**Nemo Project**

NemoSim Simulator Tool

User Guide

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Documentation Control

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Approval Table

| Version | Date | Full Name | Title | Signature |
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# Introduction

## Overview

This document describes the NemoSim simulation tool, which is used for spiking neural network architectures, and has been developed as part of the Nemo Project.

It enables researchers and engineers to model, simulate, and analyze the behavior of various neural network types, such as Leaky Integrate-and-Fire (LIF) and Brain-Inspired Unit (BIU) networks.

## Purpose

NemoSim is designed to:

* Simulate neural network architectures using user-defined configurations
* Model time-evolving neuron and synapse states in response to input currents
* Support both standard and custom network types (LIF, BIU, and extensible for new models)
* Generate outputs for scientific analysis and visualization, including detailed time-series data for neural state, synapse activity, and spikes
* Facilitate debugging and research, with outputs and tools to identify and analyze network behavior

## Key Features

* **Flexible Input**: NemoSim accepts XML-based network descriptions and plain text current input files, supporting both manual and scripted generation.
* **Extensible Design**: The modular codebase allows for easy addition of new neuron/synapse models and architectures.
* **Comprehensive Output**: The tool produces multiple output files (membrane potentials, synaptic inputs, spikes, and so on) for analysis and plotting.
* **Analysis Tools**: NemoSim includes Python scripts and guidelines for visualizing and interpreting simulation results.
* **Robust Error Handling**: The tool detects and reports errors in input files and configuration, aiding reproducibility.

## Typical Use Cases

* Computational neuroscience research
* Neuromorphic hardware prototyping and validation
* Algorithm development and prototyping for spiking neural networks

# Using the NemoSim Simulation Tool

To use the NemoSim simulation tool, do the following:

1. Prepare the XML/TXT files, as described in Section ‎2.1
2. Prepare the JSON file, as described in Section ‎2.2
3. Run the NemoSim tool, as described in Section ‎2.3
4. Plot the output, as described in Section ‎2.4

## Step 1: Preparing the XML/TXT Files

Do the following:

1. In an XML configuration file, define your network architecture, neuron parameters, and simulation settings.

|  |  |
| --- | --- |
| ***Important:*** | *The XML file must have a* ***<NetworkConfig>*** *root with a type attribute.*  *Required child elements depend on the network type (LIF, BIU, and so on).*  *All required numeric fields must be present and valid numbers.* |

For example:

* + - For a LIF network:

<NetworkConfig type="LIF">

<LIFNetwork>

<Cm>1.0</Cm>

<Cf>0.5</Cf>

<VDD>2.5</VDD>

<!-- other LIF parameters -->

</LIFNetwork>

<Architecture>

<Layer size="32"/>

<YFlash rows="32" cols="32">

<weights>

…

</weights>

</YFlash>

<!-- network connectivity, layers, weights, etc. -->

</Architecture>

</NetworkConfig>

Table ‎2‑1 defines the key parameters that are used in this section of the LIF XML configuration file.

These values are based on standard analog neuron circuit modeling practices and can be adapted depending on the simulation context.

Table ‑: LIF Network XML Configuration Parameter Definitions

| Parameter | Description | Unit | Example Value | Notes |
| --- | --- | --- | --- | --- |
| Cm | Membrane capacitance | Farads (F) | 1e-6 | Determines the neuron integration time constant |
| Cf | Feedback capacitance | Farads (F) | 1e-9 | Affects how quickly the membrane voltage resets or leaks after a spike |
| VDD | Supply voltage | Volts (V) | 5.0 | Sets the upper voltage bounds for circuit behavior |
| VTh | Threshold voltage | Volts (V) | 1.0 | Defines the spike generation threshold |
| K | Gain factor | N/A | 2 | Dimensionless scaling factor (for example, for current mirror) |
| Rmin/Rmax | Min/Max resistance in synaptic array | Ohms (Ω) | 145e3/145e6 | Used for dynamic range in weight representation |
| gm | Transconductance | Siemens (S) | 6.896e-6 | Typically from the input differential pair |
| CGB\*, CGD\*, CDB\* | Parasitic capacitances (Gate-\*, Drain-\*, Bulk-\*) | Farads (F) | ~e-18 values | Derived from transistor model extraction |
| req | Effective resistance | Ohms (Ω) | 145e3 | Used in equivalent RC modeling |
| R\_da | Driver array resistance | Ohms (Ω) | 10e3 | Series resistance from driver circuitry |
| **dt** | Simulation time step | Seconds (s) | 0.001 | Time increment for each simulation step |
| IR | Input current scaling factor | Amperes (A) | 1e-10 | Multiplies the provided input values to obtain actual currents |

|  |  |
| --- | --- |
| ***Note:*** | *Its optional to define a YFlash between the layers.*  *YFlash is a matrix of weights, in which:*   * *Each weight holds a value that represents a resistance or diode that will be multiplied by the output of each neuron.* * *Each neuron connects to the corresponding row in the YFlash, and each column of the YFlash is connected to the corresponding entrance of each neuron in the next layer.* |

* + - For a BIU network:

<NetworkConfig type="BIU">

<BIUNetwork>

<!-- BIU parameters here -->

</BIUNetwork>

<Architecture>

<Layer size="1">

<synapses rows="1" cols="1">

<weights>

<row>7.0</row>

</weights>

</synapses>

</Layer>

<!-- architecture details -->

</Architecture>

</NetworkConfig>

Each layer has its own matrix of synapses that connects to the entrance of each neuron in the layer.

Table ‎2‑2 defines the key parameters that are used in this section of the BIU XML configuration file.

These values are based on a switched-capacitor SNN architecture using programmable digital weights, charge sharing, and comparator-based thresholding.

Table ‑: BIU Network XML Configuration Parameter Definitions

| Parameter | Description | Unit | Example Value | Notes |
| --- | --- | --- | --- | --- |
| Cu | Synapse unit capacitance | Femtofarads (fF) | 4 | Defines the granularity of weight resolution |
| Cn | Neuron integration capacitor | Femtofarads (fF) | 1000 | Large capacitor for temporal integration |
| VDD | Supply voltage | Volts (V) | 1.2 | Nominal voltage for digital and analog circuitry |
| VTh | Comparator threshold voltage | Volts (V) | ±0.4 | Spike generation threshold (programmable) |
| WS | Weight sign | N/A | +1 or -1 | * Positive = VDD * Negative = VSS |
| W[3:0] | Synaptic weight (4-bit) | Digital | 0–15 | Multiplies the charge contribution per synapse |
| Refractory | Refractory period (cycles) | Integer | 1–8 | Input is blocked for N cycles after spike |
| Cl | Leakage capacitance (optional) | Femtofarads (fF) | 5e-15 | Models subthreshold leakage or passive decay |
| Vm | Neuron potential | Volts (V) | Dynamic | Computed via charge-sharing at each phase |
| Nu | Number of synaptic inputs | N/A | (varies by layer) | Determines the total Cu contribution per neuron |

1. In a plain TXT file, define the neuron values.

|  |  |
| --- | --- |
| ***Important:*** | *Each line shall contain values corresponding to the neurons in the first layer (without delimiters), representing the input current for each time step (or input channel).* |

For example:

1 0 1 0 1 1 1 0

0 0 1 0 1 1 1 0

0 0 1 0 1 1 1 0

0 0 1 0 1 1 1 0

1 0 1 0 1 1 1 0

|  |  |
| --- | --- |
| ***Tip:*** | *You can use the provided Python* ***input\_creator.py*** *script to generate input files; for example:*  python input\_creator.py  > "1e-10 \* math.sin(2 \* math.pi \* t \* 5 + 3 \* math.pi/2) + 1e-10" |

## Step 2: Preparing the JSON File

Do the following:

* In a JSON file, define your workspace parameters and input files paths.

For example:

* For a LIF network:

{

"output\_directory": "./Tests/SNN/LIF/sin\_current\_test/",

"xml\_config\_path": "./Tests/SNN/LIF/sin\_current\_test/testFull.xml",

"data\_input\_file": "./Tests/SNN/LIF/sin\_current\_test/input.txt",

"progress\_interval\_seconds": 2

}

* For a BIU network:

{

"output\_directory": "./Tests/SNN/BIU/",

"xml\_config\_path": "./Tests/SNN/BIU/test.xml",

"sup\_xml\_config\_path": "./Tests/SNN/BIU/supervisor.xml",

"data\_input\_file": "./Tests/SNN/BIU/input.txt",

"progress\_interval\_seconds": 2

}

|  |  |
| --- | --- |
| ***Note:*** | ***sup\_xml\_config\_path*** *is an optional field used only by the BIU network; all other fields are used by both the LIF and BIU networks.* |

## Step 3: Running the NemoSim Simulator Tool

Do the following:

* From the root directory, type:

NEMOSIM.exe <name of JSON file>

For example:

NEMOSIM.exe config.json

While the NemoSim is running, it will display progress messages on the screen, as demonstrated in Example ‎2‑1. If an error occurs, an error or warning message will be displayed (for details, see Section ‎3).

Example ‑: NemoSim Progress Messages

A screenshot of a computer program

AI-generated content may be incorrect.

## Step 4: Plotting the Outputs

When the NemoSim has finished running, it generates output files and places them in the output directory you specified in the JSON file (as described in Section ‎2.2).

Output files are plain text, each containing a list of numeric values (one per line). Each output file corresponds to a specific neural variable, where **<x>** is the number of the layer, and **<y>** is the number of the neuron:

* LIF Simulation (three files per neuron):
* **Iins\_<x>\_<y>.txt**: Input currents
* **Vms\_<x>\_<y>.txt**: Membrane potentials
* **Vouts\_<x>\_<y>.txt**: Output voltages (spikes)
* BIU Simulation (three files per neuron):
* **Vin\_<x>\_<y>.txt**: Synapse input values
* **Vns\_<x>\_<y>.txt**: Neural state potentials
* **Spikes\_<x>\_<y>.txt**: Output spikes

After the output files have been generated, you can plot or analyze them to look for neurons with unexpected behaviors (for example, constant potentials or no spikes) for further debugging.

Do one of the following:

* For LIF networks, use the **plot\_vm\_to\_dt.py** script.
* For BIU networks, use the **plot\_vn\_to\_dt.py** script.

For example:

python plot\_vm\_to\_dt.py Iins\_0\_0.txt vms\_0\_0.txt Vouts\_0\_0.txt

# Error Handling

|  |  |
| --- | --- |
| ***Important:*** | *All errors are considered to be critical, and will stop the NemoSim Simulator.* |

## Error Message Formats

* Errors (examples):

Error loading XML file: <description>

Error: No <NetworkConfig> root element found.

Error: Network type attribute not found in <NetworkConfig>.

## Possible Return Codes

The code uses TinyXML2, which defines error codes such as:

* XML\_SUCCESS (0): Success
* XML\_NO\_ATTRIBUTE
* XML\_WRONG\_ATTRIBUTE\_TYPE
* XML\_ERROR\_FILE\_NOT\_FOUND
* XML\_ERROR\_FILE\_COULD\_NOT\_BE\_OPENED
* XML\_ERROR\_FILE\_READ\_ERROR
* XML\_ERROR\_PARSING\_ELEMENT

For the full list, see TinyXML2's **XMLError** enum.

# References

* For details and example files for LIF, see **Tests/SNN/LIF/**.
* For details and example files for BIU, see **Tests/SNN/BIU/**.
* Output file examples: **Vin.txt**, **Vns.txt** (in the test folders).