



MODELLING OF EXCITATION AND FIRING IN SIMPLE NEURAL NETWORKS

YAKUP ÇATALKAYA

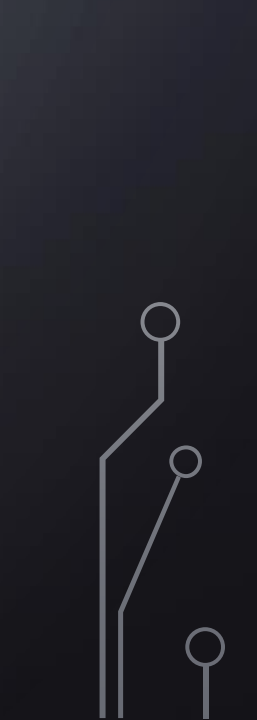


21704019

yakup.catalkaya@ug.bilkent.edu.tr



ABSTRACT

In the project, the aim is to understand how and under what conditions a neuron can be fired or excited. For that matter, by using NEURON simulation program and Python programming language, a neural network will be designed and be tested with several signals for stimulation purposes. After that, in order to understand further, the concept of firing and excitation of a neuron will be investigated by applying external stimulations in a simulation environment. At the end, how external stimulation techniques could be used to fire or excite a neuron will be answered.



THE ELECTRICAL CIRCUIT MODEL

$$\delta I = C_m \frac{dV}{dt} + G_{Na} * m^3 * h * (V - E_{Na}) + G_K * n^4 * (V - E_K) + G_{Cl} * (V - E_{Cl}) + I_{app}$$

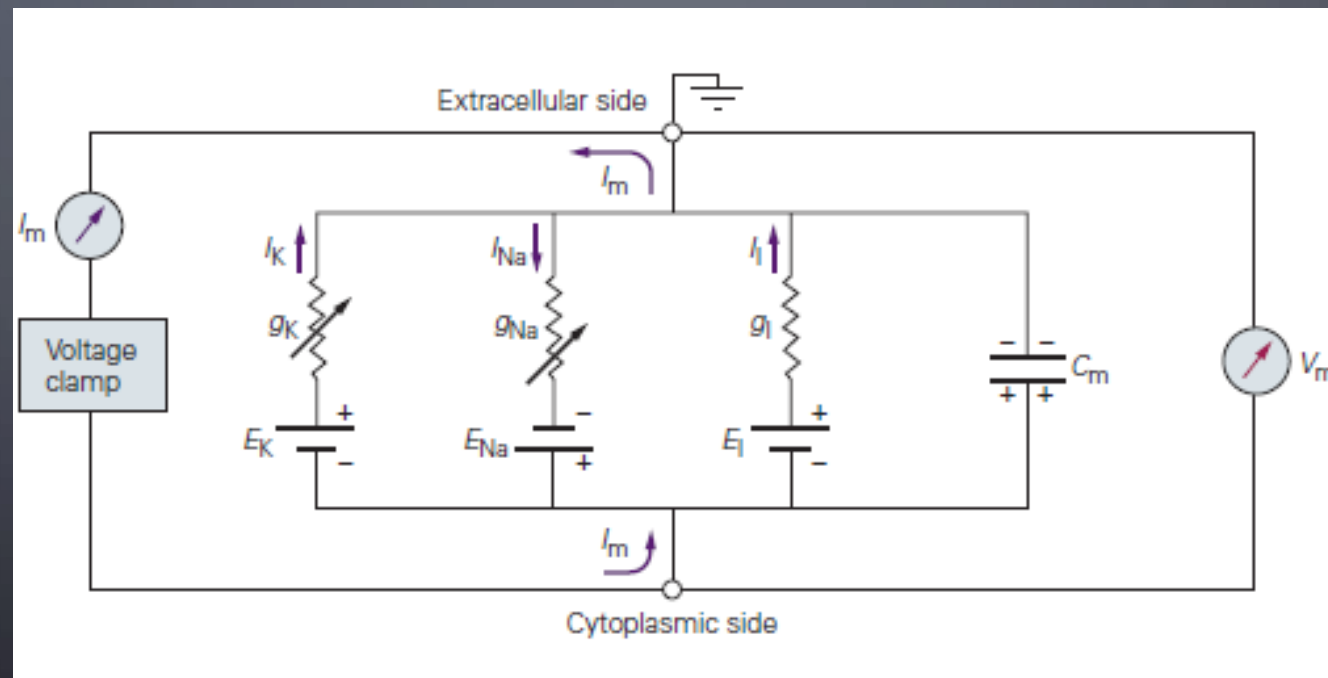


Figure 1: Electrical model

THE MATHEMATICAL MODEL

x	E _x [mV]	G _x [mS/cm ²]
Na	55	40
K	-77	35
CL	-65	0.3

Table 1: Electrical potential and conductivity of voltage gated ion channels [3]

x	α_x (u/mV) [ms ⁻¹]	β_x (u/mV) [ms ⁻¹]
n	$0.01 (V + 10) / [-1 + e^{(V+10)/10}]$	$0.125 e^{V/80}$
m	$0.1 (V + 25) / [-1 + e^{(V+25)/10}]$	$4 e^{V/18}$
h	$1 / [1 + e^{(V+30)/10}]$	$1 / [1 + e^{(V+30)/10}]$

Table 2: Coefficient equation for m, n, and h [4]

$$\frac{dn}{dt} = \alpha_n * (1 - n) - \beta_n * n$$

$$\frac{dm}{dt} = \alpha_m * (1 - m) - \beta_m * m$$

$$\frac{dh}{dt} = \alpha_h * (1 - h) - \beta_h * h$$

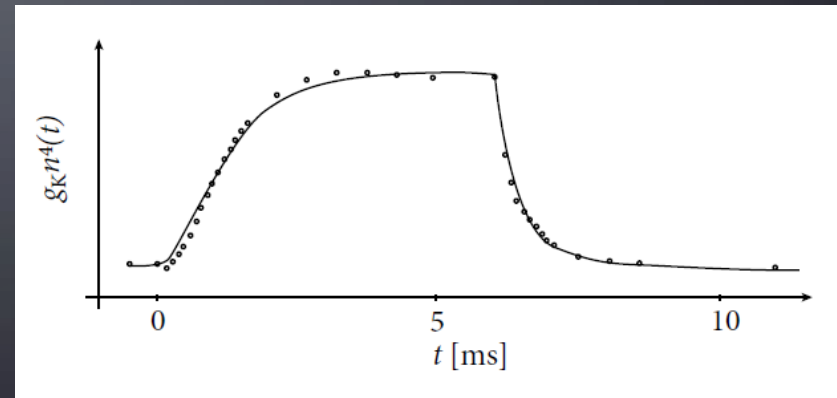


Figure 2: Voltage gated potassium channel graph

CONDUCTIVITY OF ION CHANNELS

The conductivity of ion channels in an axon change according to the membrane potential of the axon, and this change in conductivity can affect the ability of the axon to transmit electrical signals. By controlling the opening and closing of ion channels in response to changes in the membrane potential, neurons can regulate the flow of ions into and out of the cell, allowing them to generate and transmit electrical signals [1].

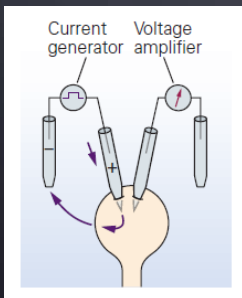
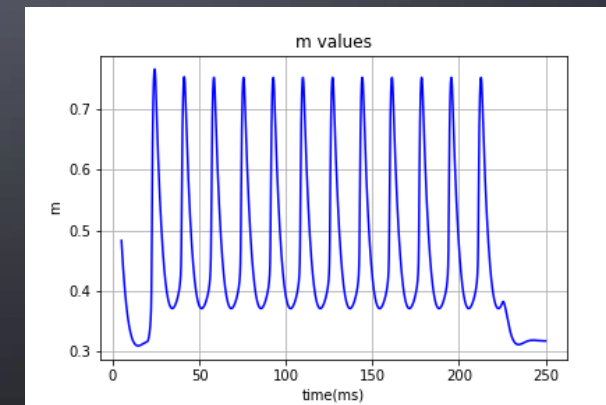
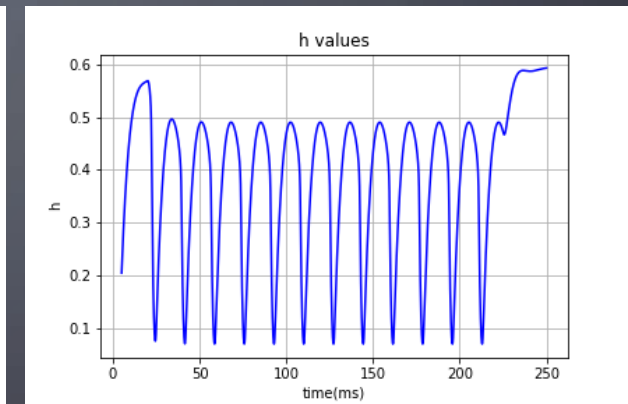
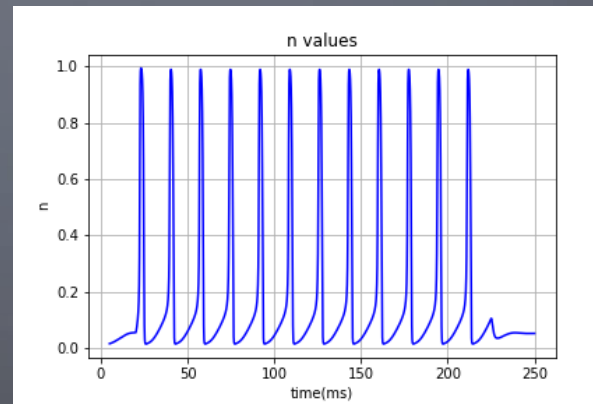
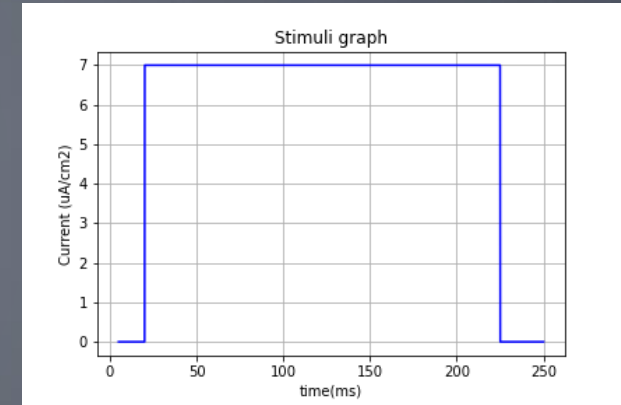
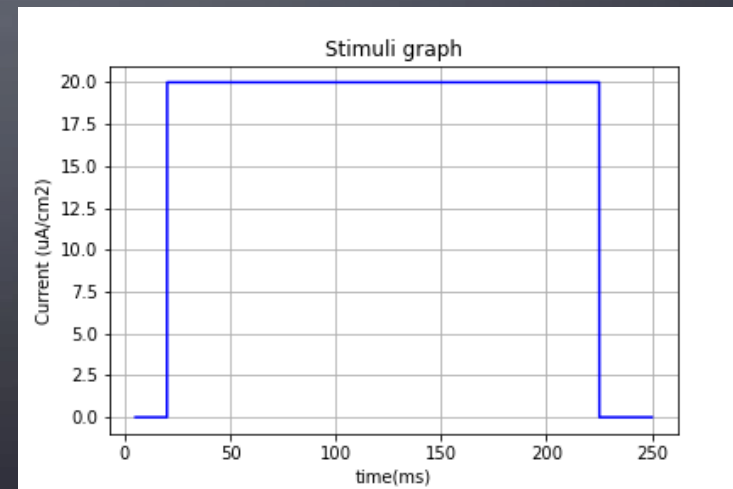
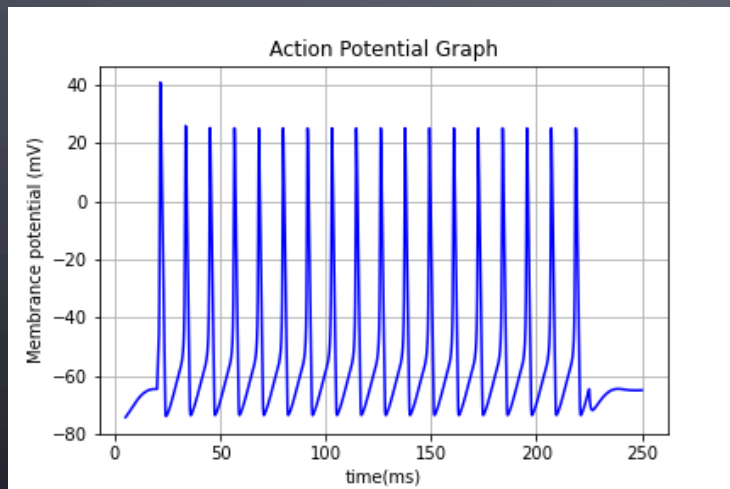
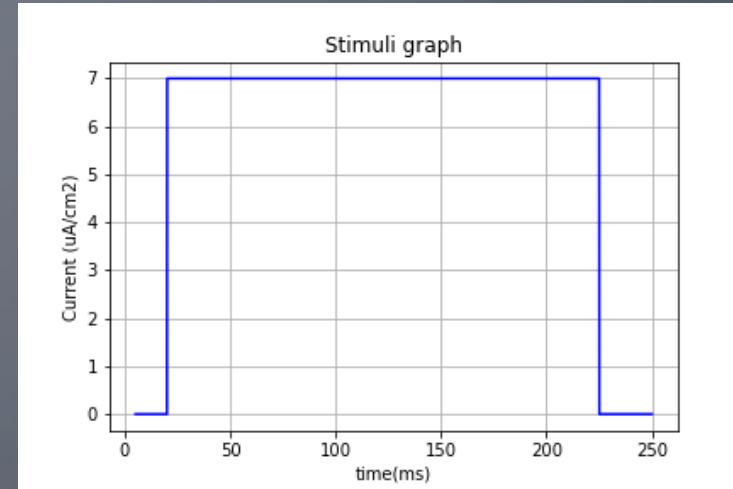
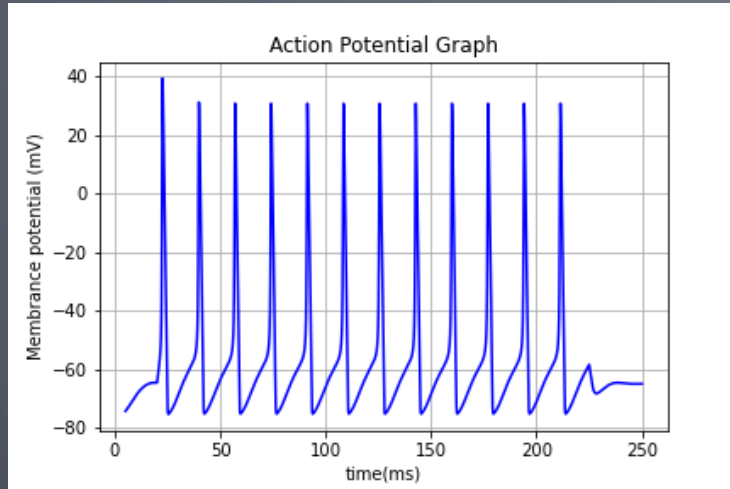


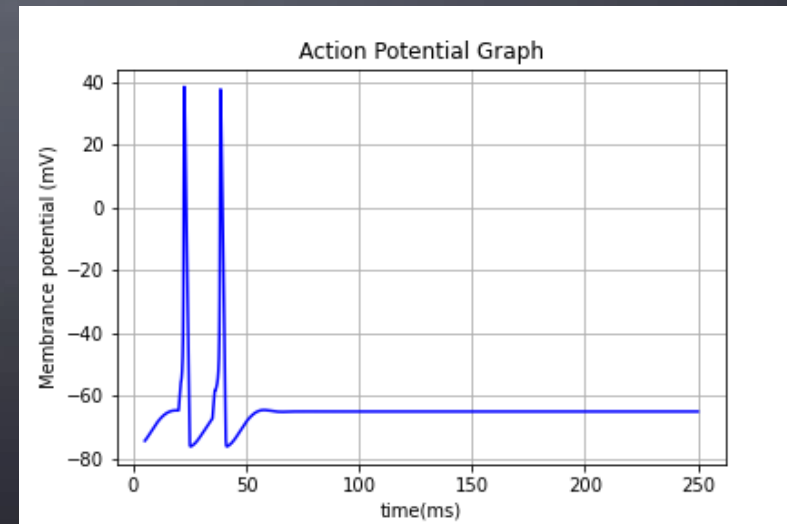
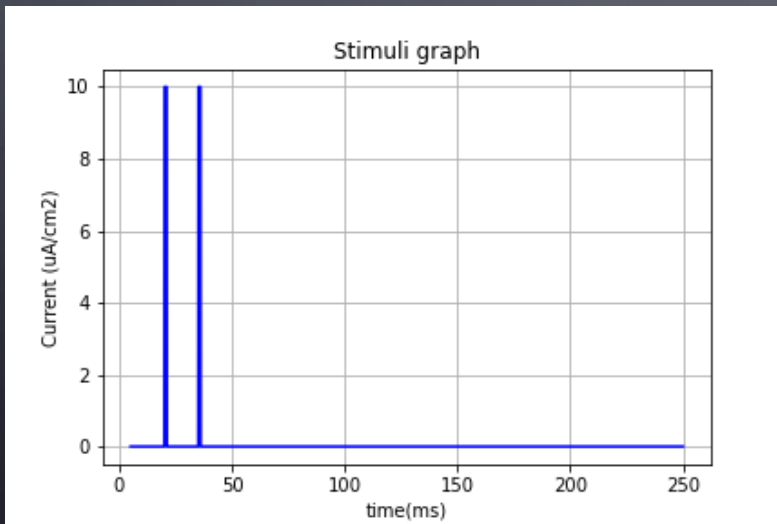
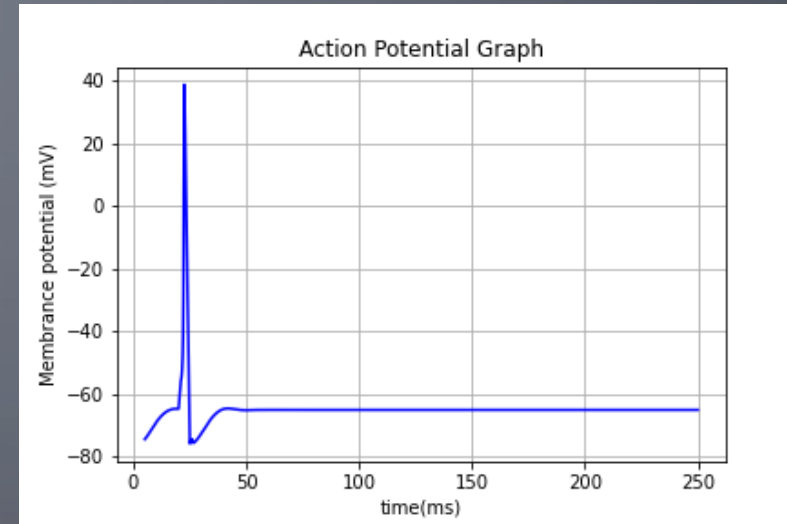
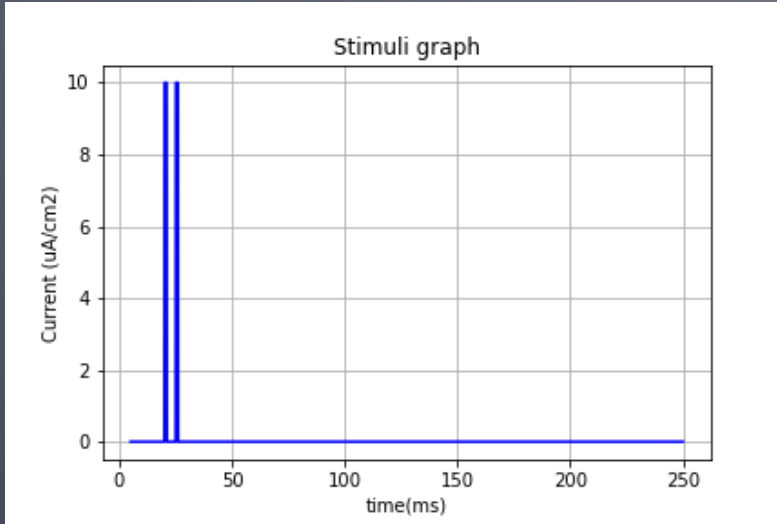
Figure 3: Microglass for current source and microelectrode for action potential recording



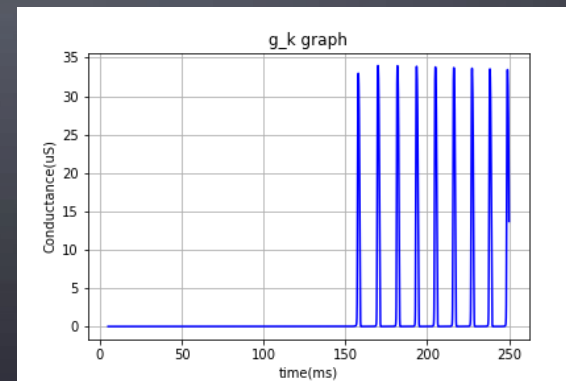
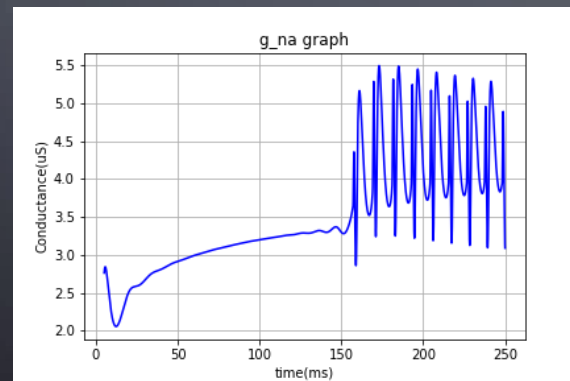
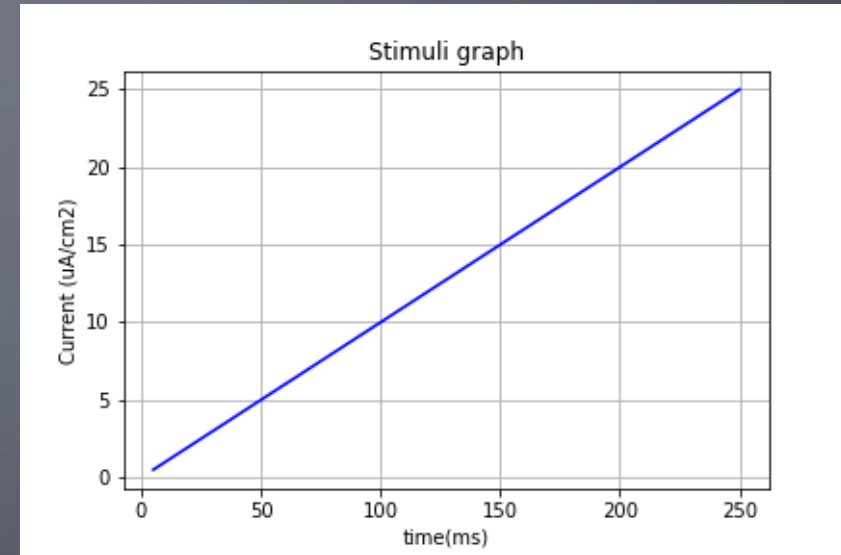
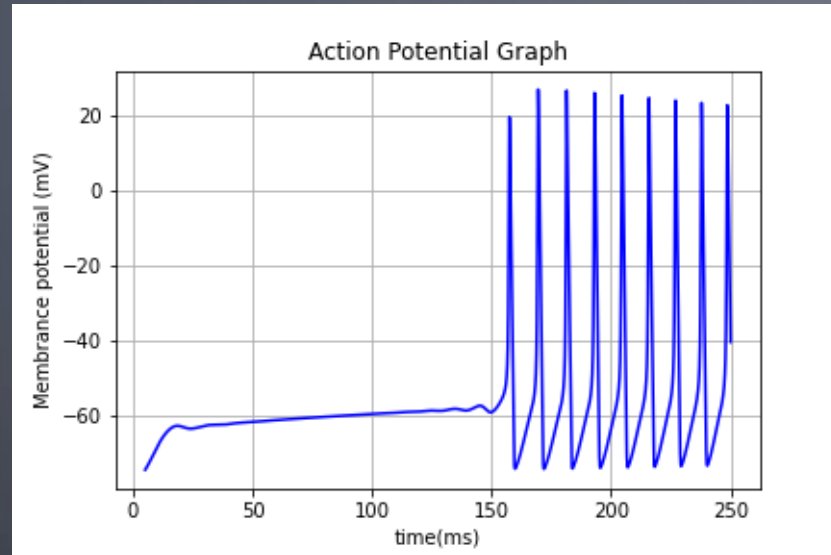
VARIOUS STIMULI AND ITS CORRESPONDING ACTION POTENTIALS



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PHYSICAL MODEL

$$\mathbf{D} = \epsilon_0 \epsilon_r \mathbf{E}$$

$$\mathbf{J}_c = \sigma \mathbf{E}$$

$$\nabla \cdot \mathbf{J} = Q_{j,v}$$

$$\mathbf{J} = \sigma \mathbf{E} + \mathbf{J}_e$$

$$\mathbf{E} = -\nabla V$$

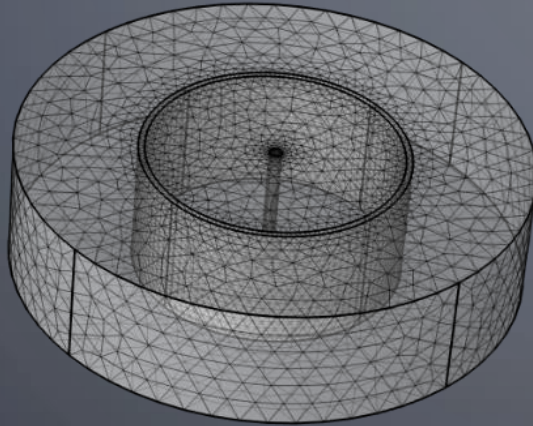


Figure 4: Physical model for axoplasm, membrane and extracellular area of an axon

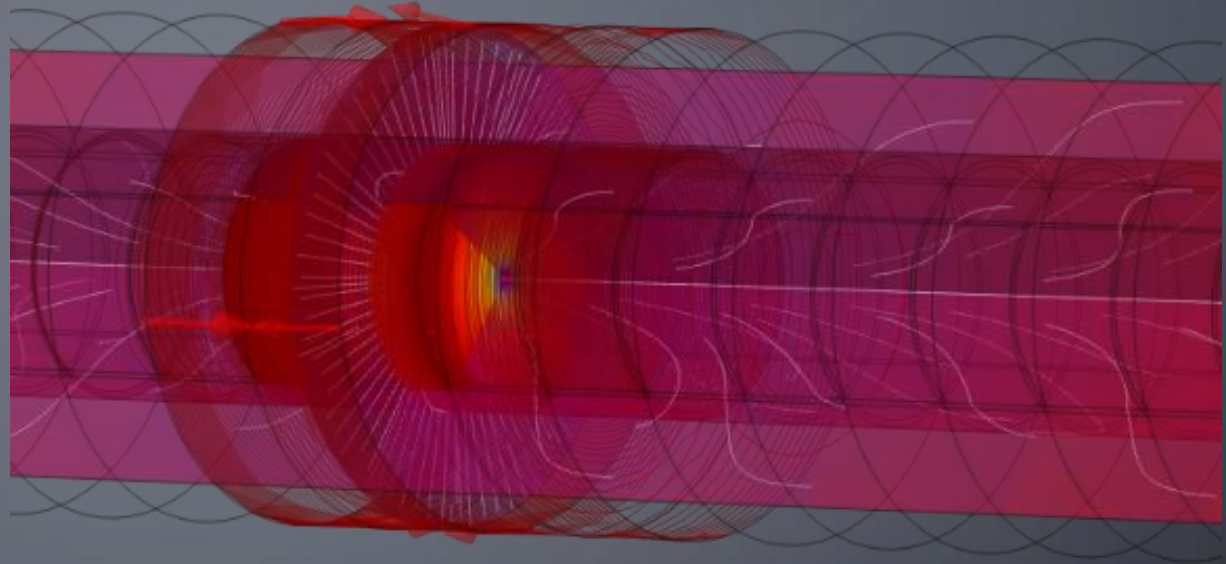
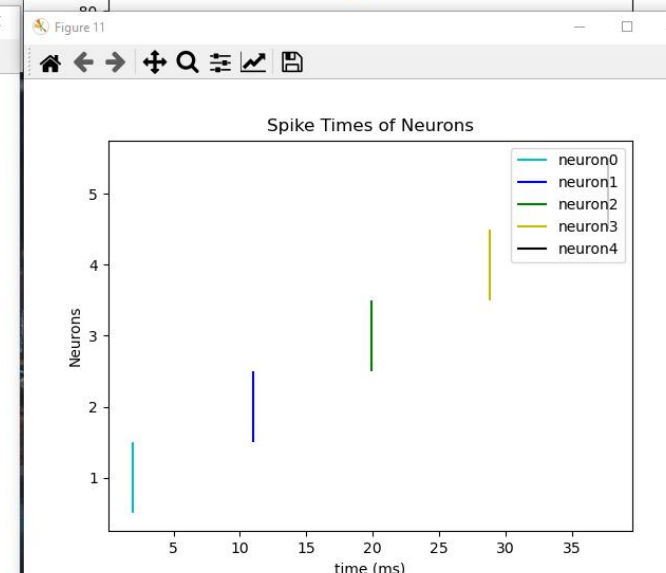
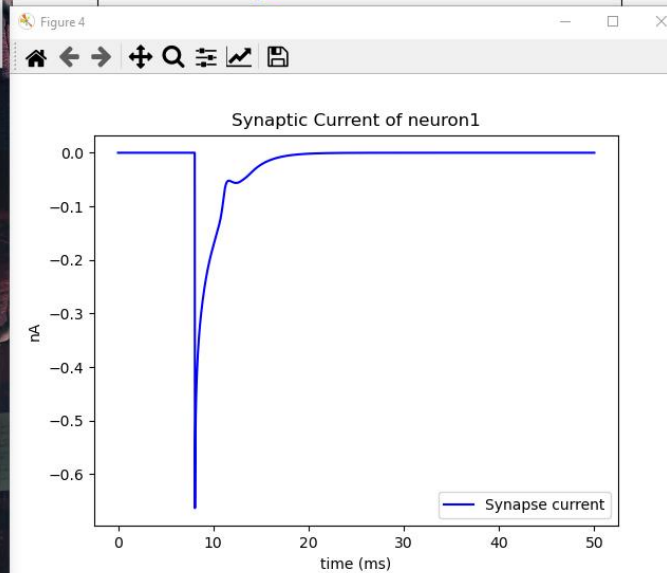
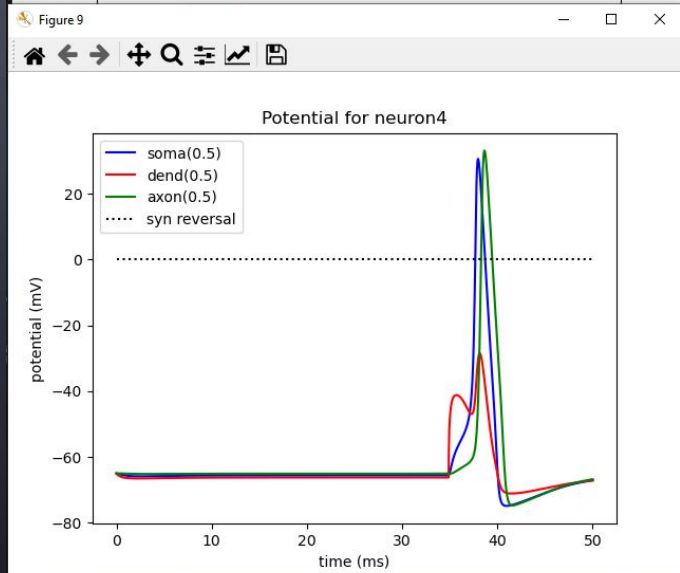
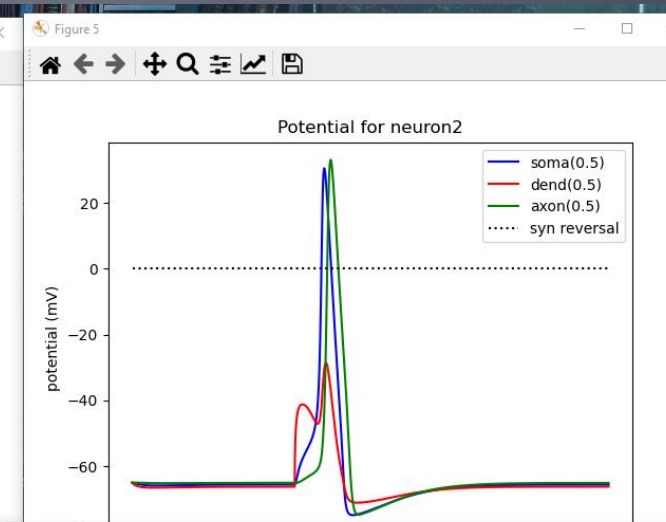
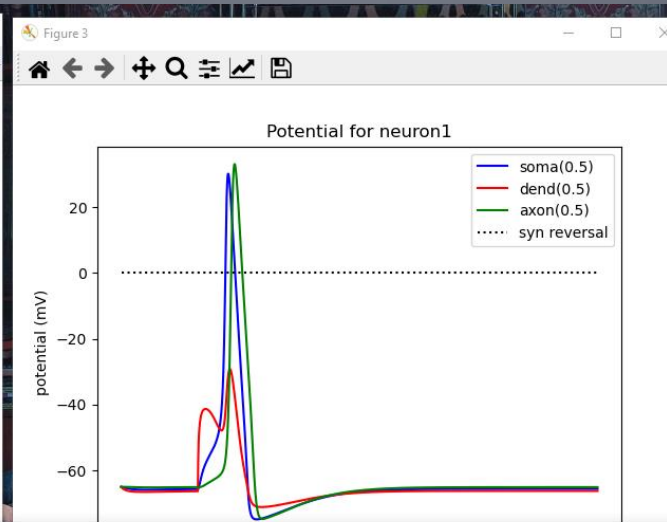
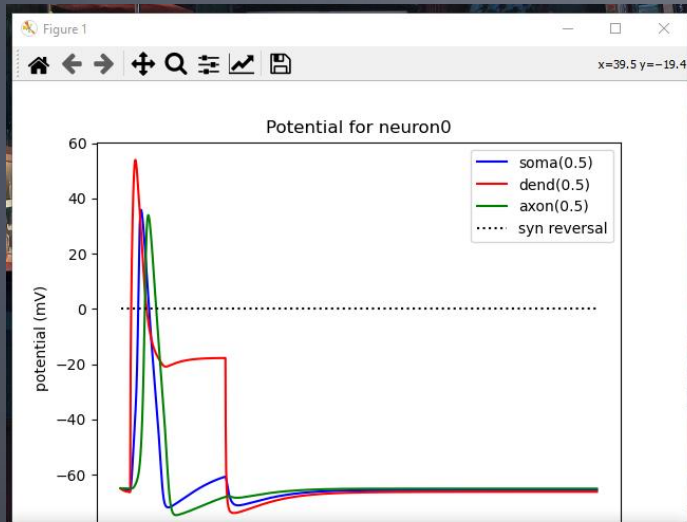


Figure 10: A physical axon model with stimuli



Figure 11: Physical model for axon and \mathbf{E} field

FURTHER RESEARCH



FURTHER RESEARCH

Untitled.mph - COMSOL Multiphysics (Trial version)

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder Model Manager Component 1 Add Component Parameters Variables Functions Parameter Case Build All LiveLink Add Material Electric Currents Add Physics Build Mesh Compute Study Add Study Electric Field Norm (ec) Add Plot Group Add Predefined Plot Windows Reset Desktop

Model Builder

- Untitled.mph (root)
 - Global Definitions
 - Parameters 1
 - m alpha (m_alpha)
 - m beta (m_beta)
 - h alpha (h_alpha)
 - h beta (h_beta)
 - n alpha (n_alpha)
 - n beta (n_beta)
 - dm (dm)
 - dn (dn)
 - dh (dh)
 - dv (dv)
 - g_k (g_k)
 - g_na (g_na)
 - Default Model Inputs
 - Materials
 - Component 1 (comp1)
 - Definitions
 - upper_v (upper_v)
 - lower_v (lower_v)
 - Boundary System 1 (sys1)
 - View 1
 - Geometry 1
 - Materials
 - Electric Currents (ec)
 - Global ODEs and DAEs (ge)
 - Mesh 1
 - Study 1
 - Results
 - Datasets
 - Derived Values
 - Tables
 - Electric Potential (ec)
 - Electric Field Norm (ec)
 - Multislice 1
 - Streamline Multislice 1
 - Contour 1
 - Arrow Line 1
 - Arrow Line 2
 - 1D Plot Group 3
 - Probe Plot Group 4
 - Export
 - Reports

Settings

Parameters

Label: Parameters 1

Name	Expression	Value
memb_int_r	1[mm]	0.001 m
memb_r	50000[nm]	5E-5 m
height	1 [mm]	0.001 m
memb_epsilon	5.65	5.65
E_na	55 [mV]	0.055 V
E_k	-72 [mV]	-0.072 V
E_cl	-49.387 [mV]	-0.049387 V
axoplasm_cond	0.5	0.5
axoplasm_epsilon	80	80
extoplasm_cond	1	1
extoplasm_epsilon	80	80
memb_capacitance	1 [uF/cm^2]	0.01 F/m^2
hole_r	0.05[mm]	5E-5 m
memb_rest_pot	-65 [mV]	-0.065 V
u	0 [mV]	0 V
memb_pot	u + memb_rest_pot	-0.065 V
g_na_const	120 [mS/cm^2]	1200 S/m^2
g_k_const	36 [mS/cm^2]	360 S/m^2
g_cl_const	0.3 [mS/cm^2]	3 S/m^2
e_na	115 [mV]	0.115 V
e_k	-12 [mV]	-0.012 V
e_cl	10.613[mV]	0.010613 V
g_cl	g_na_const / memb_capacitan...	1.2E5 1/s
i_memb	0 [mA]	0 A
memb_cond	1	1

Graphics

Multislice: Electric field norm (mV/m) Contour: Electric potential (V) Arrow Line: Current density

Arrow Line: Current density

1.59x10^4

1.77x10^-7

10^0

10^-4

10^-8

10^-12

10^-16

10^-20

1.02x10^-21

-7.08x10^-4

Add Physics

+ Add to Component 1 + Add to Selection

Recently Used

- Global ODEs and DAEs (ge)
- Electric Currents (ec)
- Electrostatics (es)
- Electrostatics, Boundary Elements (esbe)
- Electric Currents in Layered Shells (ecis)
- AC/DC
- Acoustics
- Chemical Species Transport
- Electrochemistry
- Fluid Flow
- Heat Transfer
- Optics
- Plasma
- Radio Frequency
- Semiconductor
- Structural Mechanics
- Mathematics

Physics interfaces in study

Studies	Solve
Study 1	<input checked="" type="checkbox"/>

Dependent Variables

Messages Progress Log Probe Table 1

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THANKS FOR LISTENING ...

References

- [1] Kandel, E. R., Koester, J., Mack, S., & Siegelbaum, S. (2021). Principles of Neural Science. McGraw Hill.
- [2] Moulin, C., Gliere, et Al. (2008). A new 3-D finite-element model based on thin-film approximation for microelectrode array recording of extracellular action potential. IEEE Transactions on Biomedical Engineering, 55(2), 683–692. <https://doi.org/10.1109/tbme.2007.903522>
- [3] Gerstner, W., Kistler, W. M., Naud, R., & Paninski, L. (2016). Neuronal dynamics from single neurons to networks and models of cognition. Cambridge University Press.
- [4] Hodgkin, A. L., & Huxley, A. F. (1952). A quantitative description of membrane current and its application to conduction and excitation in nerve. The Journal of Physiology, 117(4), 500–544. <https://doi.org/10.1113/jphysiol.1952.sp004764>
- [5] Elia, S., & Lamberti, P. (2013). The reproduction of the physiological behaviour of the axon of nervous cells by means of finite element models. Innovations in Intelligent Machines -3, 69–87. https://doi.org/10.1007/978-3-642-32177-1_5