POLITECNICO
MILANO 1863

# Computational Neuroscience
# EBRAINS – NEST Desktop

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

Benedetta Gambosi
benedetta.gambosi@polimi.it

Laboratory:
Neurorobotics and Medical Robotics Lab

# Simulating Single Neuron and Network Activity

Human Brain Project infrastructure: EBRAINS

Simulating software: NEST Desktop

Human Brain Project

EBRAINS

1. LIF model simulation — HANDS-ON
2. Hodgkin-Huxley model simulation — HANDS-ON
3. Network activity — HANDS-ON


Click on the logos to know more ☺

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# Human Brain Project infrastructure: EBRAINS

## Data and Knowledge

Find Data, Models and Software
Share Data, Models and Software
Live Papers

## Atlases

Multilevel Human Brain Atlas
Rat Brain Atlas
Mouse Brain Atlas
QUINT
QuickNII and VisuAlign
VoluBA
JuGEx

## Simulation

Elephant
**NEST Desktop**
NEST Simulator
NESTML
PyNN
Neuromorphic Computing
Neurorobotics Platform
The Virtual Brain
ViSimpl
NeuroScheme
NeuroTessMesh

## Brain-Inspired Technologies

Neuromorphic Computing
PyNN
Neurorobotics Platform

## Medical Data Analytics

Medical Informatics Platform

EBRAINS Collaboratory

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# Simulating Single Neuron and Network Activity

Human Brain Project infrastructure: EBRAINS

Simulating software: NEST Desktop

Human Brain Project

EBRAINS

1. LIF model simulation — HANDS-ON
2. Hodgkin-Huxley model simulation — HANDS-ON
3. Network activity — HANDS-ON

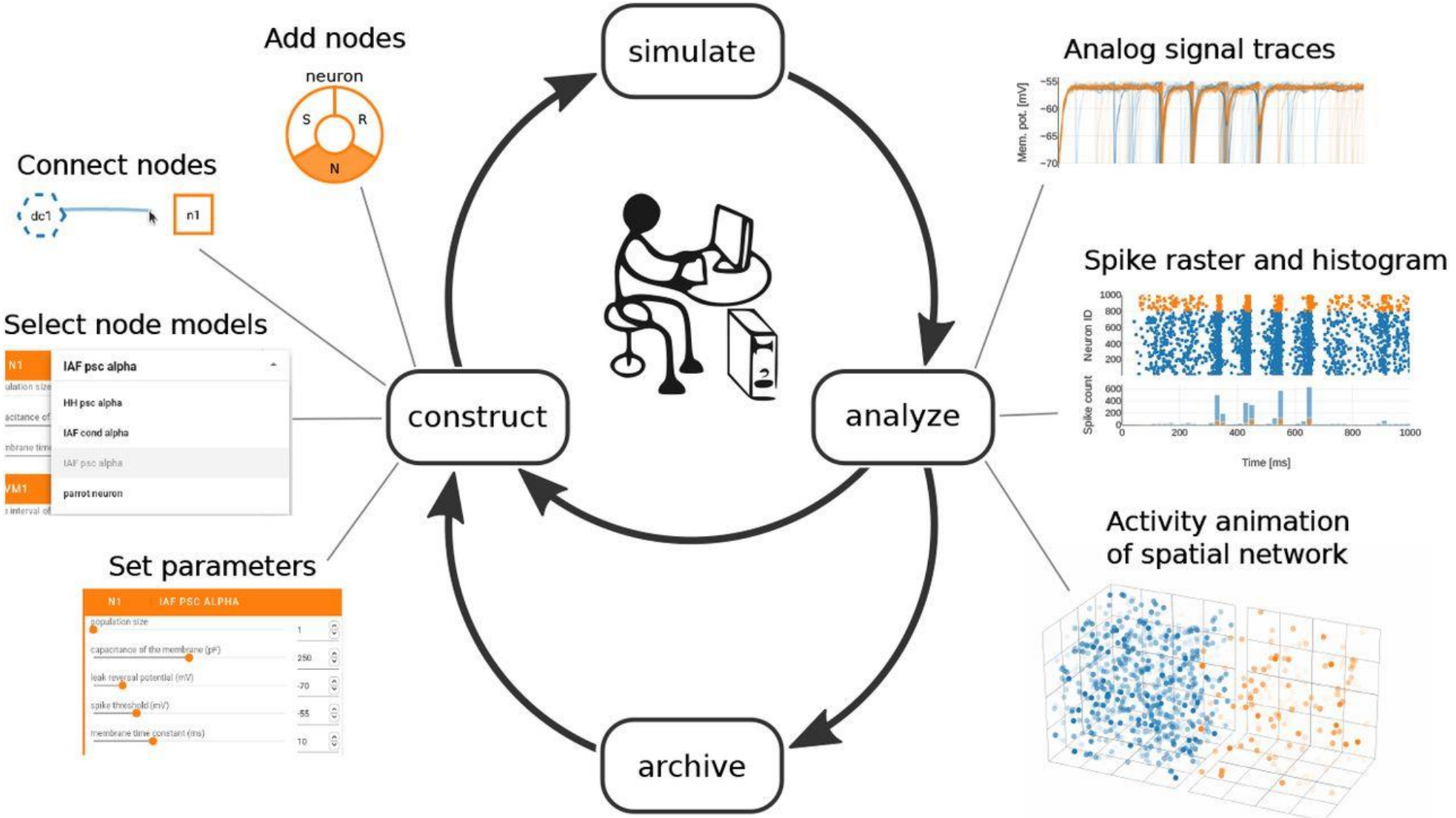

Click on the logos to know more ☺

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# Simulating software: NEST Desktop

Code

```
import nest
import numpy

nest.ResetKernel()


# Simulation kernel
nest.SetKernelStatus({
  "local_num_threads": 1,
  "resolution": 1.0,
  "rng_seed": 1
})


# Create nodes
pg1 = nest.Create("poisson_generator", 1, params={
  "rate": 6500.0
})
n1 = nest.Create("iaf_psc_alpha", 100,
  positions=nest.spatial.free(
    nest.random.uniform(-0.5, 0.5),
    num_dimensions=2
  ))
sr1 = nest.Create("spike_recorder")


# Connect nodes
nest.Connect(pg1, n1, conn_spec={
  "rule": "all_to_all"
}, syn_spec={
  "weight": 10.0
})
nest.Connect(n1, sr1, conn_spec={
  "rule": "all_to_all"
})


# Run simulation
nest.Simulate(1000)


# Define function getting activity from the recorder
def getActivity(node):
  if node.get("model") == "spike_recorder":
    nodeIds = nest.GetConnections(None, node).sources()
  else:
    nodeIds = nest.GetConnections(node).targets()
  return {
    "events": node.get("events"),
    "nodeIds": list(nodeIds)
  }

# Define function getting node positions
def getPosition(node):
  return list(zip(node.tolist(), nest.GetPosition(node)))


# Collect activities
response = {
  "kernel": {
    "biological_time": nest.GetKernelStatus("biological_time")
  },
  "activities": [
```

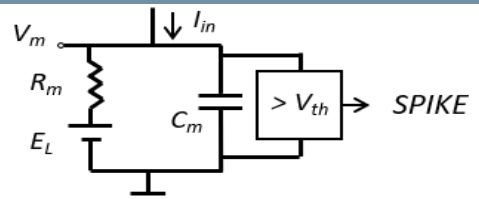


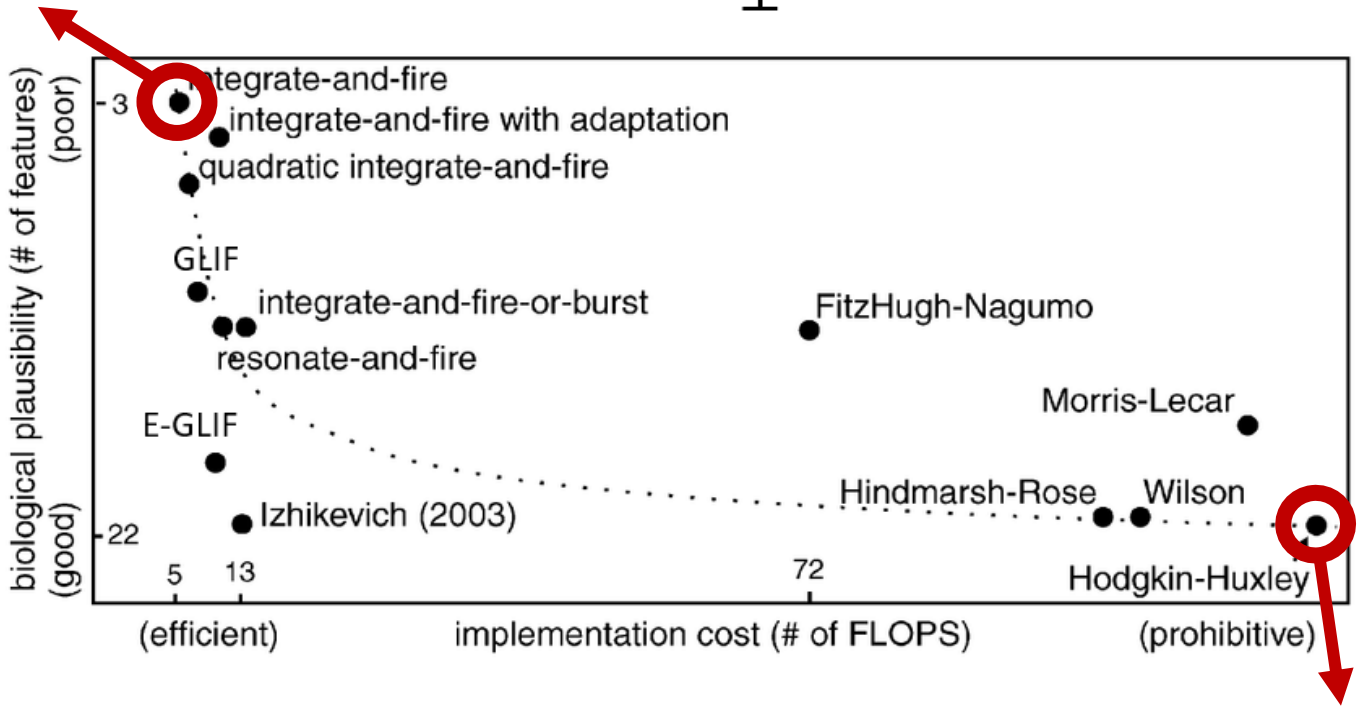


Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

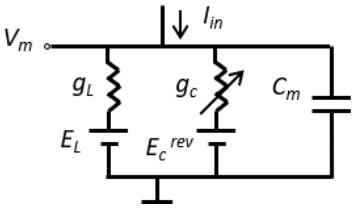
# Simulating software: NEST Desktop

LIF: Only **passive** membrane properties are considered (capacitance $C_m$ and resistance $R_m$). The output is a spike train, corresponding to time instants of threshold overcoming




HH: membrane potential $V_m$ computed considering the resting potential ($E_L$) and the contribution of each membrane **ion channel** (represented by the conductance $g_c$ and reversal potential $E_c^{rev}$).




Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# Simulating Single Neuron and Network Activity

Human Brain Project infrastructure: EBRAINS

Simulating software: NEST Desktop

Human Brain Project

EBRAINS

1. LIF model simulation — HANDS-ON
2. Hodgkin-Huxley model simulation — HANDS-ON
3. Network activity — HANDS-ON

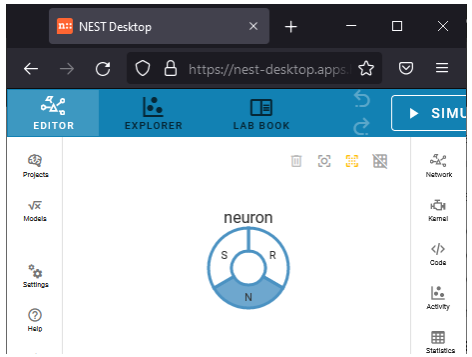

Click on the logos to know more ☺

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

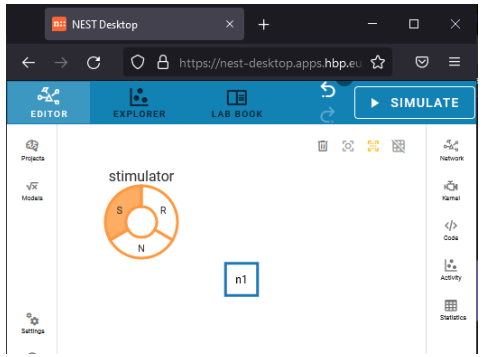
# 1 LIF model simulation

https://nest-desktop.apps.hbp.eu/#/

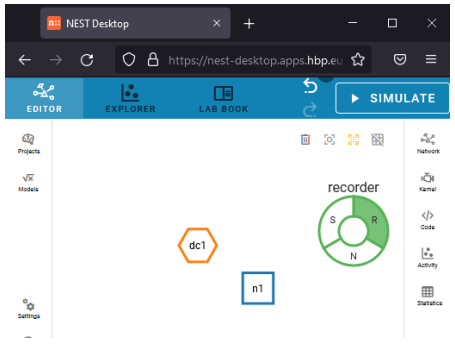
Right click → select “N”



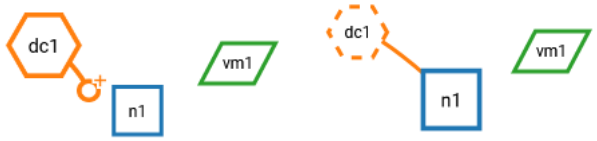

Right click → select “S”



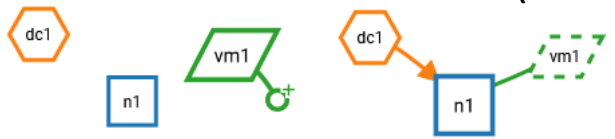

Right click → select “R”



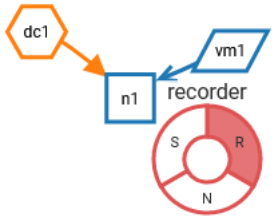

Connect the stimulator (**dc1** to **n1**)

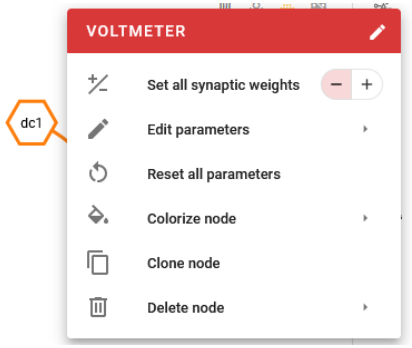


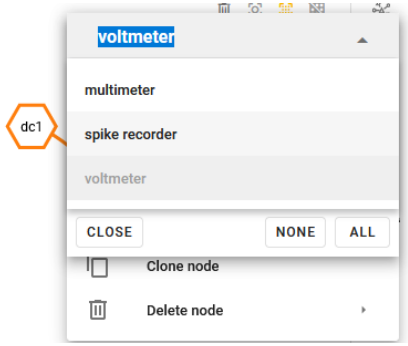

Connect the voltmeter (**vm1** to **n1**)




Add a spike recorder: change the default option “voltmeter” to “spike recorder”. Connect the spike recorder(**n1** to **sr1**)





Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

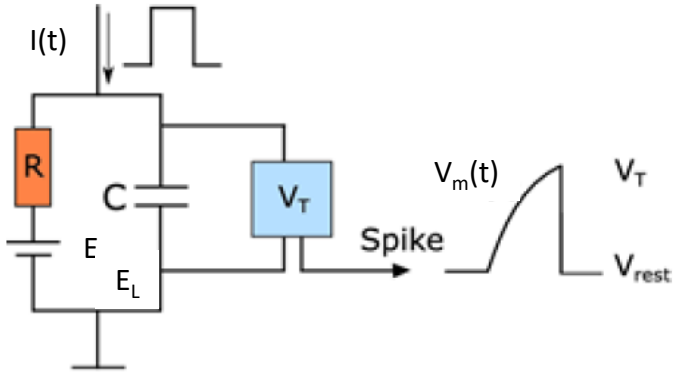
HANDS ON

# Direct current injection into single neurons

1. What is the membrane potential response for both negative and positive values of the applied current? You can measure the membrane potential by performing an intracellular recording, using a voltmeter. Try different amplitudes of the applied current and describe the phenomena you observe.

2. Explore how the membrane potential response depends on the biophysical neuron parameters. In particular, describe the influence of the spike threshold, the time constant of the membrane and the absolute refractory time on the membrane potential trajectories

$$\tau_m \frac{dV_m(t)}{dt} = -[V_m(t) - E_L] + R_m I_{in}(t)$$




Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

HANDS ON

# Poisson input into single neurons

1. Consider a LIF neuron that receives Poisson* input with a constant rate using a synapse of a specific amplitude. Analyze how the input rate influences the membrane potential and the spiking response of the neuron. The parameters of interest are the mean and the variance of the membrane potential. What happens if you change the strength of the synapse?

* Poisson input: a neuron that is firing with Poisson statistics, i.e. exponentially distributed interspike intervals. It will generate a *unique* spike train for each of it's targets.

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

EXTRAS

# Noise current injection into single neurons

1. EXTRA: Play with the parameters of the noise current over a certain range of values when there is no action potential generated, and several spikes generated. What happens to the frequency of spikes and the irregularity of spike trains as mean and/or variance if the noise is increased? The irregularity of neuronal spiking can be assessed, for example, by the coefficient of variation (CV) of the interspike intervals.
2. EXTRA: Systematically measure two types of input-output curves of the neuron:
   a) Keep the variance of the noise at a fixed level and systematically change the mean of the noise. What is the difference to the curve you obtained with pure DC input?
   b) Now keep the mean of the noise at a fixed level and systematically change the variance of the noise. What is the minimal variance ("threshold") that leads to a non-zero response rate?

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# Simulating Single Neuron and Network Activity

Human Brain Project infrastructure: EBRAINS

Simulating software: NEST Desktop

Human Brain Project

EBRAINS

1. LIF model simulation — HANDS-ON
2. Hodgkin-Huxley model simulation — HANDS-ON
3. Network activity — HANDS-ON

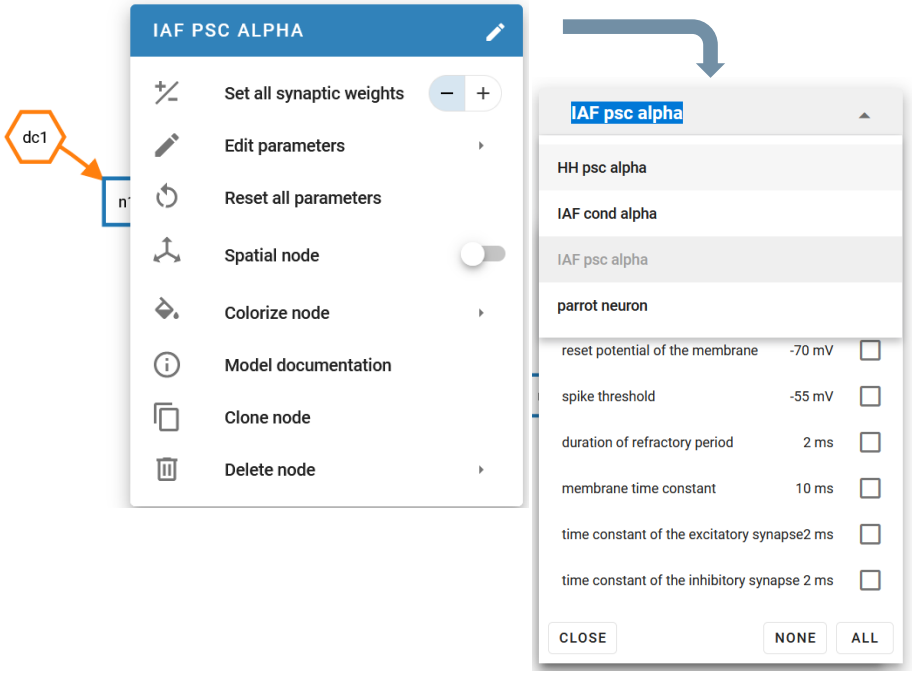

Click on the logos to know more ☺

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

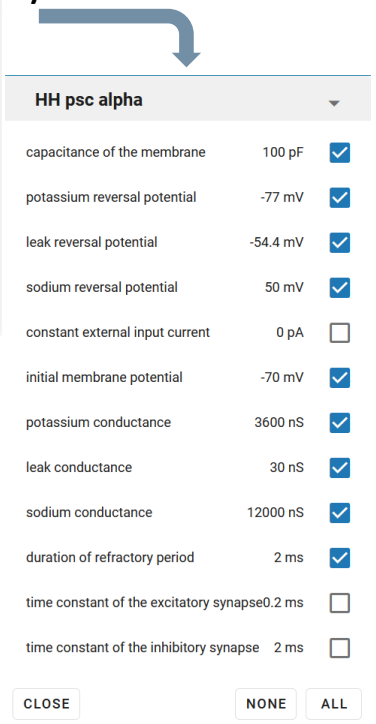
# 2 Hodgkin-Huxley model simulation

https://nest-desktop.apps.hbp.eu/#/

Change the neuron model to “HH model”.

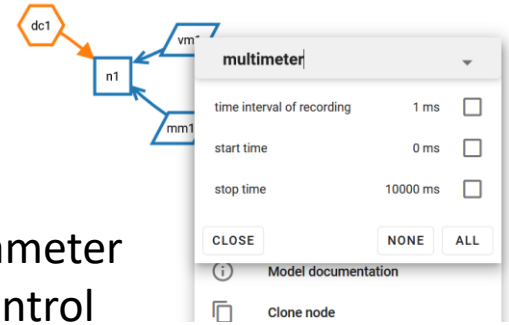



Select the parameter you want to control

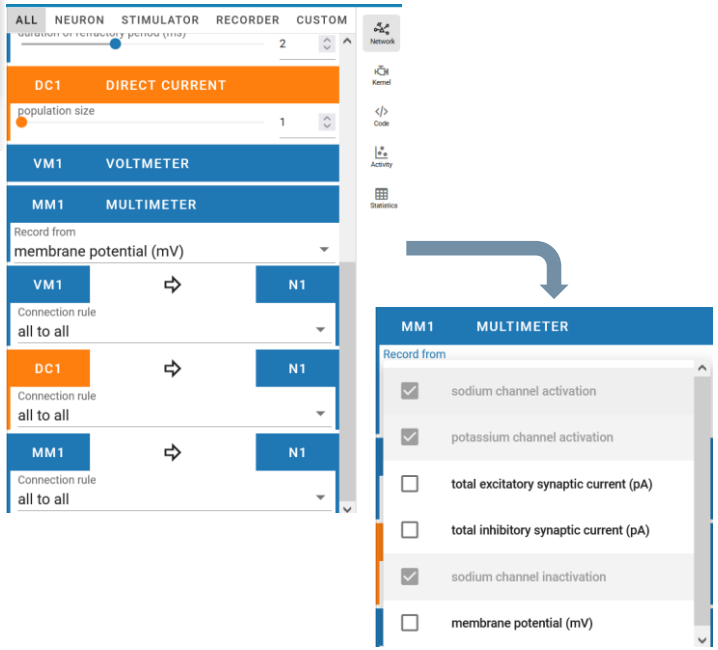



1st spike generator
2nd direct current

Connect the multimeter recorder(n1 to mm1)




Select the parameter you want to record



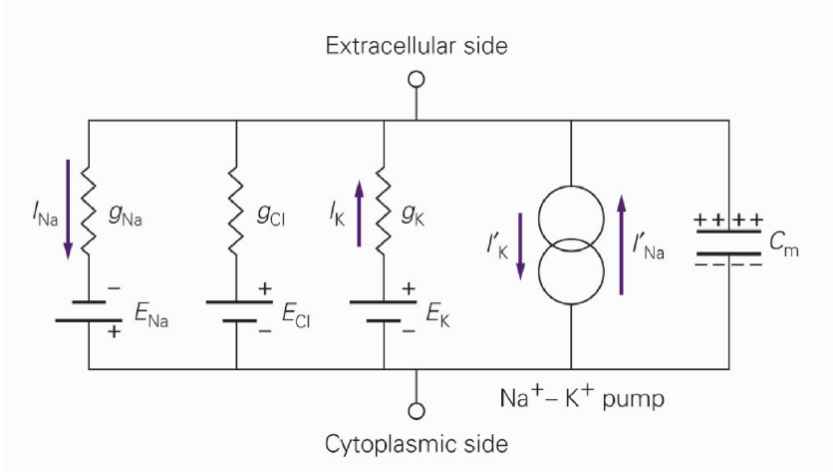

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

HANDS ON

## Sodium and potassium currents under current clamp conditions

1. Action potential generation based on voltage-dependent ion channels takes place in several stages. Use the membrane potential recording of a **single spike** to illustrate the dissection of this process.

$$C_m\frac{dV(t)}{dt} = g_{leak}[V(t)-V_{leak}]-g_{Na}(V,t)[V(t)-V_{Na}^{rev}]-g_K(V,t)[V(t)-V_K^{rev}]+I_{ext}$$

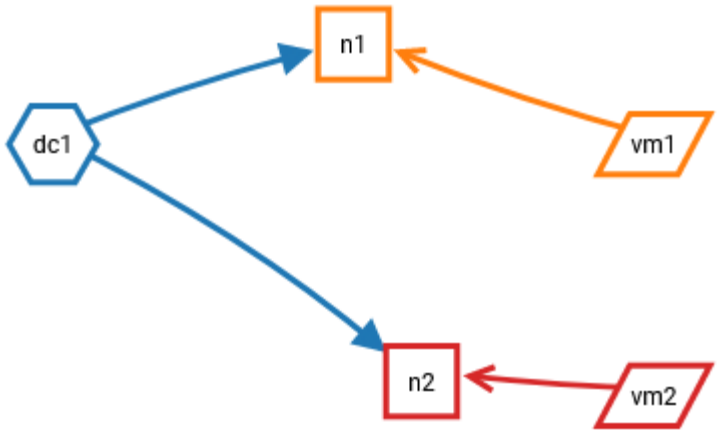


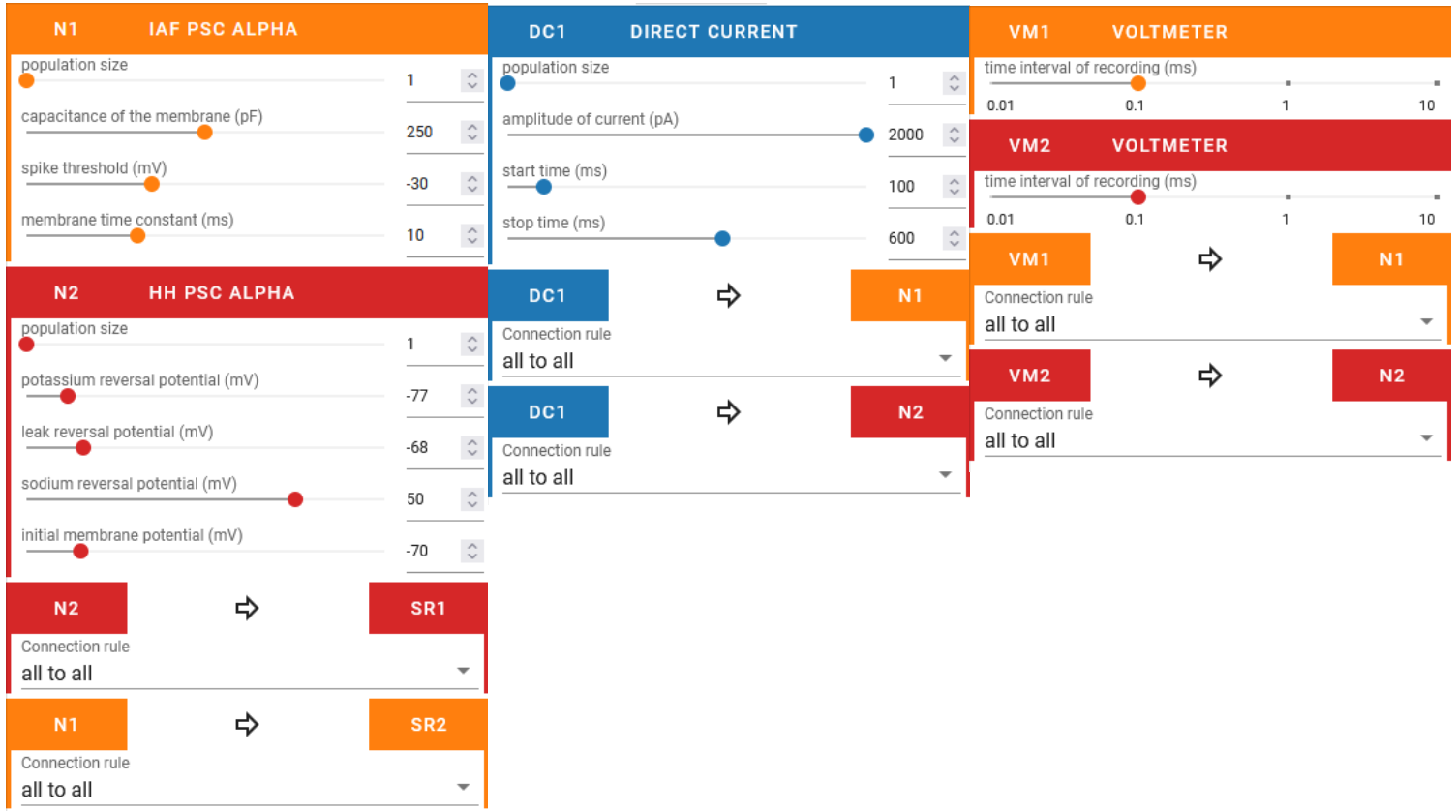

2. EXTRA: Explore the effect of the specific neurotoxins TTX and TEA on neuronal spiking. You can easily achieve this in your simulations by setting the peak conductances of either sodium channels or potassium channels, respectively, to zero. What happens if you only partially knock-out these channels by setting them to a non-zero, but reduced value? Formulate and explain your expectations before you perform the experiments.

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# 2 Hodgkin-Huxley model simulation

https://nest-desktop.apps.hbp.eu/#/




Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

HANDS ON

## Current clamp simulation of the free-running membrane

1. Verify that the subthreshold properties of the HH neuron model are similar to the properties of the LIF neuron model. To address this issue, inject a **depolarizing or hyperpolarizing current** into a LIF neuron and into a HH neuron and perform intracellular recordings to document the membrane response in both cases. Make sure the current is weak enough to not elicit a spike.

2. For strong-enough DC input current the HH model neuron will fire a train of action potentials. Inspect the spike waveform carefully and relate it to the spikes generated in a LIF neuron. Is the spike waveform of the HH neuron really the same for different input scenarios (e.g. weak vs. strong current)?

3. EXTRA: Use a spike recorder to characterize the spiking response to superthreshold current input. The goal is again to characterize the neuron by a curve that depicts the firing rate response as a function of the applied current.

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# Simulating Single Neuron and Network Activity

Human Brain Project infrastructure: EBRAINS

Simulating software: NEST Desktop

Human Brain Project

EBRAINS

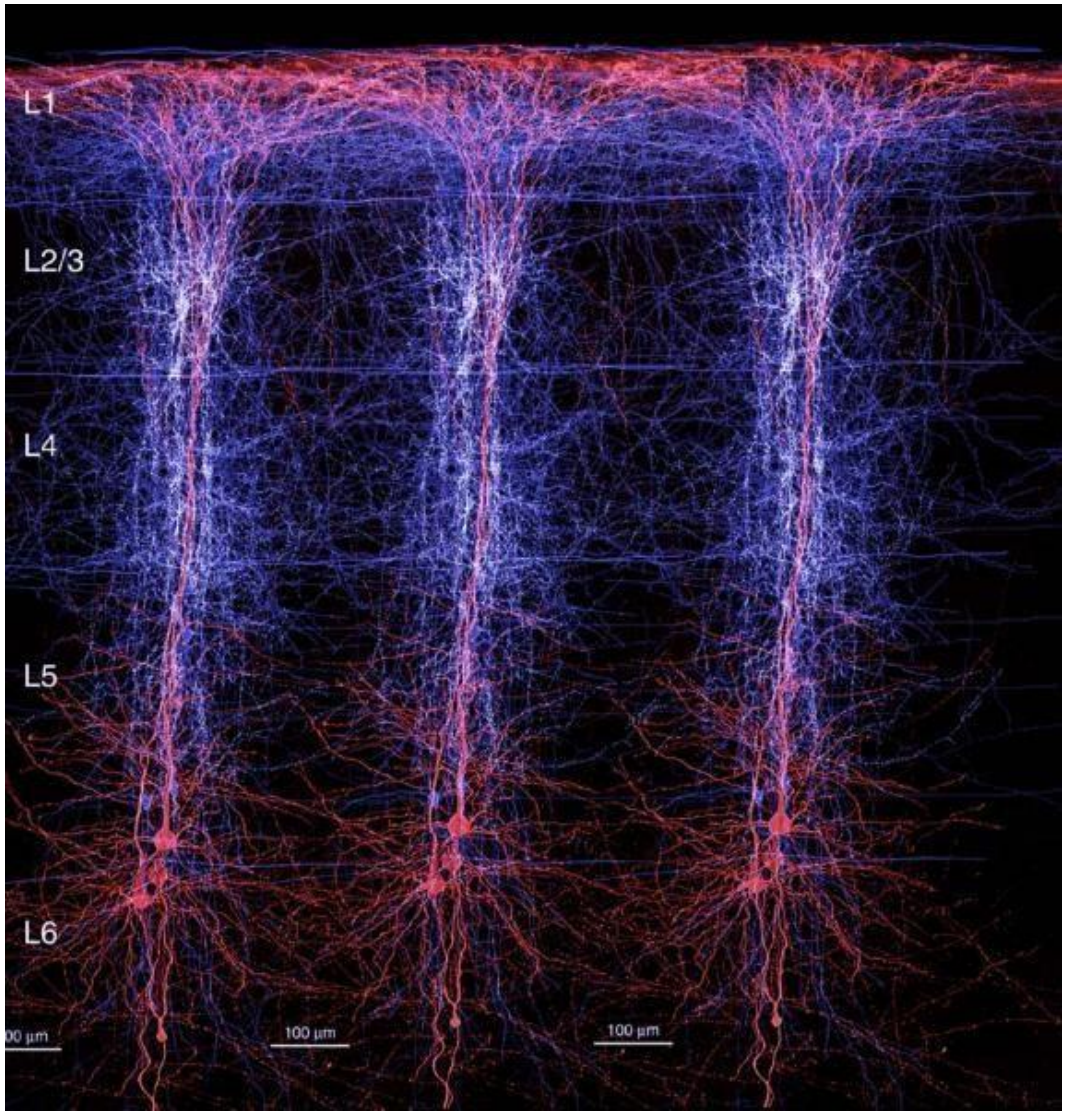
1. LIF model simulation — HANDS-ON
2. Hodgkin-Huxley model simulation — HANDS-ON
3. Network activity — HANDS-ON

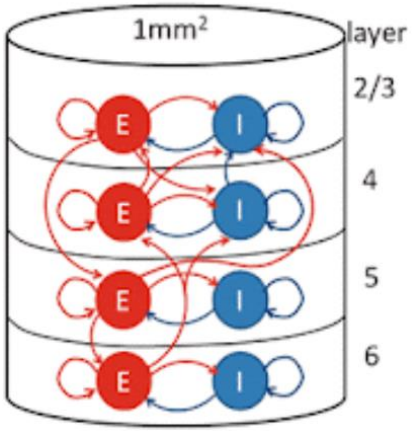

Click on the logos to know more ☺

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# 3 Network activity

Cells in the cortex form columns. In this image the red neurons, called pyramidal cells, are revealed to be entwined by blue fibers from other, inhhibitory neurons that slow their firing.

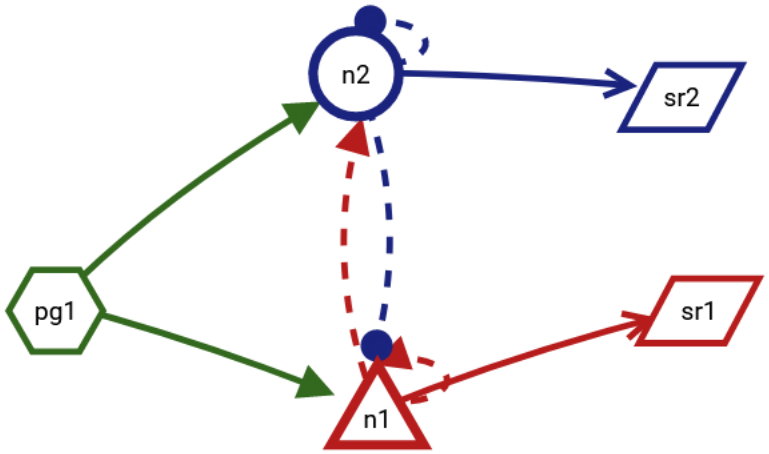


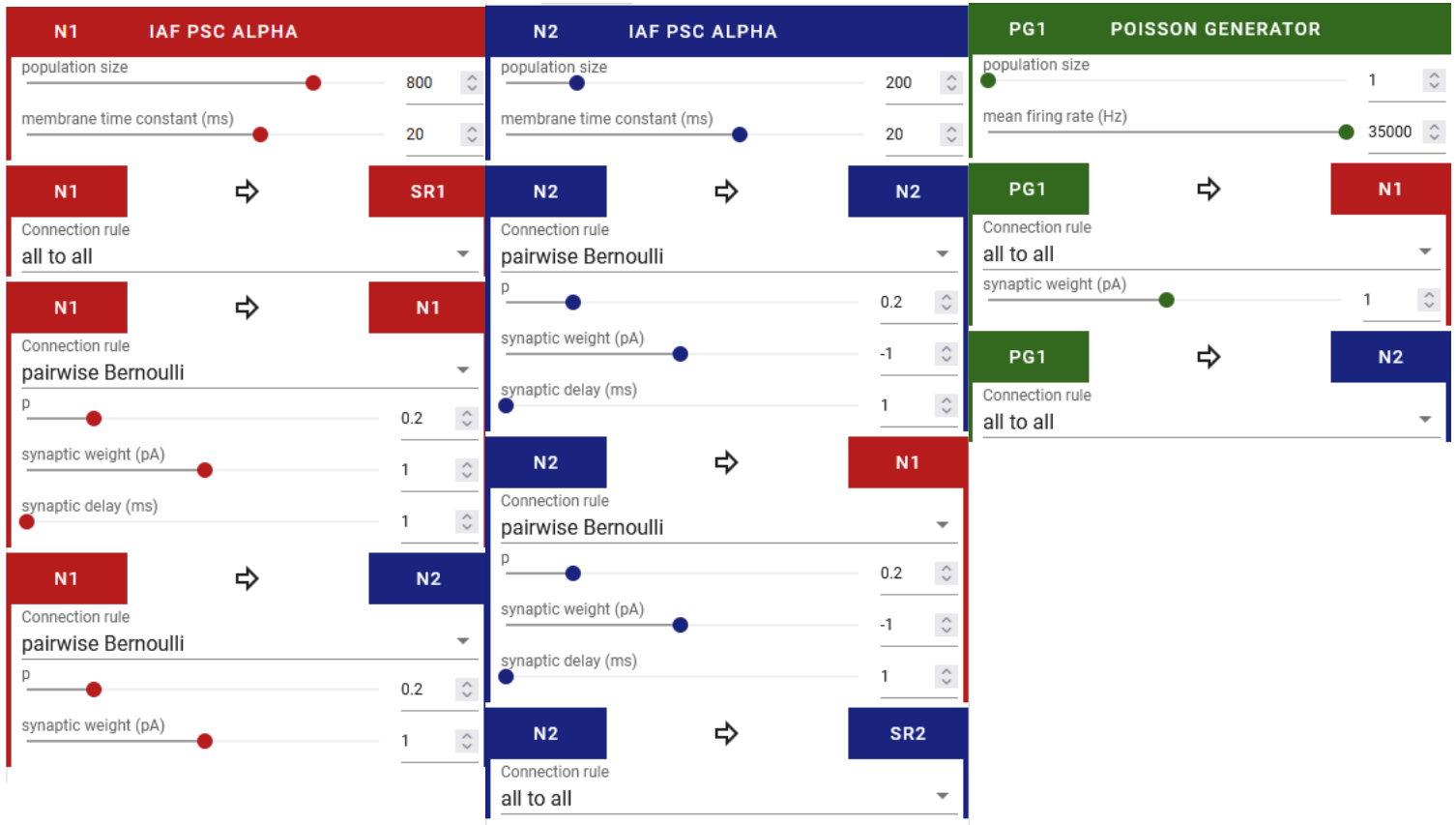




Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

# 3 Network activity

https://nest-desktop.apps.hbp.eu/#/




Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

HANDS ON

# Recurrent networks of excitatory and inhibitory neurons

Set up a large-enough population of excitatory neurons and one inhibitory, based on the standard LIF model. Establish random synaptic connections among neurons.

Explore the role of external input for the dynamics of the recurrent network. As this external input is normally provided by other neurons that are not part of the local network in question, a Poisson generator represents an adequate model for it. Fix a good value for the rate of the external drive, just above threshold.

Monitor neuronal activity in the network(membrane potentials and spike trains).

The goal should be to establish stable activity in the network, which is characterized by low firing rates, irregular (Poisson-like) spike trains, and a low degree of synchrony across neurons.

Alessandra Maria Trapani
alessandramaria.trapani@polimi.it

HOT DEALS

# Available master thesis on Computational Neuroscience

## Prof. Pedrocchi

| tutors | title |
|---|---|
|  | **Analysis of microendoscopic calcium imaging and behavioural data recorded in-vivo in freely-moving mice** |
|   | **Diffusive plasticity model in spiking neural network** |