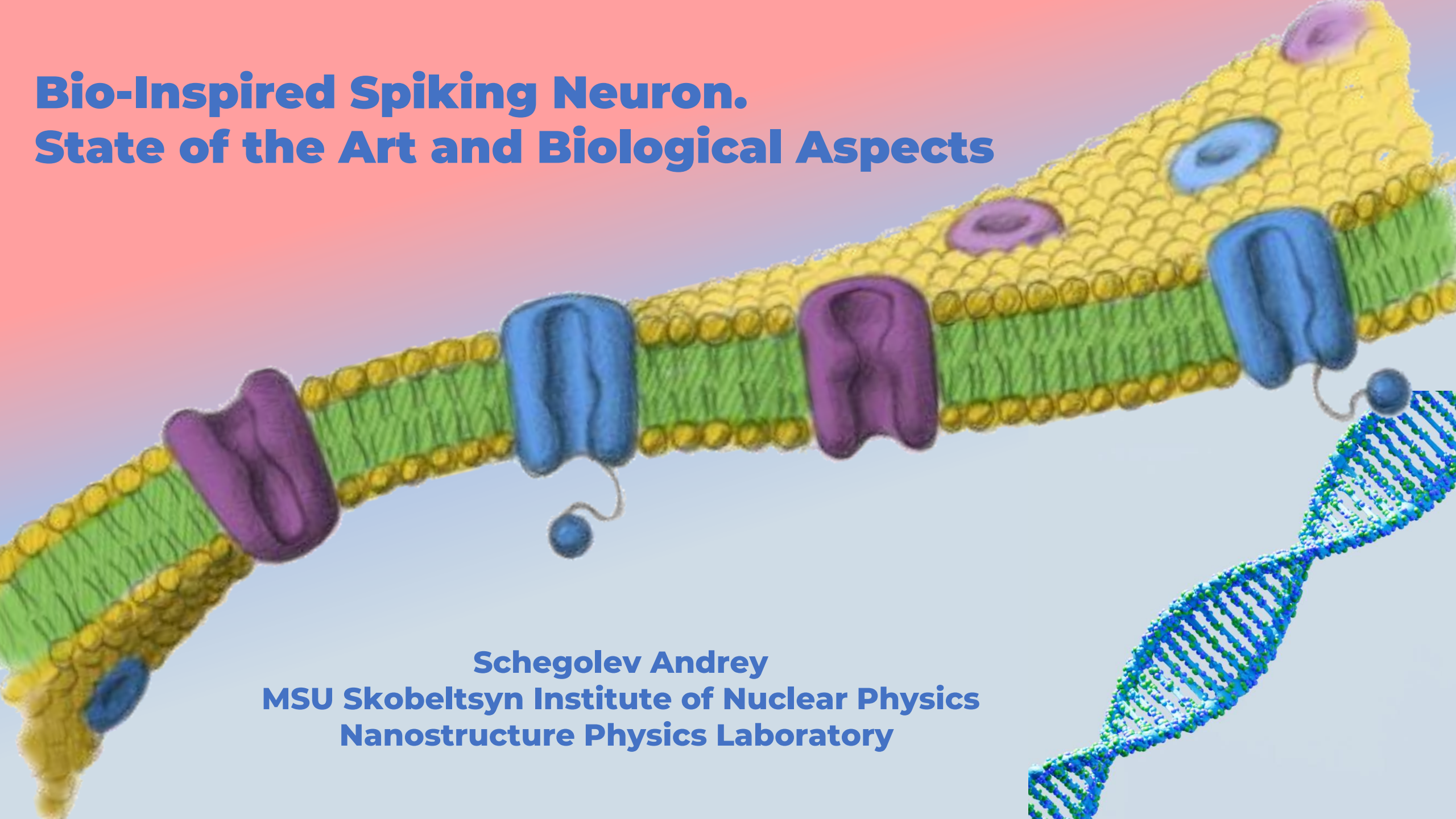
Bio-Inspired Spiking Neuron. State of the Art and Biological Aspects



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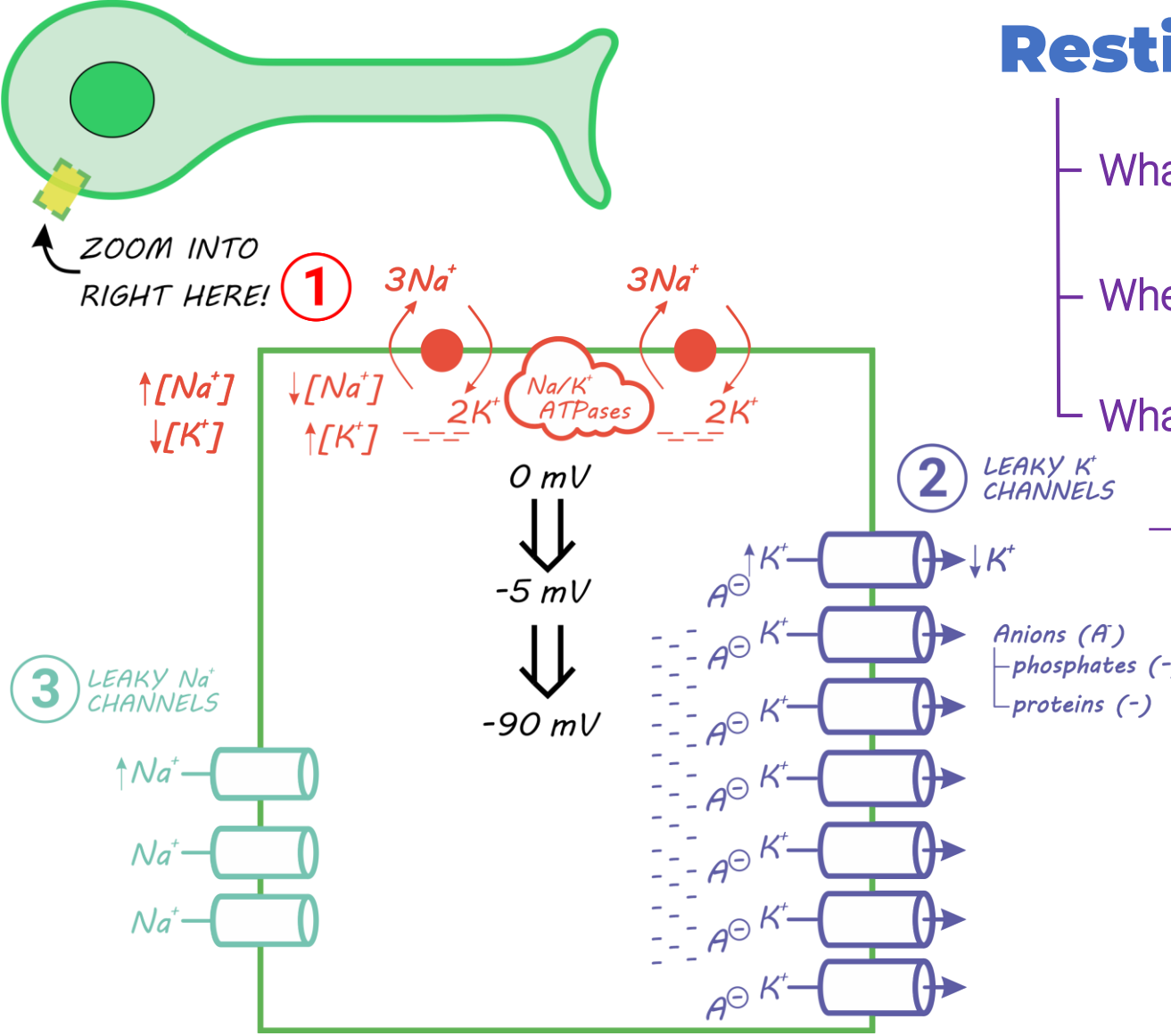
What are we gonna talk about?

- Ionic mechanisms in neuron cells:
  Resting Membrane, Graded and Action Potentials
- Absolute and Relative refractory periods
- What's new at the front of Bio-Inspired Superconducting Neural Networks
- Actual tasks

Ionic mechanisms in neuron cells: Resting Membrane, Graded and Action Potentials

Resting Membrane Potential (RMP)

- What is RMP? — RMP is a voltage difference across the cell membrane when the cell is in a **rest**
- Where RMP exist? — RMP exist **in all cells**
- What is RMP value? — from **-90 mV** to **-70 mV**



$$E_{K+} = 61{,}5 \times lg\left(\frac{5}{150}\right)\left[\frac{K^+_{out}}{K^+_{in}}\right] = -90\ mV\ (\sim 90\%\ perm.)$$

$$E_{Na+} = 61{,}5 \times lg\left(\frac{140}{10}\right)\left[\frac{Na^+_{out}}{Na^+_{in}}\right] = +70\ mV\ (\sim 10\%\ perm.)$$

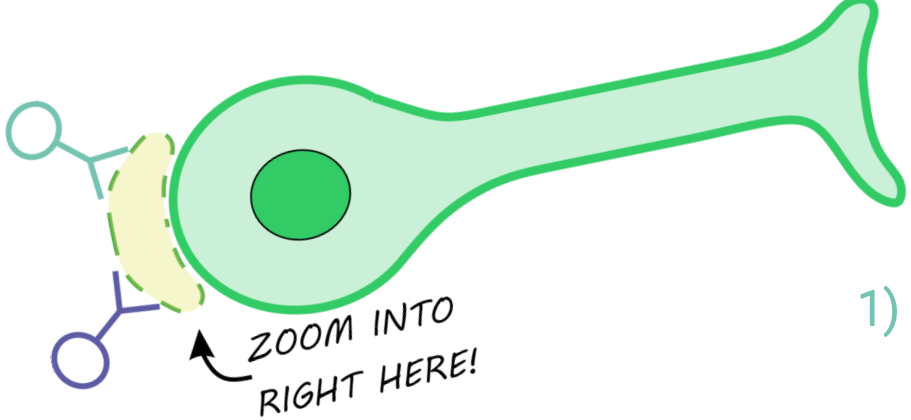
RMP ≈ –70 mV

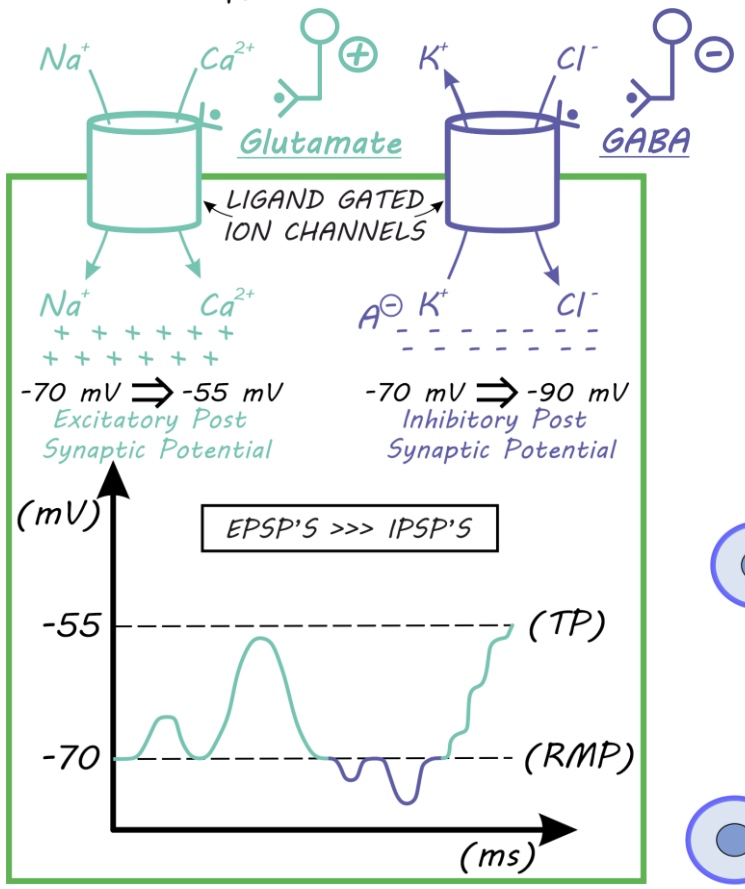
How we get -90 mV / -70 mV ?

1) Na/K⁺ ATPases:
   a) makes inside the cell a little bit more negative;
   b) establish the concentration gradient of Na and K ions – $[Na^+]_{inside} < [Na^+]_{outside}$ and $[K^+]_{outside} < [K^+]_{inside}$
2) Leaky K⁺ channels:
   a) allow for K⁺ in/out the cell freely and passively;
   b) K⁺ leave the cell until voltage get around -90 mV.
3) Leaky Na⁺ channels:
   a) allow for Na⁺ in/out the cell freely and passively;
   b) Na⁺ leave the cell until voltage get up to -70 mV.

When flows of ions from $\vec{\nabla}_{[\dots]}$ and $\vec{\nabla}_{+}$ are become equal the Nernst Potential is reached

Graded Potential (GP)



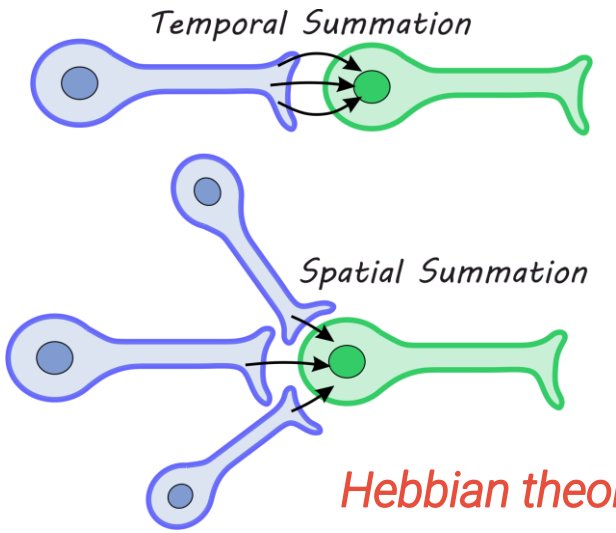


What are the purposes of GP?

1) (EPSP) Take RMP and move it closer to threshold (≈ -55 mV) → *depolarisation*

2) (IPSP) Take RMP and move it away from threshold (≈ -90 mV) → *hyperpolarisation*

- EPSP get inside the cell positively charged ions to rise Membrane Potential from *-70 mV* to *-55 mV* using Glutamate NeuroTransmitter
- IPSP get inside the cell negatively charged ions and get outside the cell positively charged ions that *hyperpolarised* the Membrane Potential from *-70 mV* to *-90 mV* using GABA (*gamma-aminobutyric acid*) NT

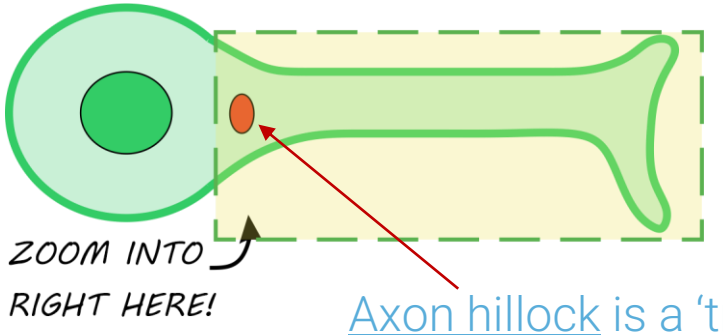


There is a constant battle between Excitatory and Inhibitory signals in neuron.

The main goal is make EPSP more than IPSP to reach the Threshold Potential (TP) and force the neuron to fire

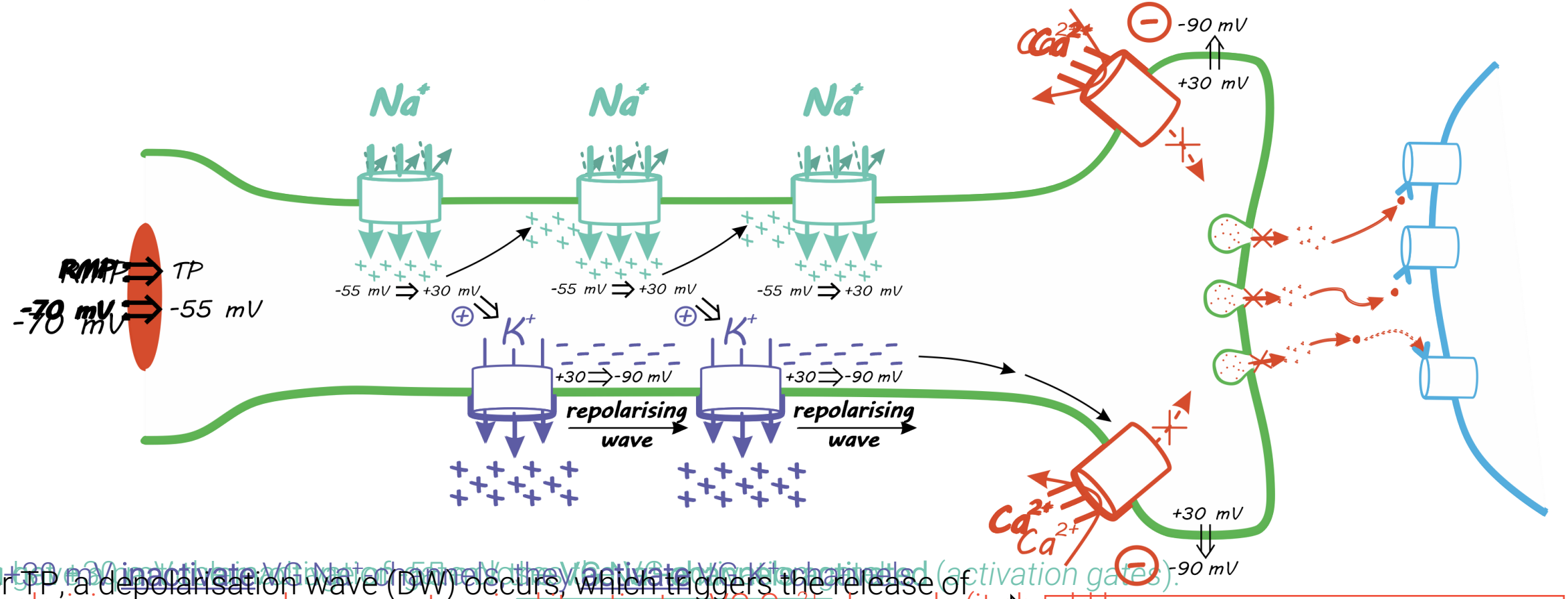
Hebbian theory: Wire together – Fire together

Action Potential (AP)



The -55 mV is a very important value because some ion channels are very sensitive to the value of potential

Axon hillock is a 'trigger' zone, cause there are a big number of Voltage Gated (VG) Channels!

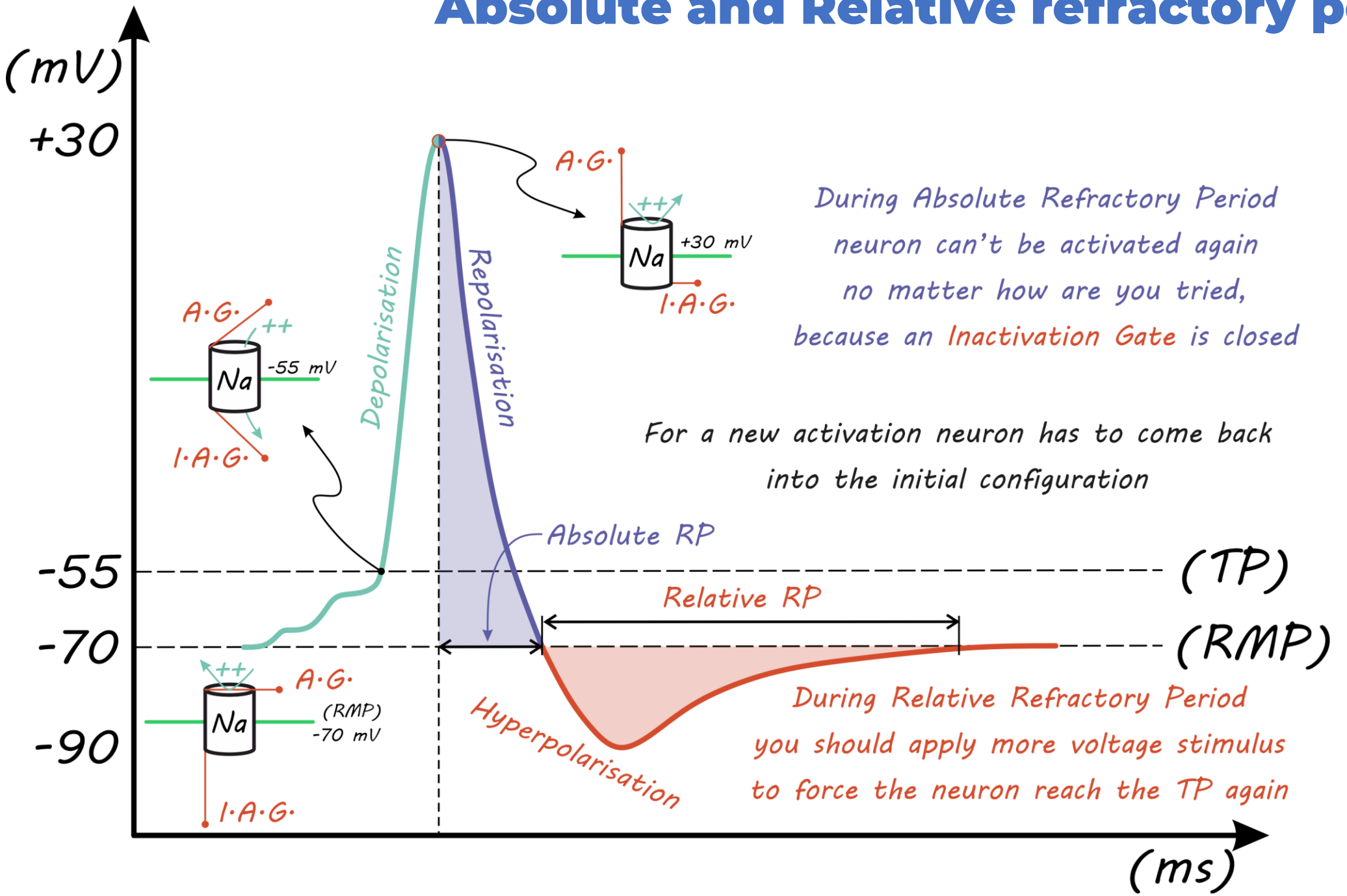


Thus, after TP, a depolarisation wave (DW) occurs, which triggers the release of K^+. The depolarisation wave is followed by a repolarisation wave (RW).
Since K^+-channels are little slow to close the MP has become hyperpolarised.

As far as -30 to +30 mV activate VG Na+ channels & they VG K+ channels (activation gates).
When depolarising wave reach an axon terminal it activates VG Ca^{2+} channels (it should be +30 mV to activate them). Ca^{2+} helps NTs to release into the synaptic space.

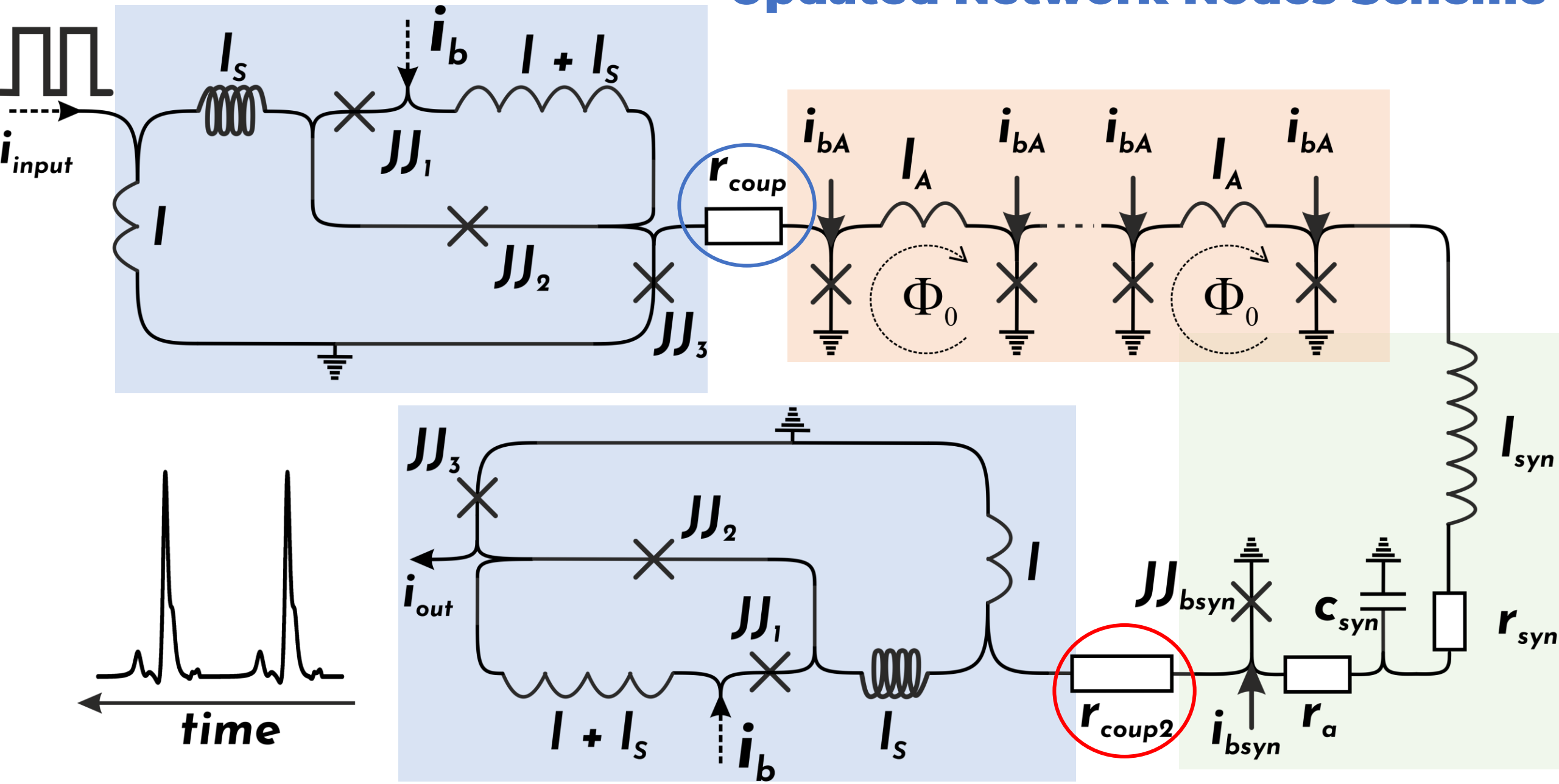
Resting potential's mechanisms on

Absolute and Relative refractory periods

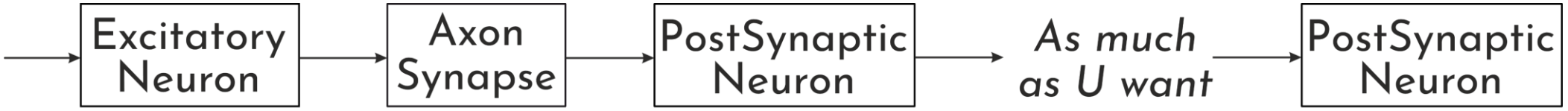


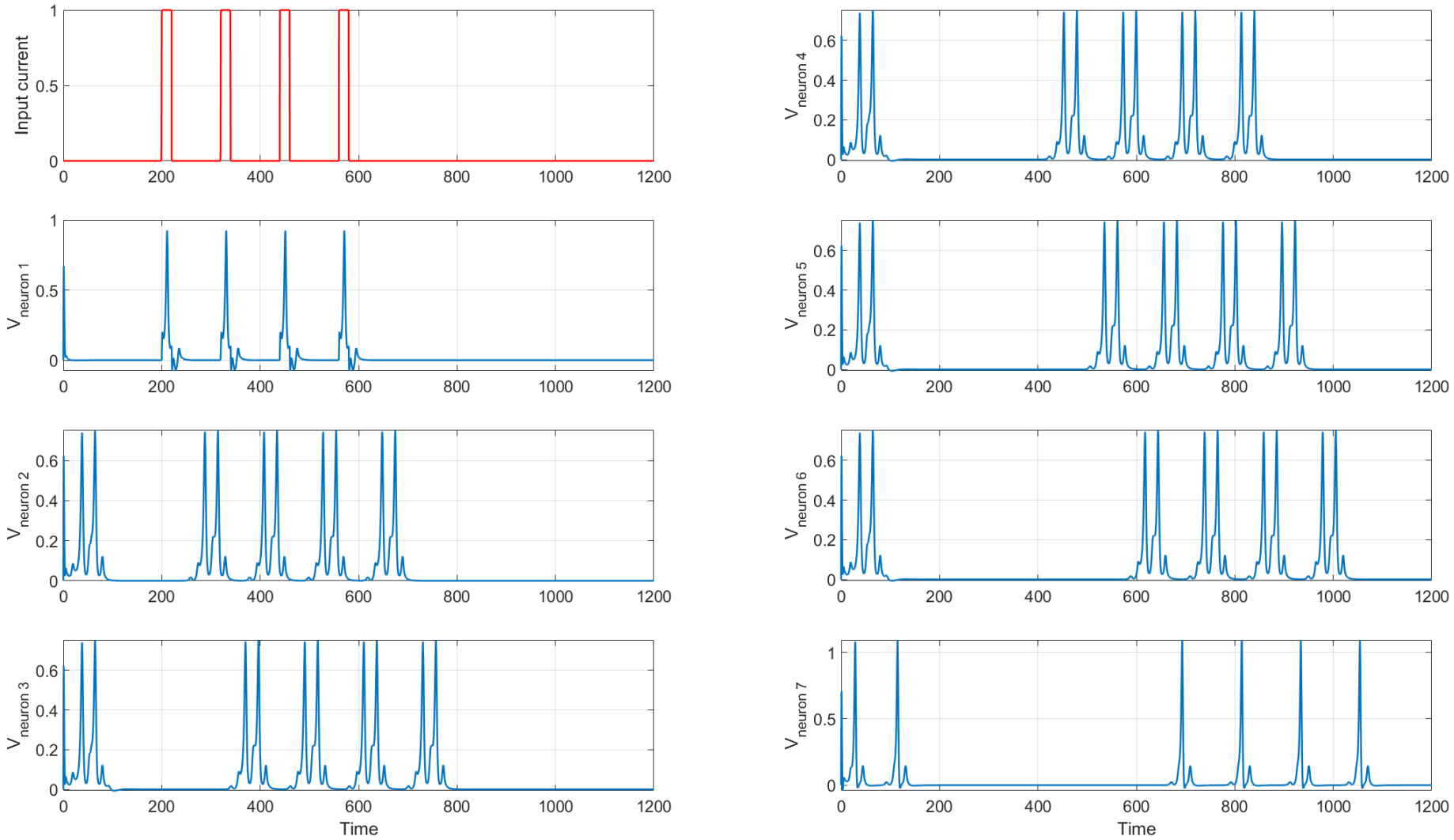
What’s new at the front of Bio-Inspired Superconducting Neural Networks

Updated Network Nodes Scheme



What structures we can model now?





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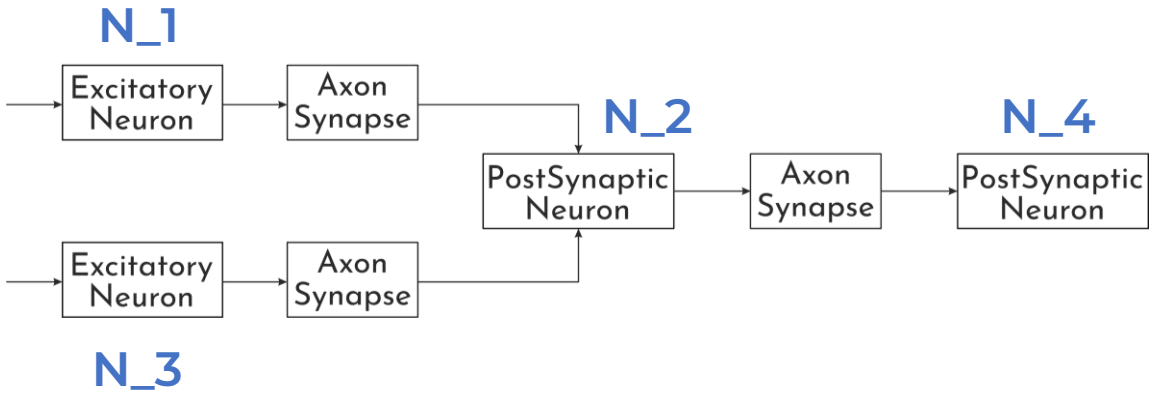
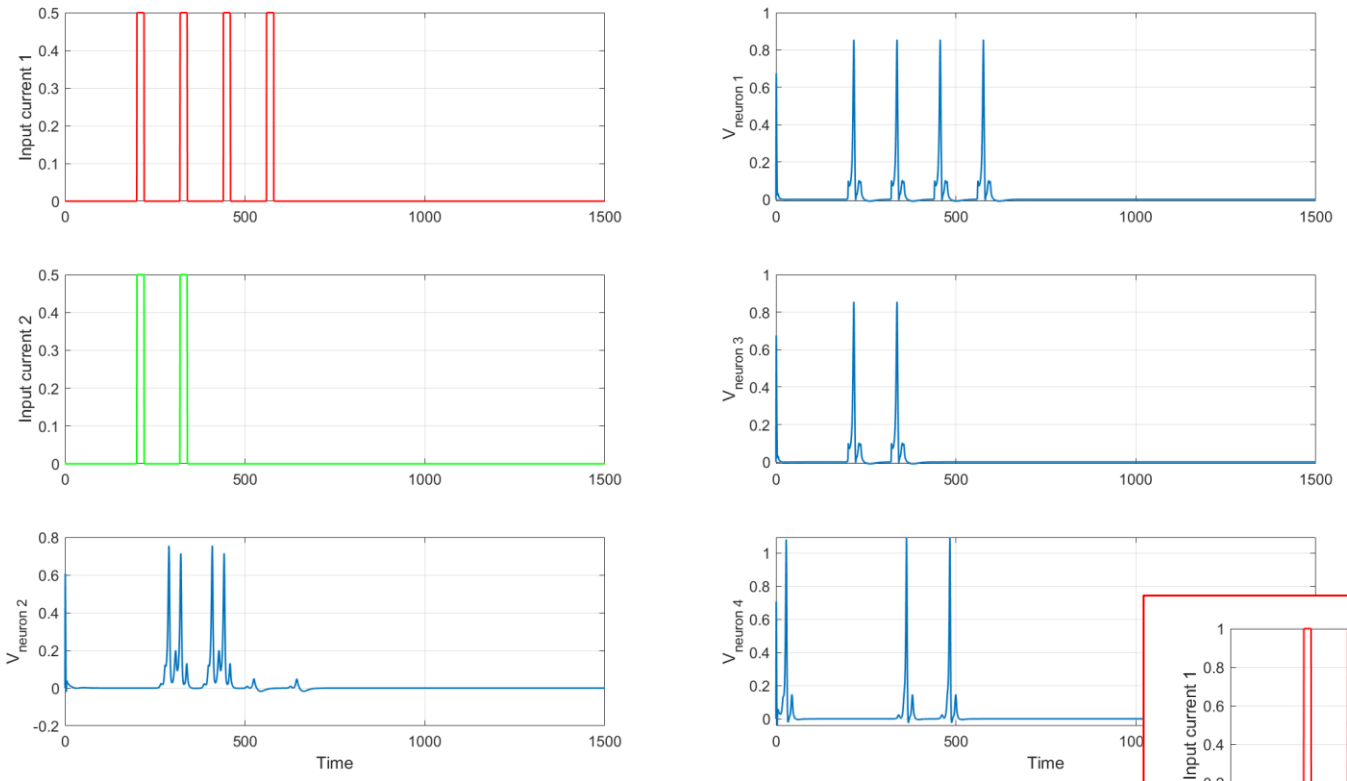
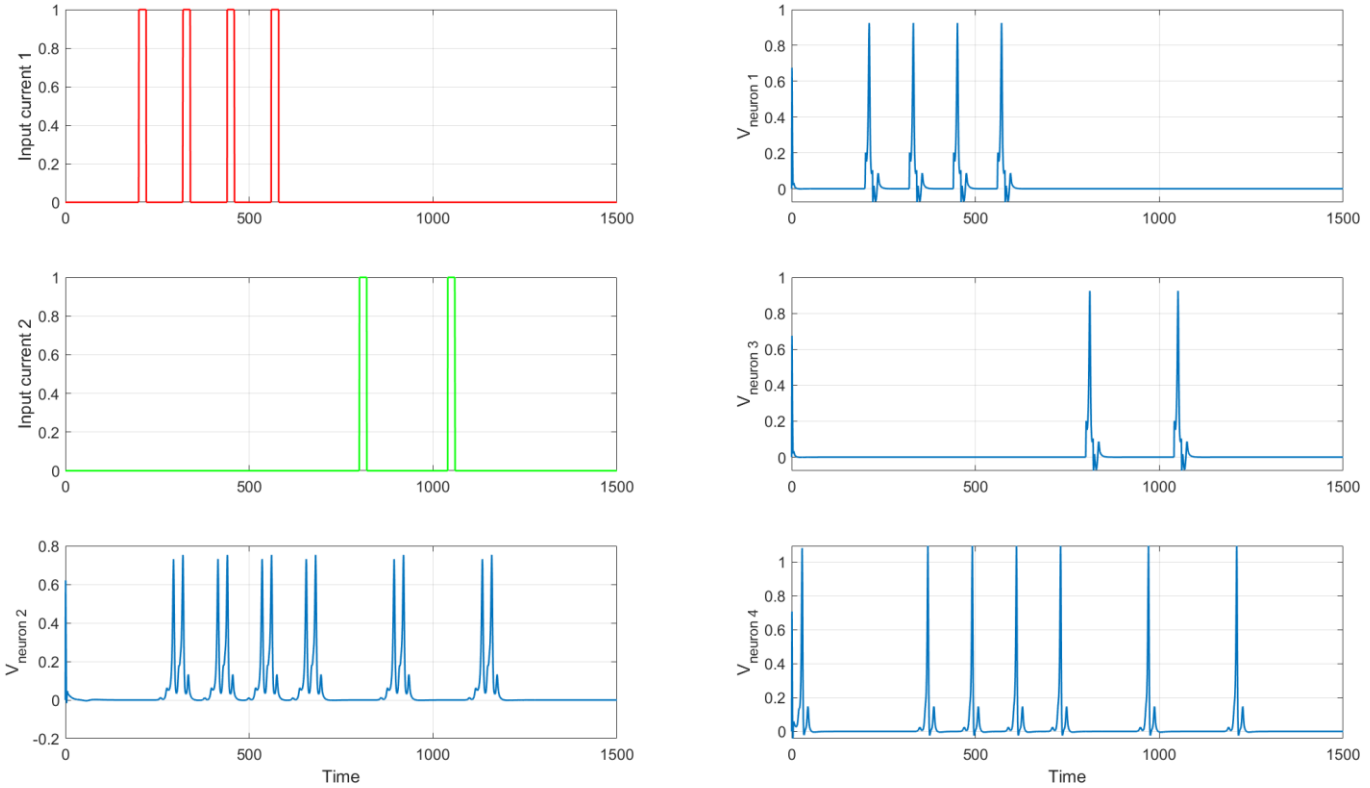




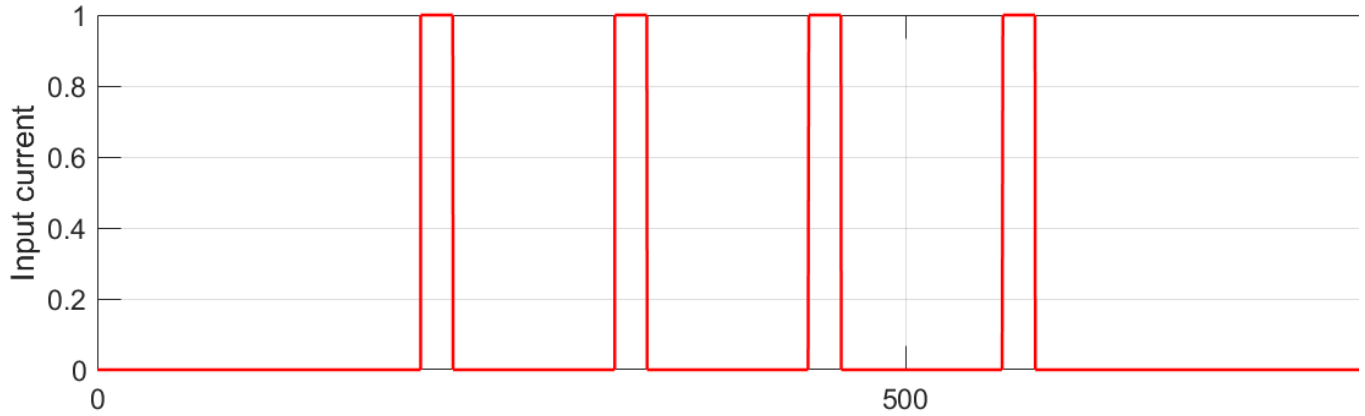
Not enough excitation!

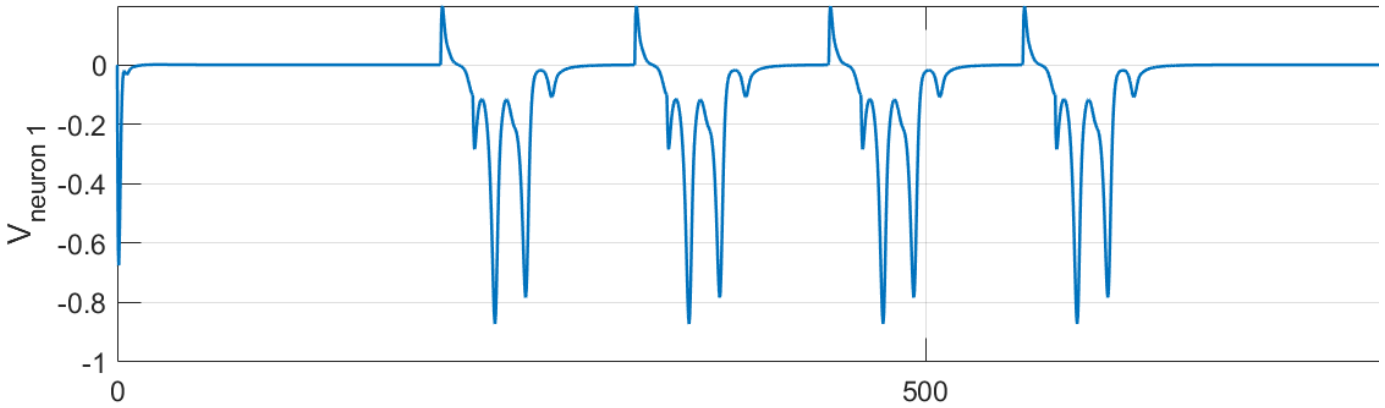
Spatial summation

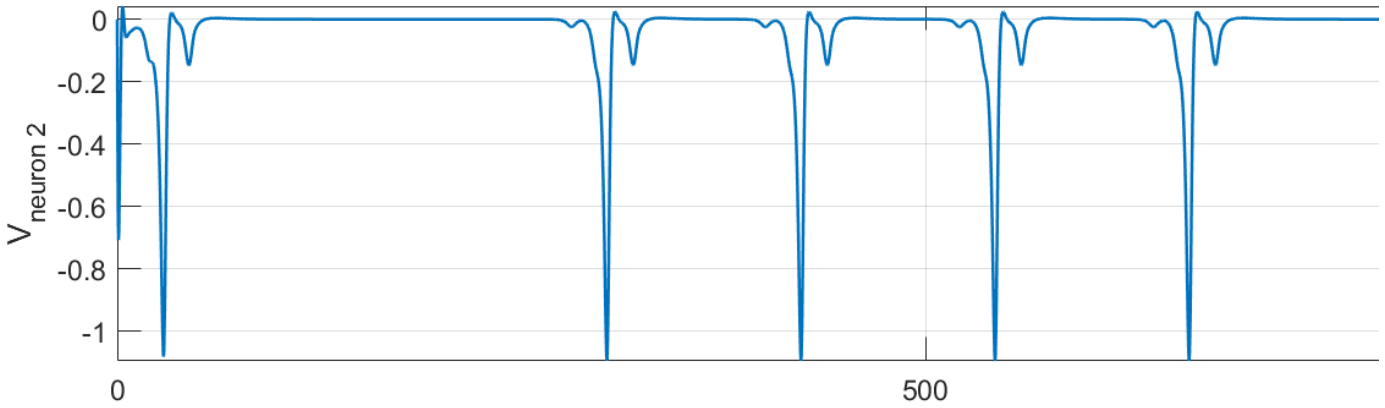
Enough excitation!



Inhibitory neuron

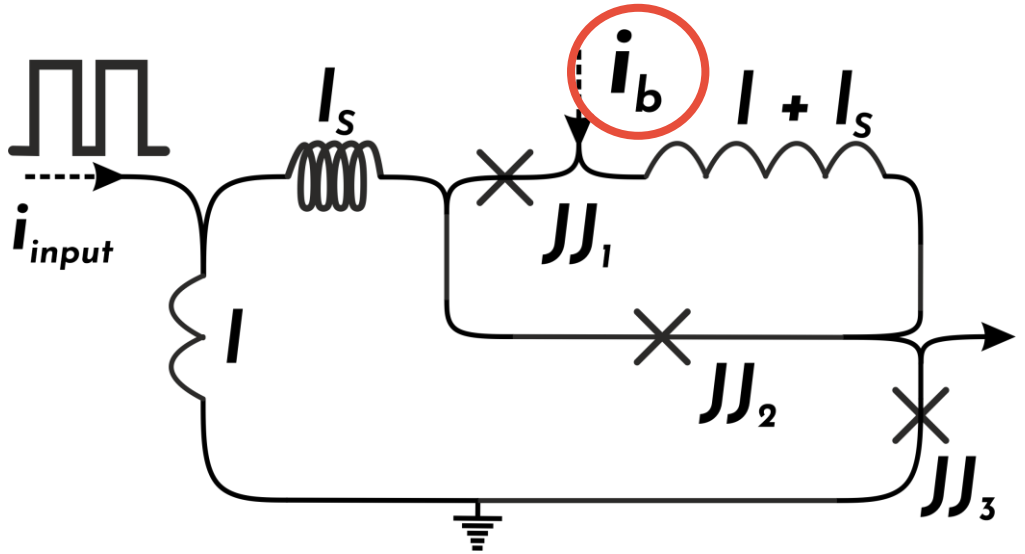






Change the direction of bias current

$i_b \rightarrow -i_b$



Actual Tasks

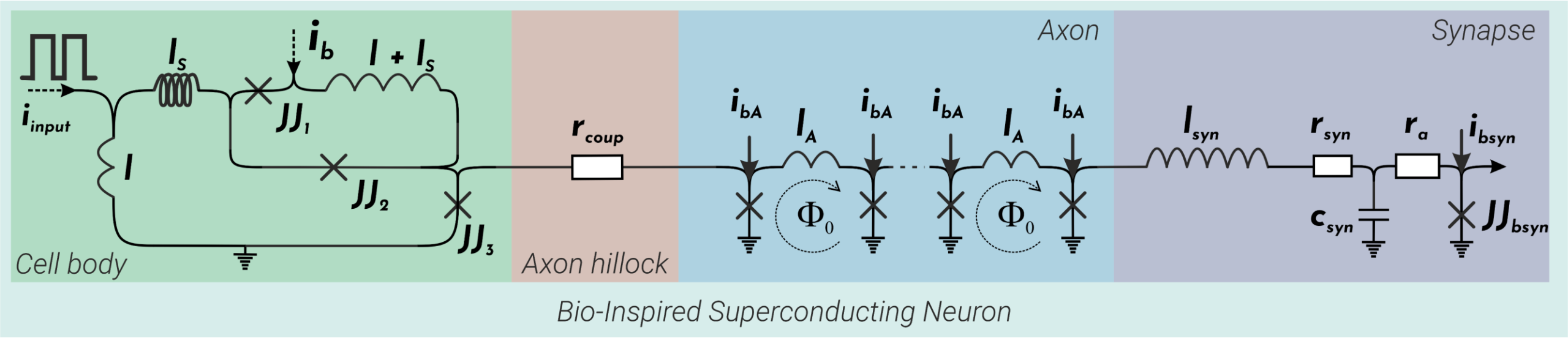
1. What is the best **inhibitor realisation** in the frame of large spiking neural network construction?

2. Large spiking neural network setup.

3. Throughput capacity harmonisation between JTL, RLCJ-filter and Neuron.

4. Spiking neural network initialisation: whether we should save the initial initialisation pulse of the system or can silence it? “Soft Start”?

New neuron concept



Bio-Inspired Superconducting Neuron