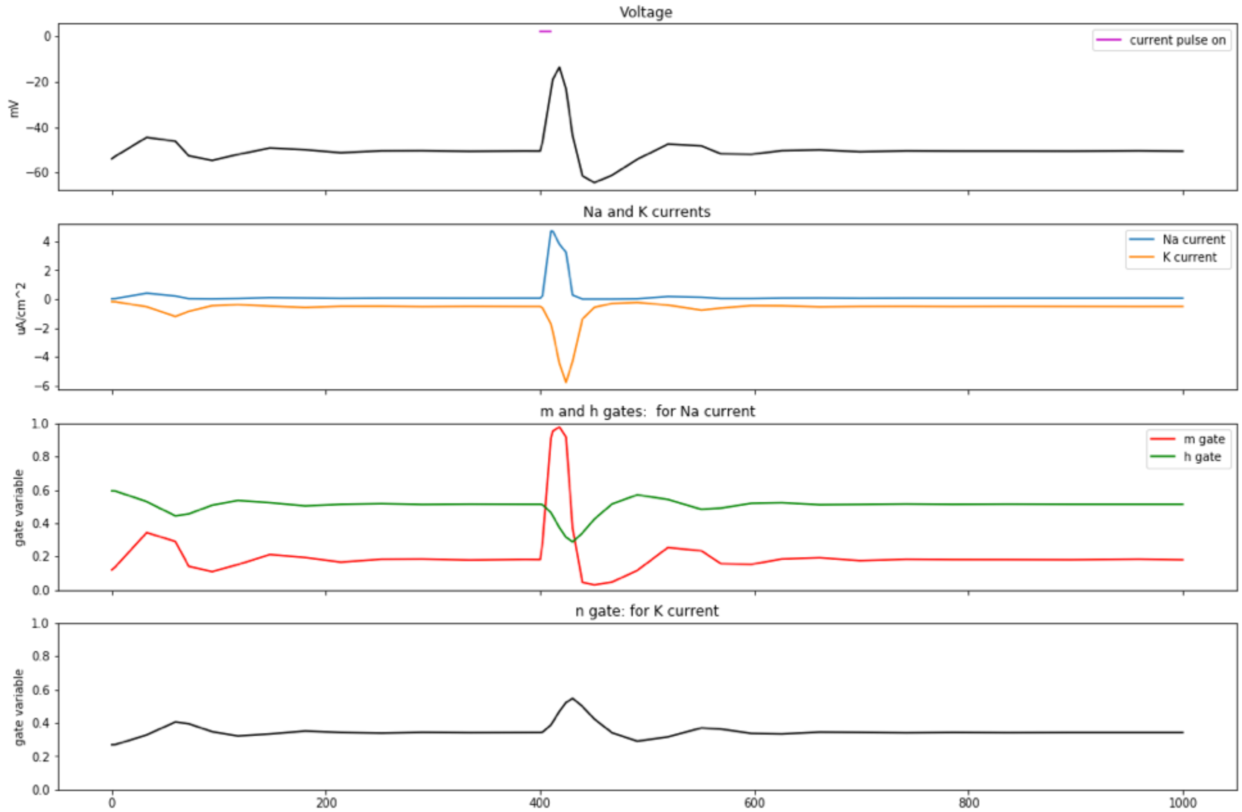
Neuron 3: t_pulse=10.0, I_pulse=1.25, I_base=0.5



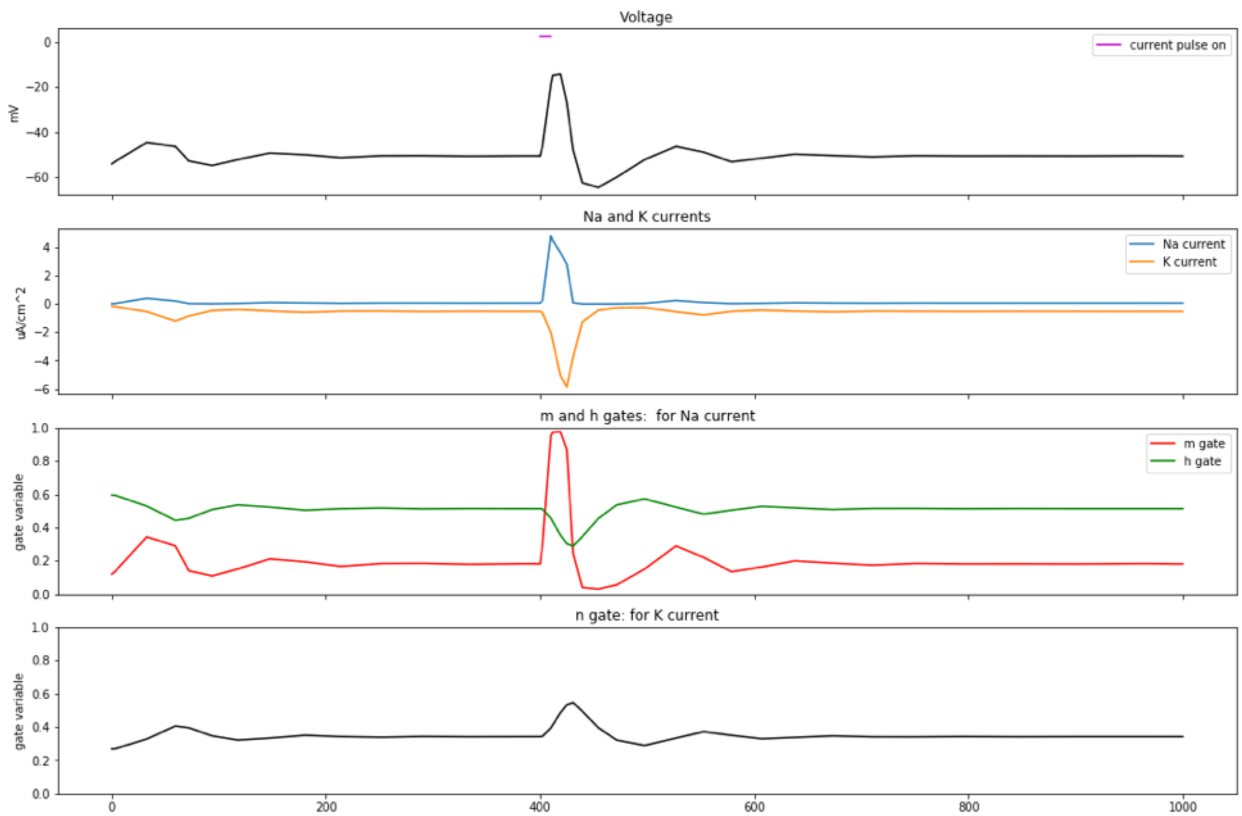
Neuron 3: t_pulse=10.0, I_pulse=1.5, I_base=0.5



Neuron 3: t_pulse=10.0, I_pulse=1.75, I_base=0.5

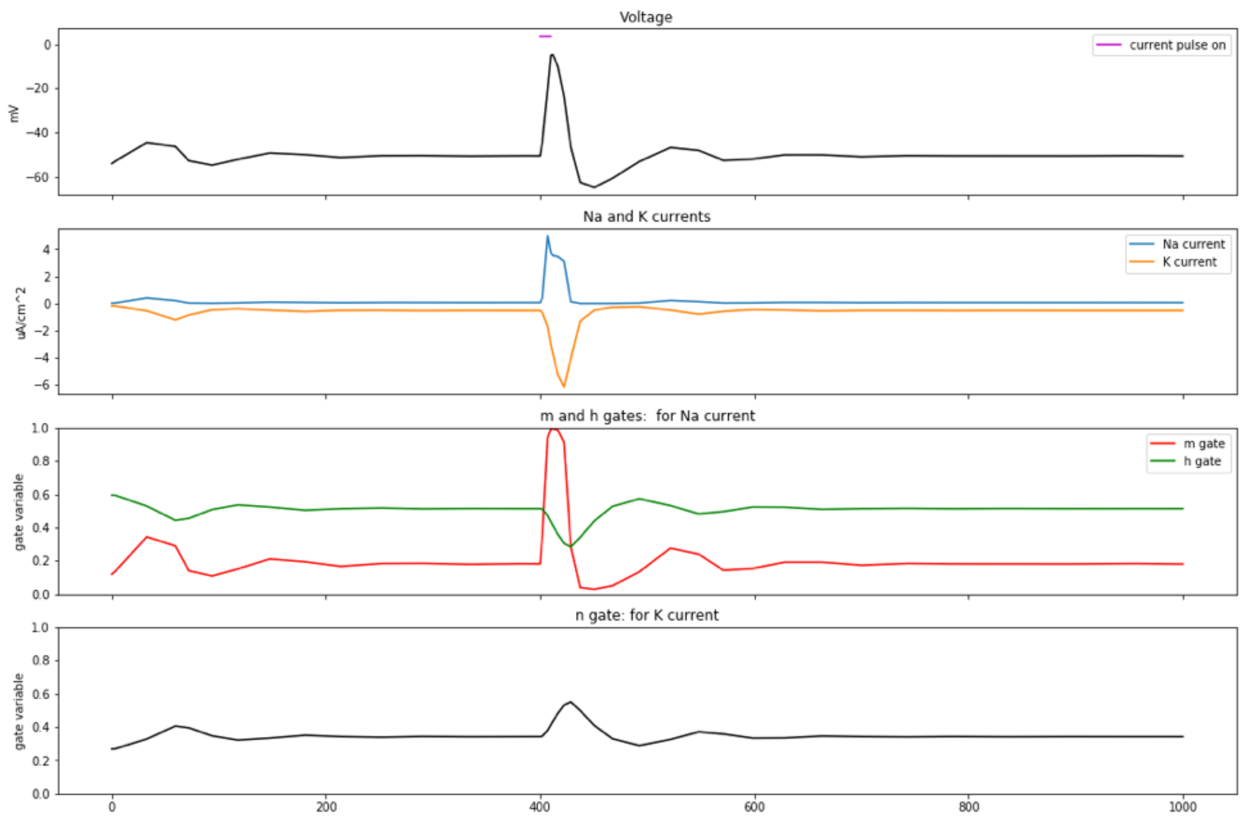


Neuron 3: t_pulse=10.0, I_pulse=2.0, I_base=0.5



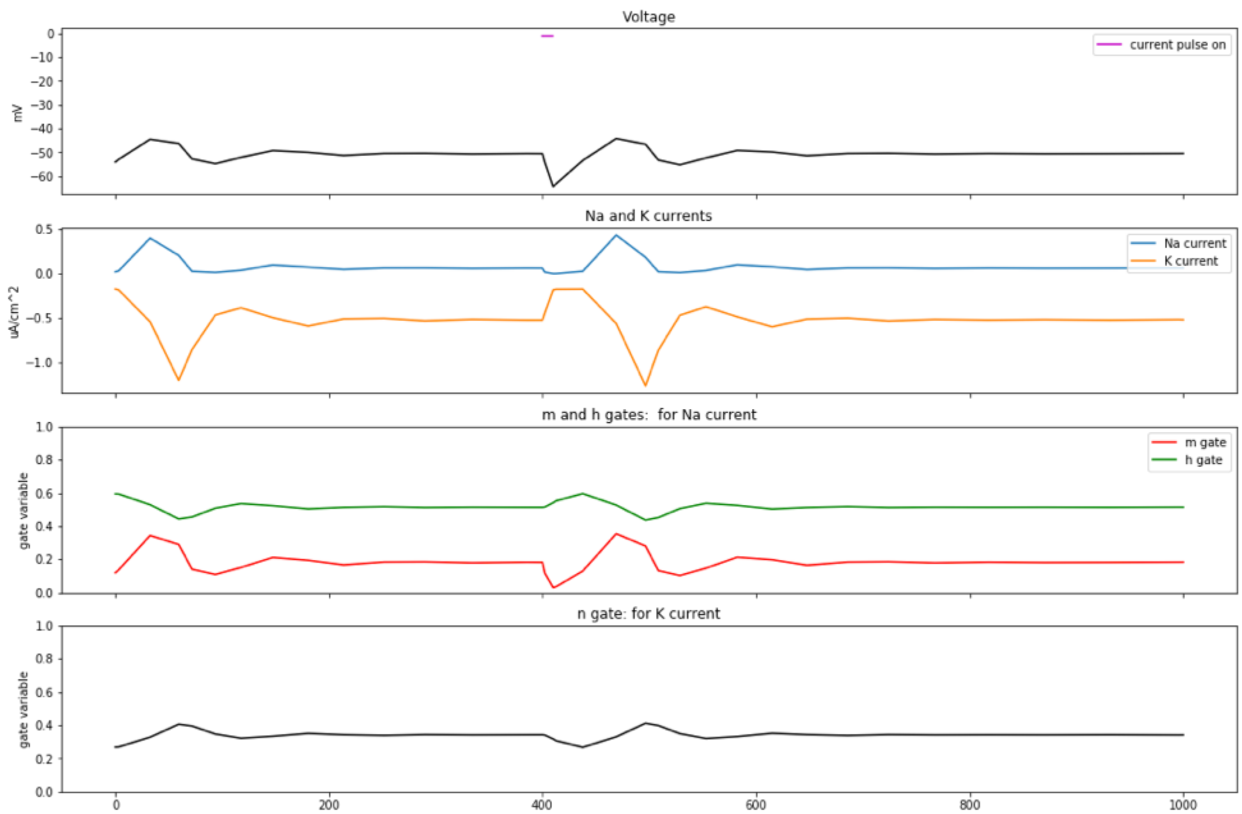
… then, a bit higher input current. Looks qualitatively similar, but the peak in voltage is lower

Neuron 3: t_pulse=10.0, I_pulse=3.0, I_base=0.5



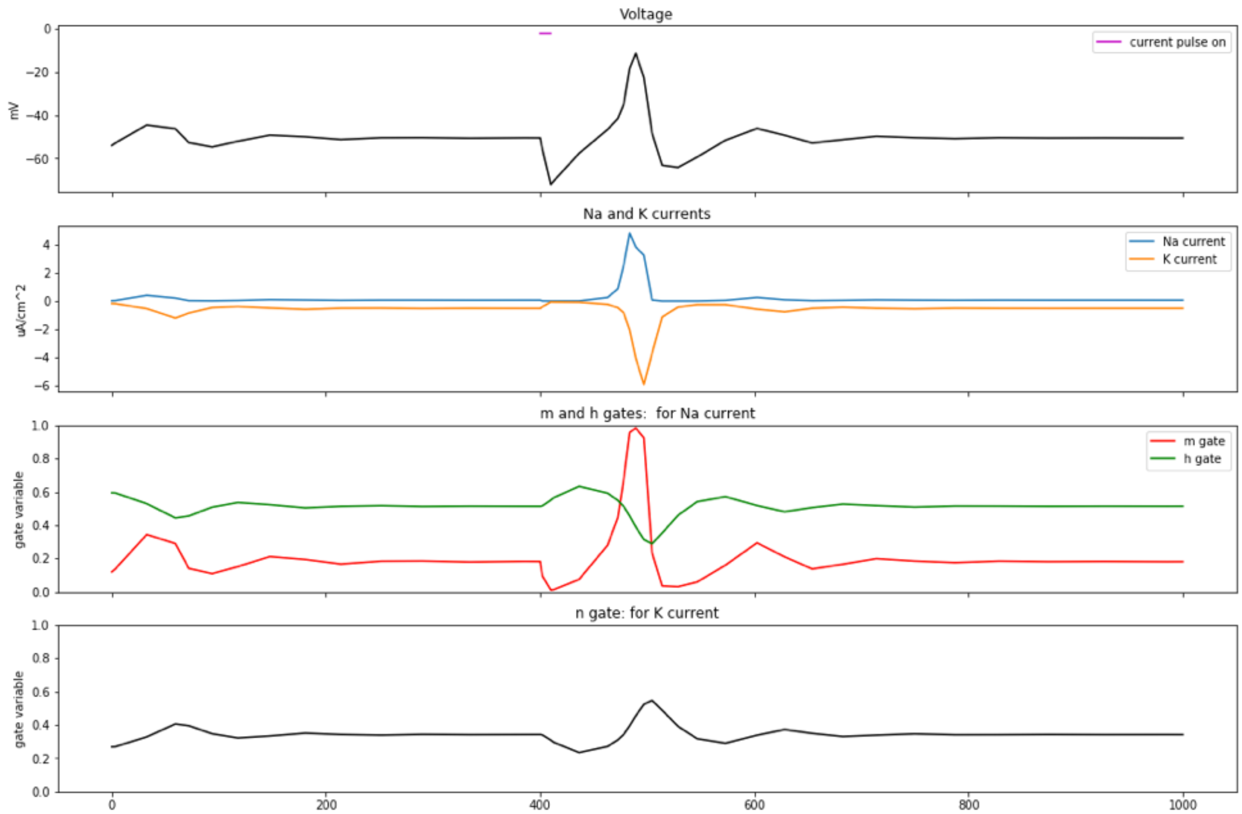
Inhibitory currents. For small inhibitory current, there is just oscillation

Neuron 3: t_pulse=10.0, I_pulse=-1.6, I_base=0.5



Then, in increase the magnitude of the pulse, it triggers a rebound spike:

Neuron 3: t_pulse=10.0, I_pulse=-2.5, I_base=0.5



Unlike the other neurons, this one acts as an "integrator" of the inhibitory input, which can be seen if make the inhibitory input pulse very long in duration

Neuron 3: t_pulse=100.0, I_pulse=-2.5, I_base=0.5