P01 report file

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Abstract

This report consists of an overview on the first project.

1 INTRODUCTION

As requested, three models have been implemented using the Euler method, and various input currents such as sinusoidal, step, constant, noise and linear current have been provided to them. Additionally, features such as refractory time and adaptivity have been incorporated into these models, which we analyze and examine in this report.

2 ANALYSIS AND BEHAVIORS

2.1 Different Input Currents

2.1.1 LIF Model

Model parameters are listed in Table 1, and the corresponding results are presented in Figure 1. The model exhibits the anticipated behavior. When the initial potential is set at -75 mV, we observe a periodic response for constant current, attributed to potential resetting after reaching the threshold. Notably, when linear current is applied, the frequency of spikes increases. This phenomenon arises due to the increased $RI(t)$ term, resulting in accelerated graph growth. By applying step currents, the model exhibits a typical behavior. Prior to and following the application of current, it approaches the resting potential due to the influence of the leakage term. However, upon applying input current, the model begins to exhibit spikes. This phenomenon arises from the $RI(t)$ term, resulting in an increase in the growth rate of the graph. When sinusoidal current is applied, growth rate of neuron's potential changes due to the current's value and it leads to observing a wavy behavior in neuron's potential chart untill it reaches the threshold. By applying short strong pulses we see a sudden increase in neuron's potential but since the duration of the pulse is very short it is not enough for neuron to have spike.

Table 1: LIF parameters.

Model	Parameters				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF	-45	1	-55	-75	10

Figure 1: LIF

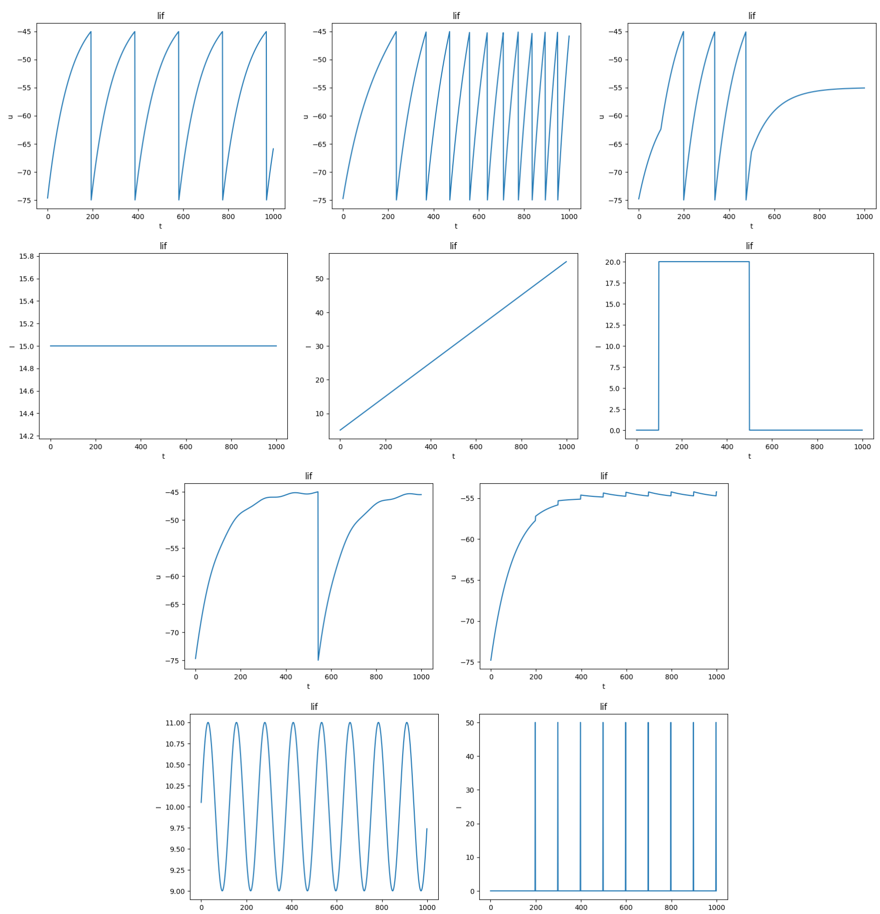


Table 2: EXLIF parameters.

Model	Parameters						
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**
EXLIF	-35	1	-55	-75	10	-50	0.5

2.1.2 EXLIF Model

Model parameters are shown in Table 2, and the corresponding results are presented in Figure 2. The dashed orange line represents the rh potential. In all scenarios, the neuron exhibits exponential behavior upon reaching the rh potential and subsequently resets upon reaching the threshold value, denoted as θ_{reset}. The application of a constant current induces the expected periodic spiking characteristic of the EXLIF neural model. Interestingly, when a linear current is applied, the spike frequency of the neuron increases due to the influence of the $RI(t)$ term. Notably, the neuron tends to approach the rest potential both before and after step current application. However, immediately after discontinuing the current, if the neuron's potential remains higher than the rh, spikes can still occur due to the exponential behavior. It is important to note that this phenomenon is not necessarily observed below the rh potential. The application of sinusoidal current yields distinct shapes of potential behavior. Short pulses require a significantly strong magnitude to induce a spike. We will revisit the distinction between short pulses and step currents for EXLIF model later in our discussion.

Figure 2: EXLIF

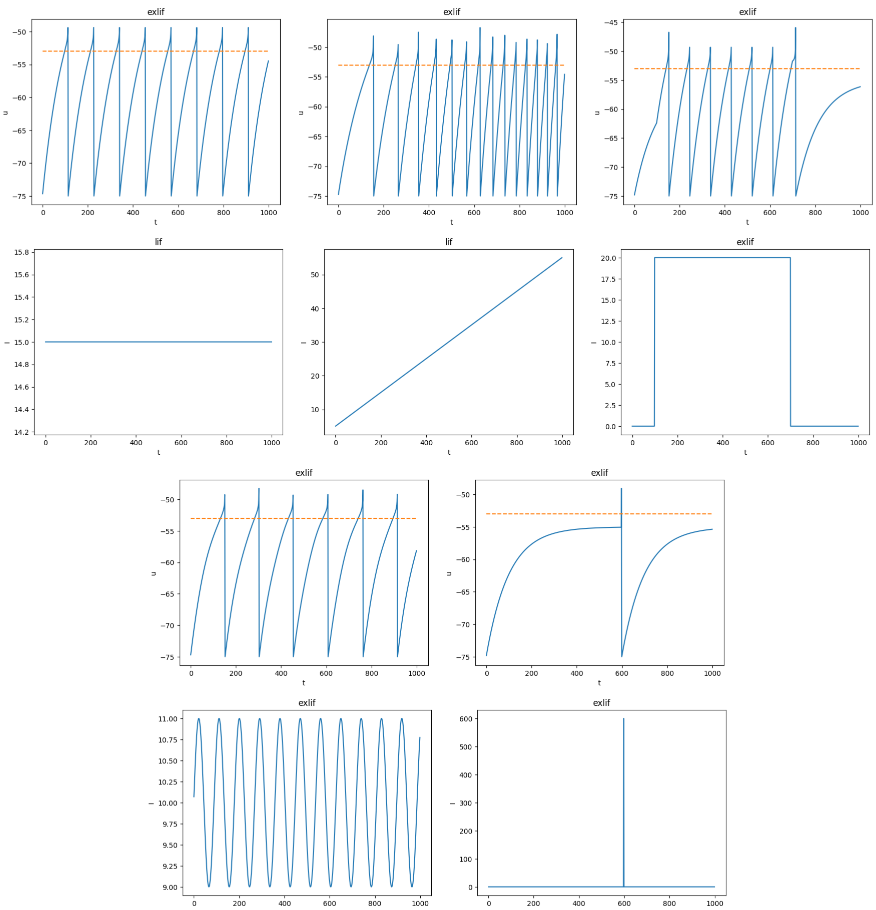


Table 3: AELIF parameters.

Model	Parameters								
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**	**a**	**b**
AELIF	-35	1	-55	-75	10	-50	0.5	5	100

2.1.3 AELIF Model

Model parameters are shown in Table 3, and the corresponding results are presented in Figure 3. The dashed orange line represents the rh potential. In all scenarios, the neuron exhibits exponential behavior upon reaching the rh potential and subsequently resets upon reaching the threshold value, denoted as θ_{reset}. The application of a constant current induces the expected periodic spiking characteristic of the AELIF neural model, Moreover, adaptability is observable: following each spike, there is a sudden increase in the value of parameter w, leading to an adaptive response characterized by a reduction in spike frequency.
Interestingly, when a linear current is applied, the spike frequency of the neuron increases due to the influence of the $RI(t)$ term. It is evident that the frequency does not escalate to the same amount as observed in the EXLIF model. This difference highlights the role of w in modulating the behavior.
Remarkably, the neuron tends to approach the resting membrane potential both before and after step current application. Although the adaptivity rate remains higher than at the beginning of the simulation, it gradually decreases after the initial current cutoff due to the absence of spikes for a period. Notably, the neuron loses some of its adaptation after the current cessation, yet it remains more adapted than the begining of the simulation. Furthermore, during the time when current is present, the neuron continues to enhance its adaptation.
The application of sinusoidal current yields wavy shapes of potential behavior. Short pulses require a significantly strong magnitude to induce a spike. For a better understanding the rh and starting potential are a bit different from other figures (other parameters are the same.) as we can see every time there is a spike there is a sudden increase of w, the increase of w cause more adaptivity, resulting in a requirement for more pulses to observe subsequent spikes. Furthermore, when w is higher, each pulse has less impact on the potential chart.

Figure 3: AELIF

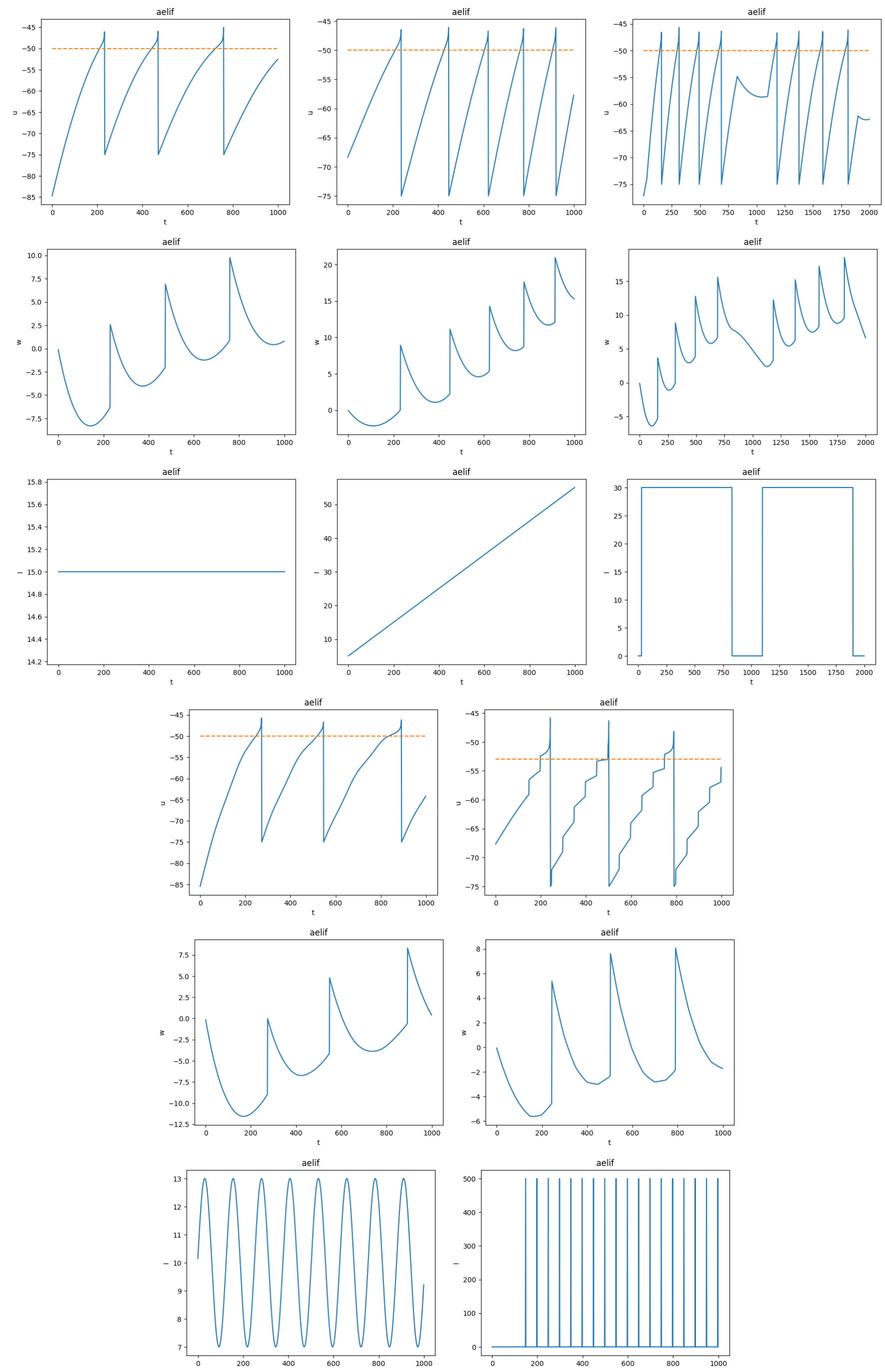


Table 4: LIF parameters.

Model	Parameters				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF	-45	1	-55	-75	10

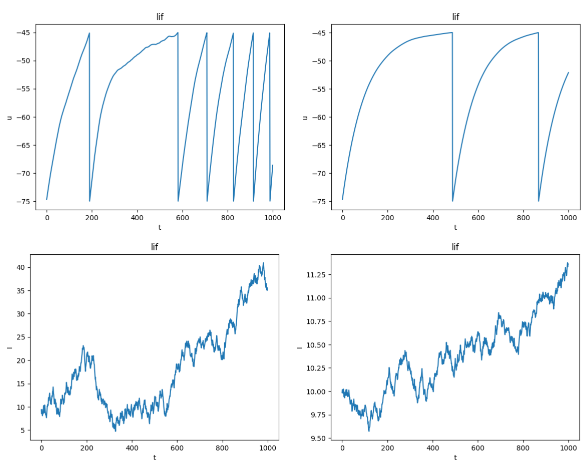


Figure 4: LIF uniform noise 2 and 0.1

2.2 NOISE EFFECT

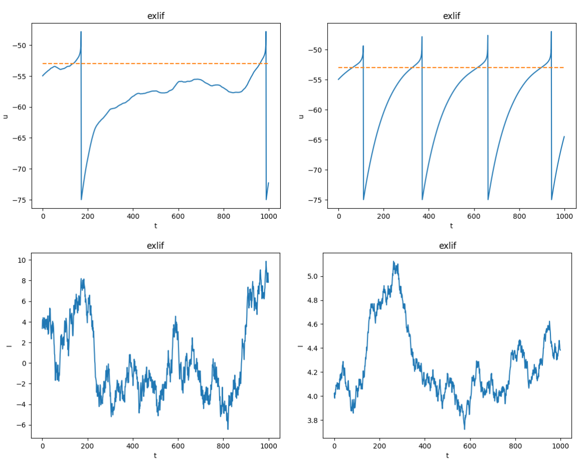
2.2.1 LIF Model

Model parameters are shown in Table 4, and the corresponding results are presented in Figure 4. By examining two noise levels (2 and 0.1), we observe that reduced noise leads to decreased sensitivity in the neuron model. Notably, when the input current contains higher noise, there is greater fluctuation in the neuron's membrane potential.

Table 5: EXLIF parameters.

Model	Parameters						
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**
EXLIF	-45	1	-55	-75	10	-50	0.5

Figure 5: EXLIF uniform noise 2 and 0.1



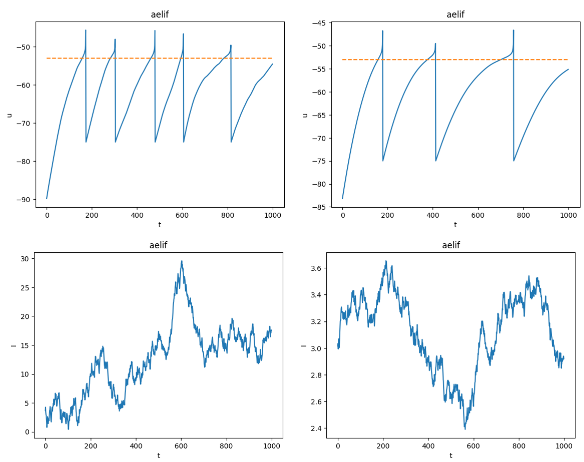
2.2.2 EXLIF Model

Model parameters are shown in Table 5, and the corresponding results are presented in Figure 5. By examining two noise levels (2 and 0.1), we observe that reduced noise leads to decreased sensitivity in the neuron model. Notably, when the input current contains higher noise, there is greater fluctuation in the neuron's membrane potential and lower noises result in smoother charts. The exponential behavior of neuron model is still observable after rh potential.

Table 6: AELIF parameters.

Model	Parameters								
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**	**a**	**b**
AELIF	-45	1	-55	-75	10	-50	0.5	5	100

Figure 6: AELIF uniform noise 2 and 0.1



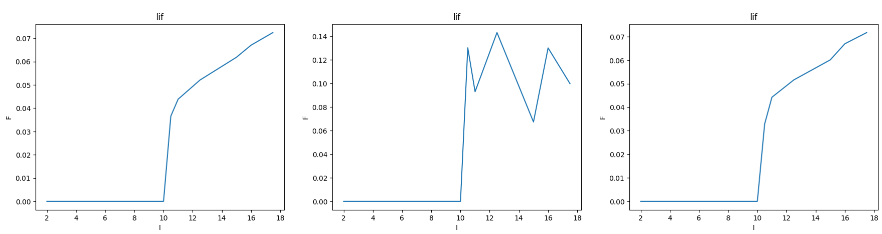
2.2.3 AELIF Model

Model parameters are shown in Table 6, and the corresponding results are presented in Figure 6. By examining two noise levels (2 and 0.1), we observe that reduced noise leads to decreased sensitivity in the neuron model. Notably, when the input current contains higher noise, there is greater fluctuation in the neuron's membrane potential and lower noises result in smoother charts. The exponential behavior of neuron model is still observable after rh potential. Furthermore, the adaptability becomes more obvious when the noise level is set to 0.1 and with higher noise levels, the model's adaptation is less visible due to the influence of random input currents.

Table 7: LIF parameters.

Model	Parameters				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF	-45	1	-55	-75	10

Figure 7: LIF constant and noise freq.



2.3 FREQUENCY

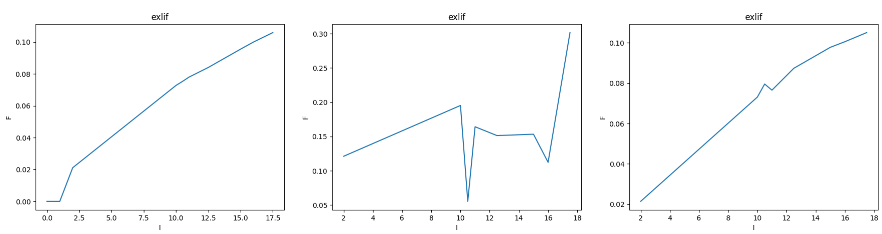
2.3.1 LIF Model

Model parameters are shown in Table 7, and the corresponding results are presented in Figure 7. The frequency is determined by measuring the number of spikes during a specific duration while running the model with constant currents. The frequency remains zero until the input current reaches a specific threshold. After this threshold, the neuron begins to spike, and the frequency increases in proportion to the magnitude of I.
The second picture shows the F-I (frequency-current) chart obtained by applying currents with a high noise level (4). The observed behavior is not reasonable due to the presence of noise in the input current. However, when we reduce the noise level to 0.1, the behavior becomes more sensible and aligned with expectations.

Table 8: EXLIF parameters.

Model	Parameters						
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**
EXLIF	-45	1	-55	-75	10	-50	0.5

Figure 8: EXLIF constant and noise freq.



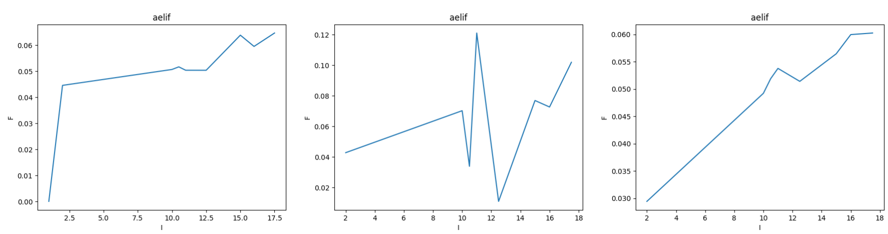
2.3.2 EXLIF Model

Model parameters are shown in Table 8, and the corresponding results are presented in Figure 8. The frequency is determined by measuring the number of spikes during a specific duration while running the model with constant currents. The frequency remains zero until the input current reaches a specific threshold. After this threshold, the neuron begins to spike, and the frequency increases in proportion to the magnitude of I.
The second picture shows the F-I (frequency-current) chart obtained by applying currents with a high noise level (4). The observed behavior is not reasonable due to the presence of noise in the input current. However, when we reduce the noise level to 0.1, the behavior becomes more sensible and aligned with expectations.

Table 9: AELIF parameters.

Model	**Parameters**								
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**	**a**	**b**
AELIF	-45	1	-55	-75	10	-50	0.5	5	100

Figure 9: AELIF constant and noise freq.



2.3.3 AELIF Model

Model parameters are shown in Table 9, and the corresponding results are presented in Figure 9. The frequency is determined by measuring the number of spikes during a specific duration while running the model with constant currents. The frequency remains zero until the input current reaches a specific threshold. After this threshold, the neuron begins to spike, and the frequency increases in proportion to the magnitude of I.
The second picture shows the F-I (frequency-current) chart obtained by applying currents with a high noise level (4). The observed behavior is not reasonable due to the presence of noise in the input current. However, when we reduce the noise level to 0.1, the behavior becomes more sensible and aligned with expectations.
Note that adaptivity does not impact the chart since the frequency is measured after the simulation completes. For observing frequency during simulation reach the section 2.1.3.

Table 10: LIF parameters.

Model	Parameters				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF	-45	1	-55	-75	10

2.4 REFRACTORY

2.4.1 LIF Model

Model parameters are shown in Table 10, and the corresponding results are presented in Figure 10. The refractory interval is implemented in two modes: with adaptive threshold and without. By blocking the current for a time interval, the membrane potential behaves like when there is no current so it approaches the rest potential, as soon as the refractory time is finished input current shows its impact on the membrane potential. two fisrt pictures of figure 10 are LIF model with refractory time of 100 and 300. the two last pictures show the behavior of neuron when threshold is adaptive we have the refractory time of 100 and 300.

Figure 10: LIF Refractory

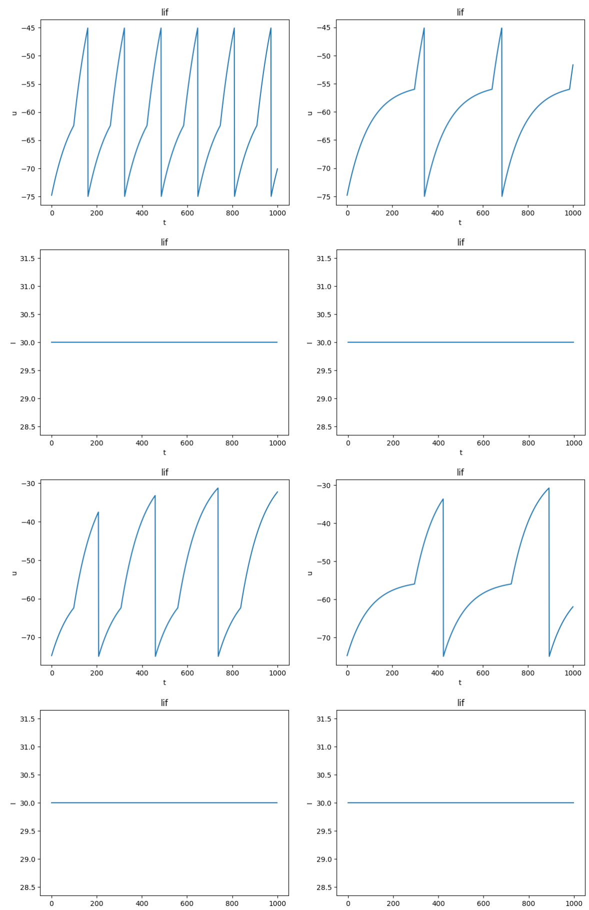
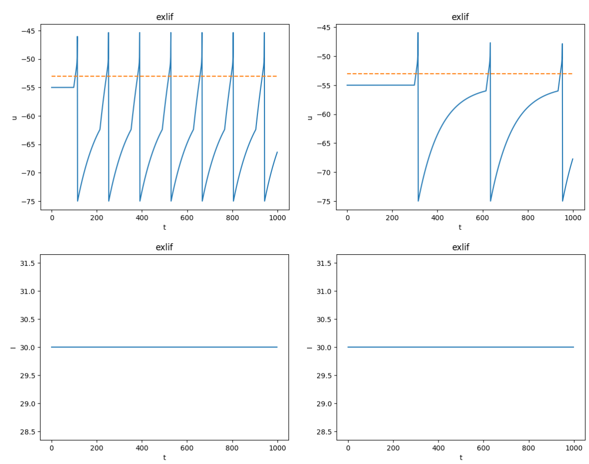


Table 11: EXLIF parameters.

Model	Parameters						
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**
EXLIF	-45	1	-55	-75	10	-50	0.5

Figure 11: EXLIF Refractory



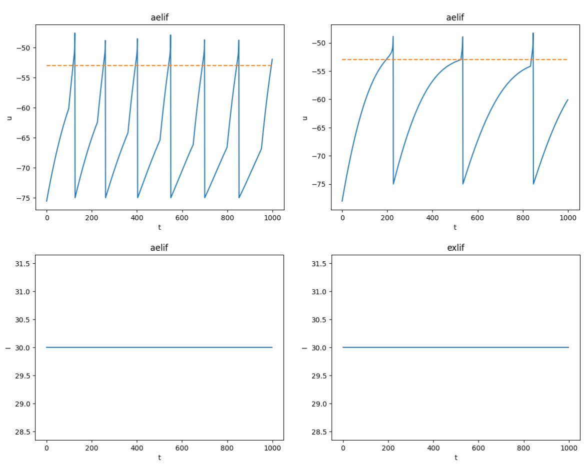
2.4.2 EXLIF Model

Model parameters are shown in Table 11, and the corresponding results are presented in Figure 11. The refractory interval is implementedby blocking the current for a time interval, which leads to that the membrane potential behaves like when there is no current so it approaches the rest potential, as soon as the refractory time is finished input current shows its impact on the membrane potential. two first pictures of Figure 11 are EXLIF model with refractory time of 100 and 300.

Table 12: AELIF parameters.

Model	Parameters								
	thresh	R	u rest	u reset	tau	rh	delta	a	b
AELIF	-45	1	-55	-75	10	-50	0.5	5	100

Figure 12: AELIF Refractory



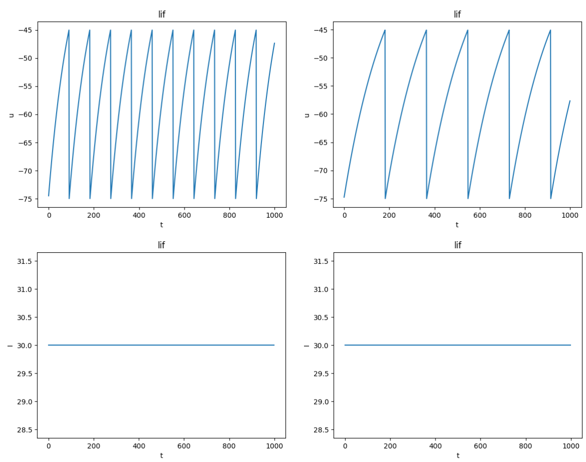
2.4.3 AELIF Model

Model parameters are shown in Table 12, and the corresponding results are presented in Figure 12. The refractory interval is implemented by blocking the current for a time interval, which leads to that the membrane potential behaves like when there is no current so it approaches the rest potential, as soon as the refractory time is finished input current shows its impact on the membrane potential. two first pictures of Figure 12 are AELIF model with refractory time of 100 and 300. Note that the adaptivity is still sensible.

Table 13: LIF parameters.

Figure	Parameters				
	thresh	**R**	**u rest**	**u reset**	**tau**
13 Left	-45	1	-55	-75	10
13 Right	-45	1	-55	-75	20

Figure 13: LIF τ



3 INTERESTING RESULTS

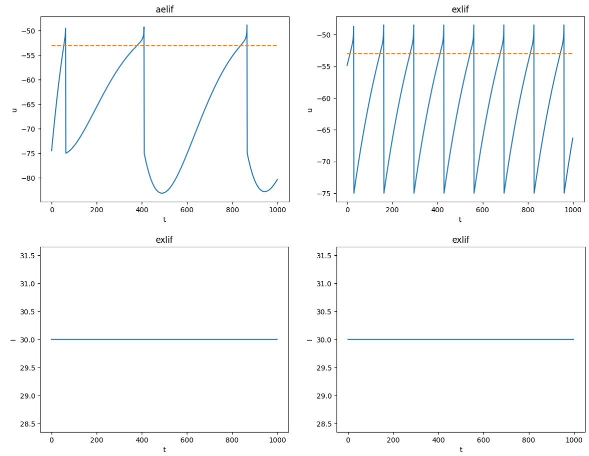
3.1 Different τs in LIF

Model parameters are shown in Table 13, and the corresponding results are presented in Figure 13. In the figures, it is evident that an increase in the parameter τ leads to a decrease in frequency of spiking.

Table 14: EXLIF parameters.

Figure	Parameters						
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**
14 Left	-45	1	-55	-75	10	-50	0.5
14 Right	-45	1	-55	-75	20	-50	0.5

Figure 14: EXLIF τ



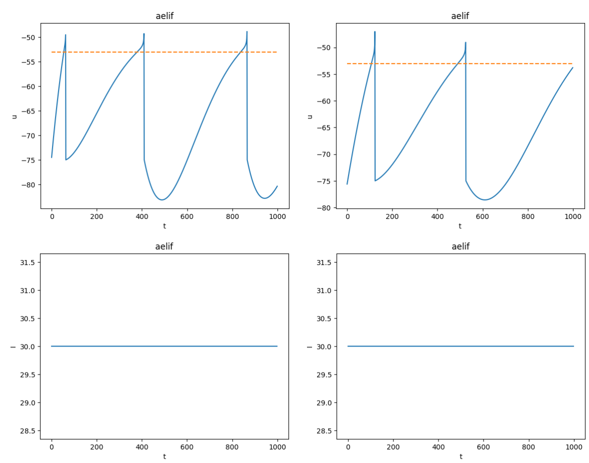
3.2 Different τs in EXLIF

Model parameters are shown in Table 14, and the corresponding results are presented in Figure 14. In the figures, it is evident that an increase in the parameter τ leads to a decrease in frequency of spiking. Also the exponential behavior of the neuron is visible after the rh potential.

Table 15: AELIF parameters.

Figure	Parameters								
	thresh	**R**	**u rest**	**u reset**	**tauM**	**rh**	**delta**	**a**	**b**
15 Left	-45	1	-55	-75	10	-50	0.5	5	500
15 Right	-45	1	-55	-75	20	-50	0.5	5	500

Figure 15: AELIF τ_M



3.3 Different τs in AELIF

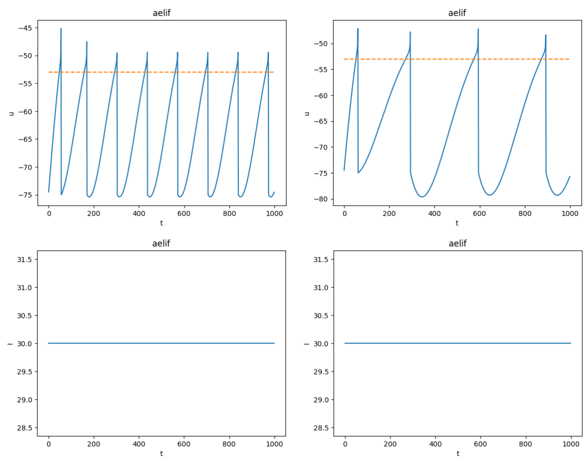
3.3.1 τ_M

Model parameters are shown in Table 15, and the corresponding results are presented in Figure 15. In the figures, it is evident that an increase in the parameter τ_M leads to a decrease in frequency of spiking. Also the exponential behavior of the neuron is visible after the rh potential. The adaptivity is also observable.

Table 16: AELIF parameters.

Figure	Parameters								
	thresh	**R**	**u rest**	**u reset**	**tauW**	**rh**	**delta**	**a**	**b**
16 Left	-45	1	-55	-75	20	-50	0.5	5	500
16 Right	-45	1	-55	-75	60	-50	0.5	5	500

Figure 16: AELIF τ_M



3.3.2 τ_W

Model parameters are shown in Table 16, and the corresponding results are presented in Figure 16. In the figures, it is evident that an increase in the parameter τ_W leads to an increase in adaptivity of neuron. Also the exponential behavior of the neuron is visible after the rh potential.

Table 17: AELIF parameters.

Figure	Parameters								
	thresh	**R**	**u rest**	**u reset**	**tauM**	**rh**	**delta**	**a**	**b**
16 Left	-45	1	-55	-75	20	-50	0.5	0	500
16 Right	-45	1	-55	-75	20	-50	0.5	10	500

3.4 Different as in AELIF

Model parameters are shown in Table 17, and the corresponding results are presented in Figure 17. By applying 0 to a the model will have no subthreshold adaptivity which cause the less decrease rate in w and thus higher adaptivity.

Figure 17: AELIF a

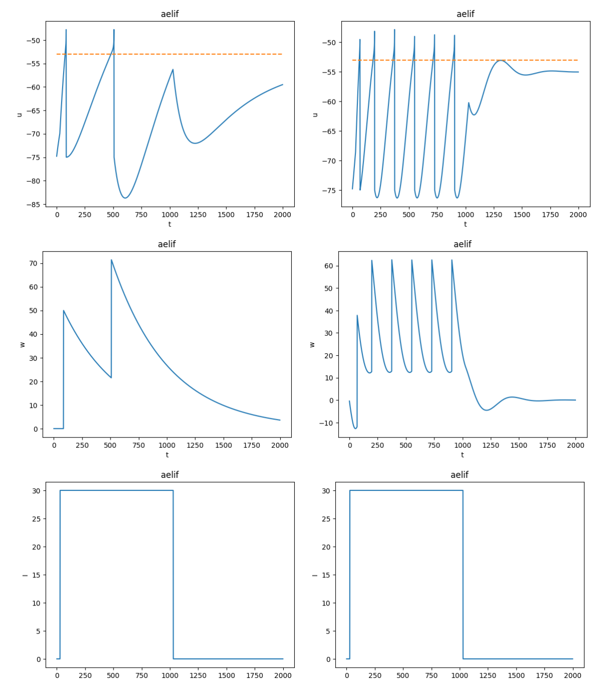


Table 18: AELIF parameters.

Figure	Parameters								
	thresh	**R**	**u rest**	**u reset**	**tauM**	**rh**	**delta**	**a**	**b**
18 Left	-45	1	-55	-75	20	-50	0.5	0	500
18 Right	-45	1	-55	-75	20	-50	0.5	0	50

3.5 Different bs in AELIF

Model parameters are shown in Table 18, and the corresponding results are presented in Figure 18. The higher the b the higher the adaptivity!

Figure 18: AELIF b

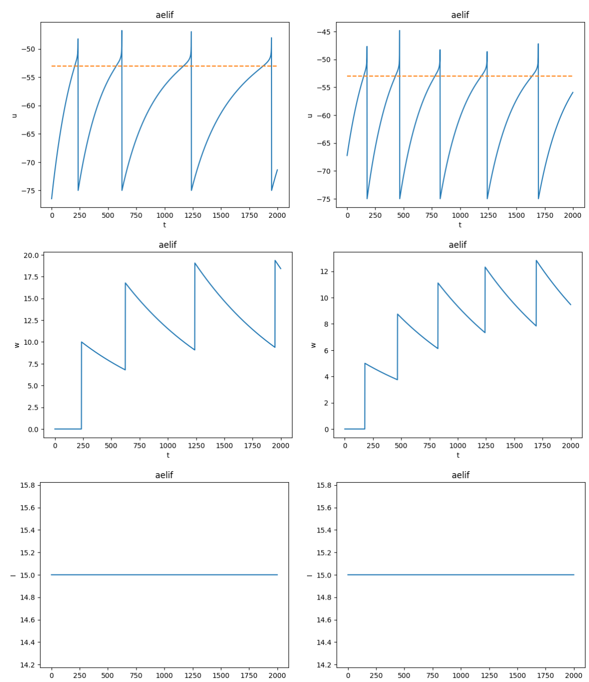


Table 19: EXLIF parameters.

Model	Parameters						
	thresh	**R**	**u rest**	**u reset**	**tau**	**rh**	**delta**
EXLIF	-45	1	-55	-75	10	-50	0.5

3.6 Step VS. Pulse currents in EXLIF

As we saw in the lectures, step currents with lower magnitude result in different behavior from short pulses with higher magnitude. A short current pulse $I(t) = q\delta(t-t_0)$ injected into related differential equation delivers at time t_0 a total charge q and causes a voltage step of $\Delta u = Rq/\tau$. The voltage $u+u_{rest}+\Delta u$ serves as initial condition for the integration of the differential equation after the input pulse. For $u < \Theta$ (which is somewhere above rh) the membrane potential returns to the resting potential, while for $u > \Theta$ the membrane potential increases furthur, until the increase is stopped at the numerical threshold. Thus the unstable fixed point Θ serves as a voltage threshold, if the neuron model is simulated by a short current pulse.
Under the application of a constant current, the picture is different. If the current is sufficiently large, both fixed points disappear so that du/dt is always positive. As a result, the voltage increases until it hits threshold,at which point it is reset and the same picture repeats. Model parameters are shown in Table 19, and the corresponding results are presented in Figure 19.

Figure 19: EXLIF