Glial modeling with NEST

Creating neuron-astrocyte networks

LASCON 2026 Tutorial

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Tutorial contents

1) Motivation

2) Introduction and background of the implemented model

3) Hands-on examples with EBRAINS platform (credentials needed)

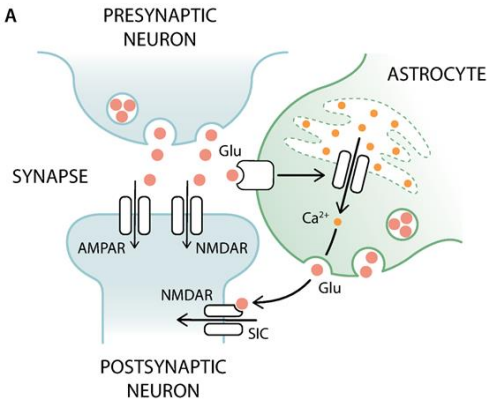
Jiang, J. Aćimović, T. Manninen, I. Ahokainen, J. Stapmanns, M. Lehtimäki, M. Diesmann, S.J. van Albada, H.E. Plesser, M.-L. Linne.

Modeling neuron-astrocyte interactions in neural networks using distributed simulation.

PLoS Computational Biology 21(9):e1013503, 2025.

What is the tutorial about?

- Modeling single astrocyte with **calcium** dynamics
  - The astrocyte model by Li & Rinzel (1994)
    - Based on De Young and Kaiser (1992)
    - Input and output adapted according to Nadkarni & Jung (2003)



- Modeling a small neuron-astrocyte network with **slow inward currents from astrocytes to neurons**
  - The astrocyte model by Li & Rinzel (1994)
  - The neurons modeled with an adaptive exponential integrate-and-fire model (AdEx)

The implemented model

Slow Inward Current (SIC) in brief

In brief:

1) Presynaptic excitatory spike releases glutamate, which activates IP3 prodcution in the astrocyte
2) IP3 opens CICR channel, which releases Ca^{2+} from ER to cytosol
3) Cytosolic Ca^{2+} induces glutamate release to perisynaptic areas of the postsynaptic neuron
4) Perisynaptic NMDA receptors on postsynaptic neuron are activated and SIC is generated.

Note: Steps 3 and 4 are modeled with simple phenomenological relations.

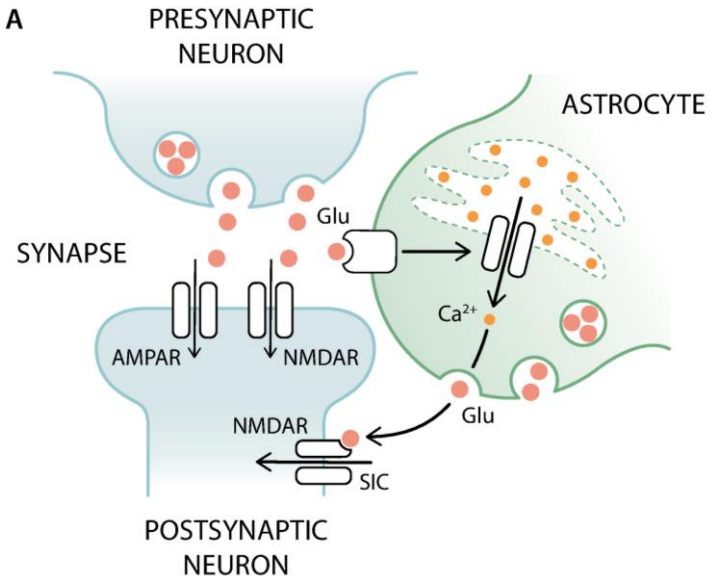


Figure from:
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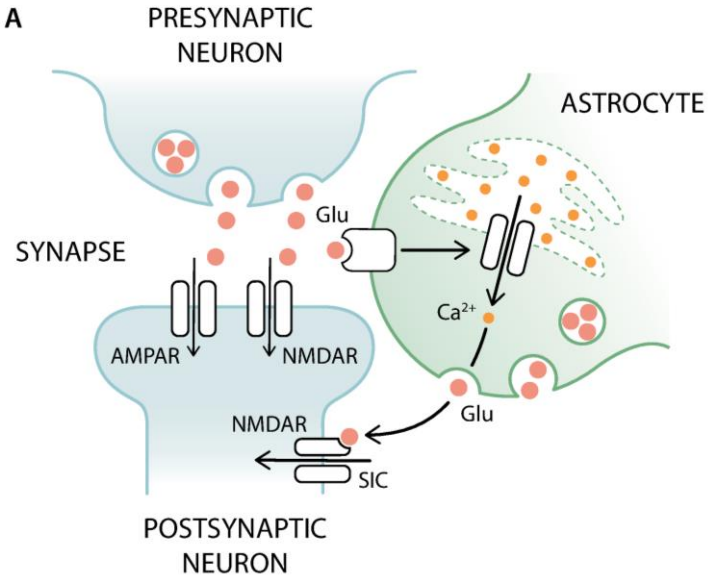
How to model SIC?

- Modelled astrocyte components (dynamic states):
  - Cytosolic calcium $[Ca^{2+}]_c(t)$
  - Free Inositol Trisphosphate (IP3) [IP3](t)
  - Fraction of IP3 receptor channels that are not inactivated by $[Ca^{2+}]_c(t)$, h
- The total amount of calcium in astrocyte is fixed
- SIC is given as a logarithmic transformation from a scaled $[Ca^{2+}]_c(t)$

See Refs.
Young&Keizer (1992) Proceedings of National Academy of Sciences;
Li&Rinzel (1994) Journal of Theoretical Biology;
Nadkarni&Jung (2003) Physical Review Letters



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Calcium dynamics in an astrocyte

IP3 concentration: $$\frac{d[IP_3]\,(t)}{dt} = \frac{[\mathrm{IP_3}]_0 - [IP_3]}{\tau_{IP3}} + \Delta_{IP3}\ \cdot J_{syn}(t)$$

Cytosolic Ca^{2+}: $$\frac{d[Ca^{2+}]_c(t)}{dt} = J_{channel}(t) - J_{pump}(t) + J_{leak} + J_{noise}$$

Ca^{2+} currents: $$J_{channel}(t) = r_{ER,cyt} \cdot v_{IP_3R} \cdot m_\infty^3(t) \cdot n_\infty^3(t) \cdot h_{IP_3R}^3(t) \cdot ([Ca^{2+}] - [Ca^{2+}]_{ER})$$

$$J_{pump}(t) = \frac{v_{SERCA} \cdot [Ca^{2+}]^2(t)}{K_{m,SERCA}^2 + [Ca^{2+}]^2(t)}$$

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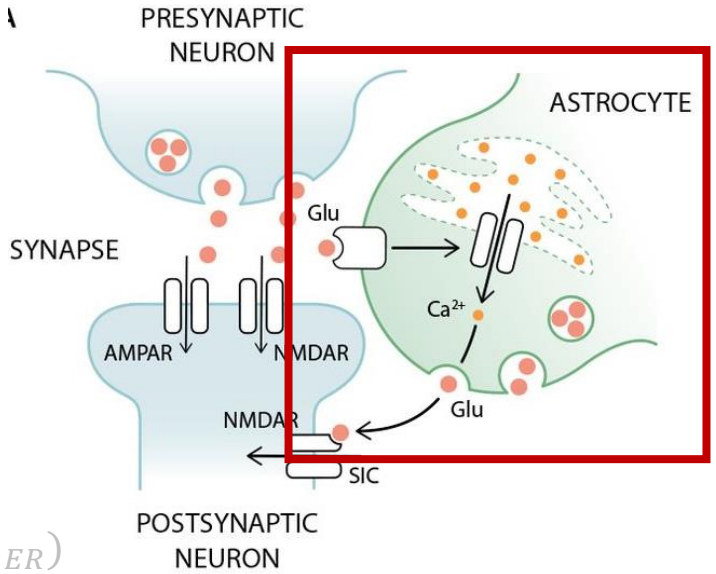

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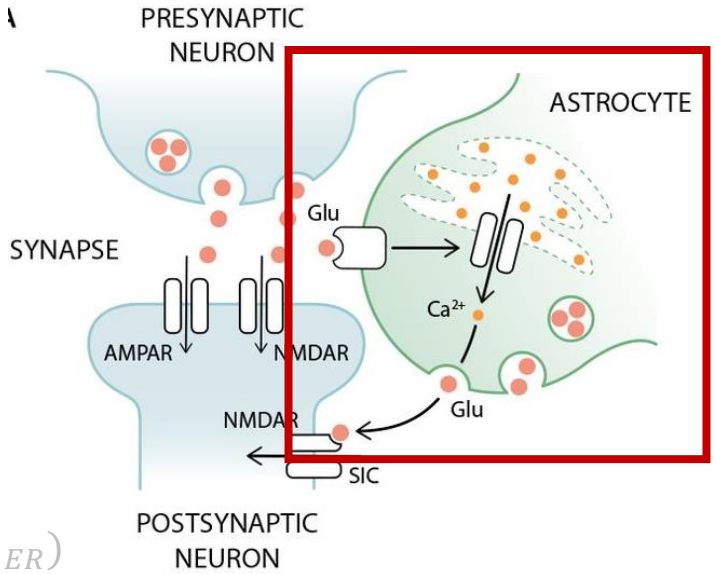

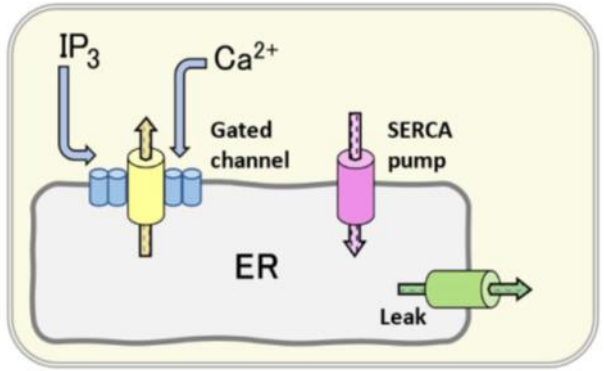

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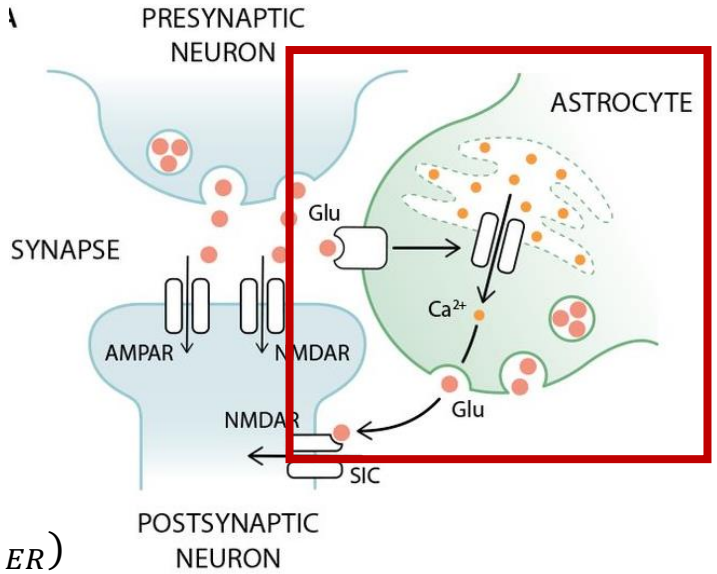

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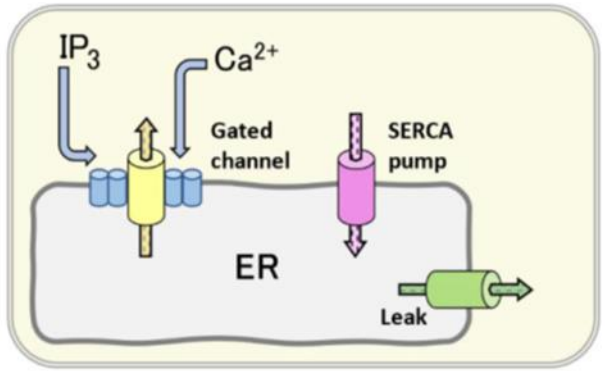

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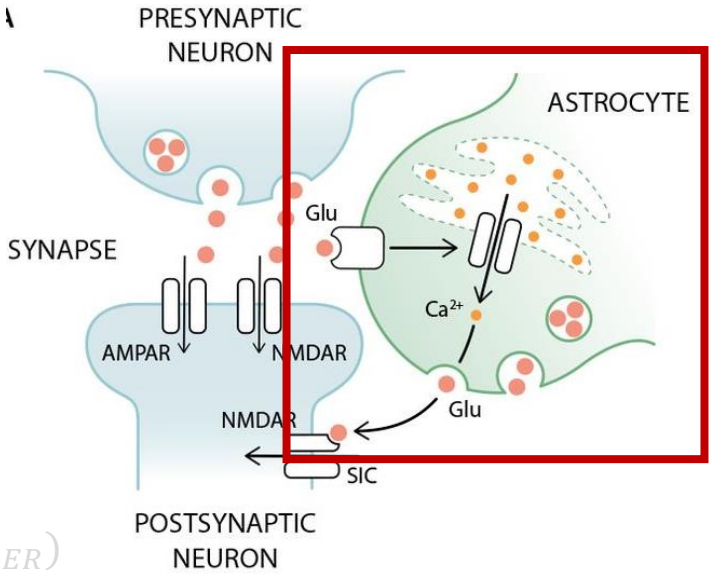

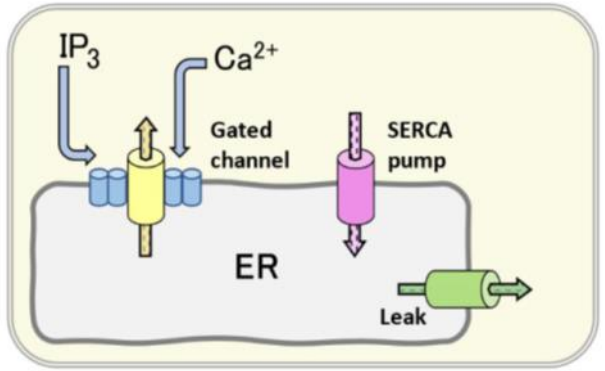

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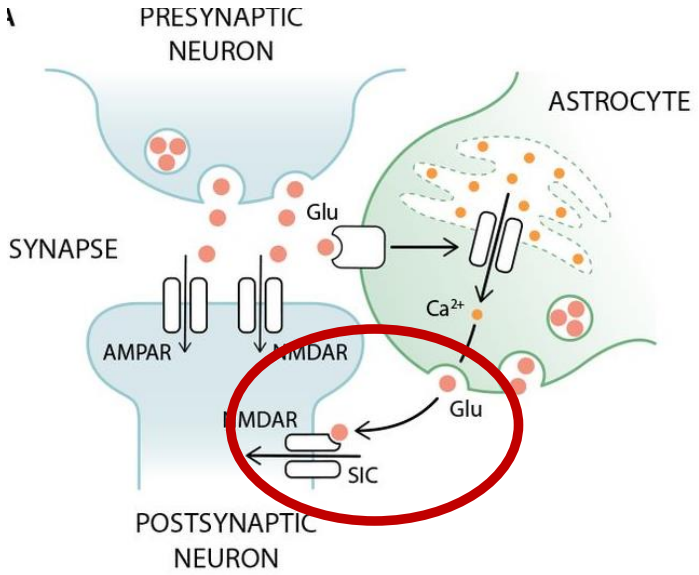
SIC to postsynaptic neuron

SIC from astrocyte to postsynaptic neuron is modelled as a logarithm of a scaled calcium *y* (Nadkarni & Jung, 2003):

$$I_{SIC} = SIC_{scale} \cdot H(\ln(y)) \cdot \ln(y)$$

$$y = \frac{[Ca^{2+}] - SIC_{th}}{1\,nM}$$



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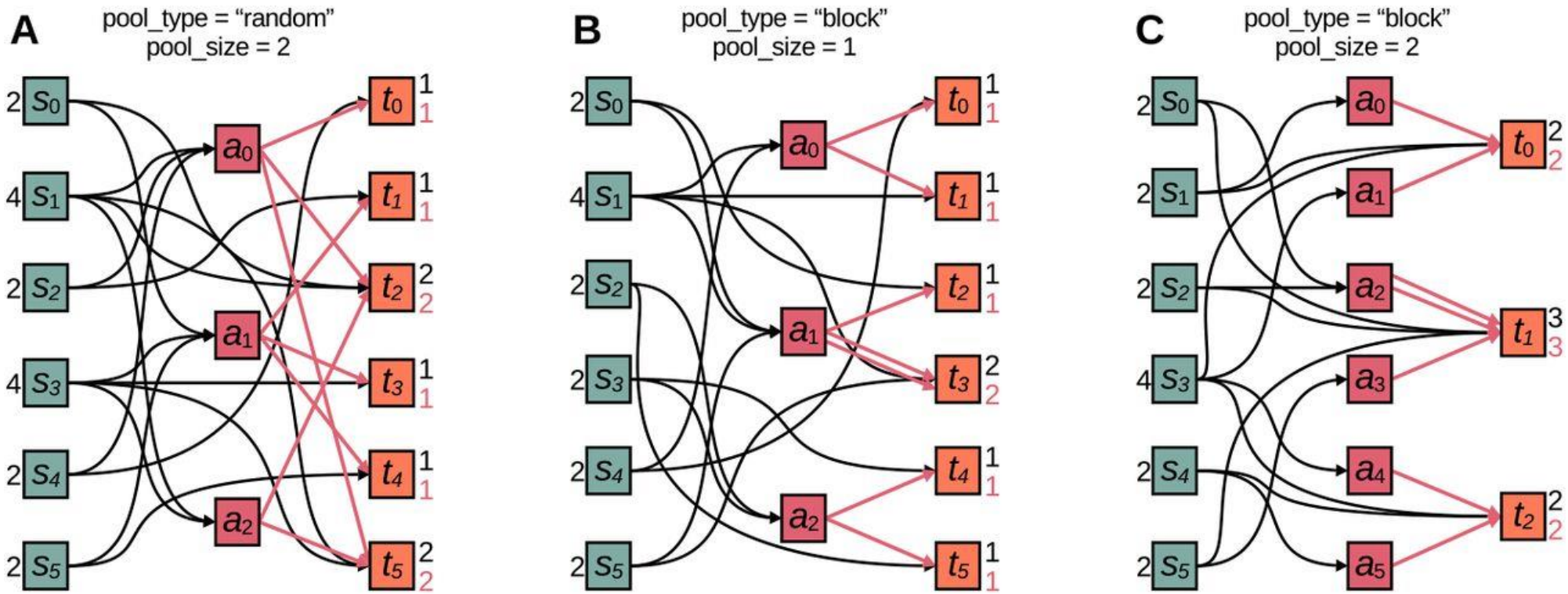
Examples of tripartite neuron-astrocyte connectivity created with NEST support



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Tutorial notebook outlook

Notebook	Description
astrocyte_single.ipynb	Calcium dynamics in a single astrocyte
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Go to the website:

https://nest-simulator.readthedocs.io/en/stable/auto_examples/astrocytes/

https://nest-simulator.readthedocs.io/en/stable/auto_examples/astrocytes/astrocyte_single.html

→ Click “**Try it on EBRAINS**”