Can Memristors Act as Artificial Synapses?

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1 Biological problem

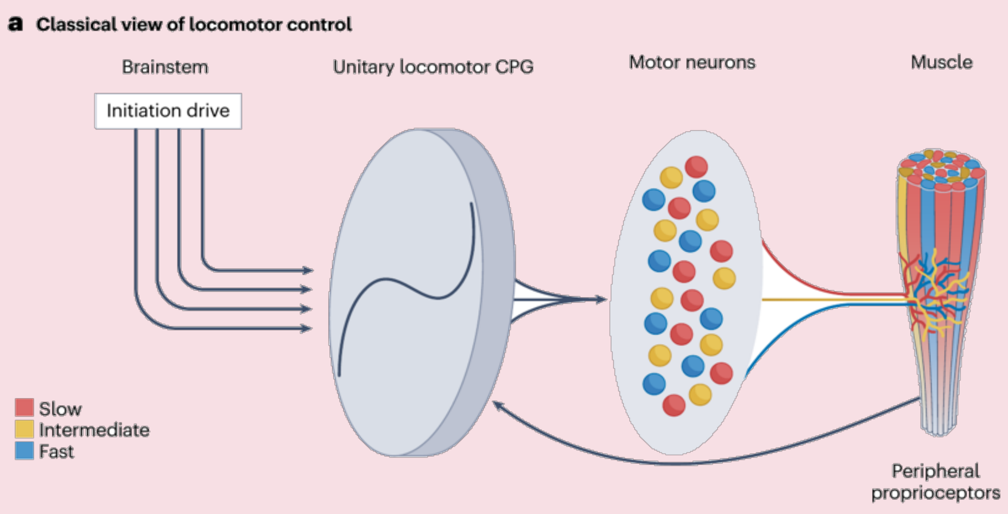


Figure 1. Locomotor central pattern generator, motor neurons and muscle. El Manira (2026)

- A spinal central pattern generator coordinates rhythmic movement.
- Neurons within the CPG communicate through synapses.
- Motor neurons carry the CPG output to the muscles.
- Proprioceptors return movement information to the spinal circuit.

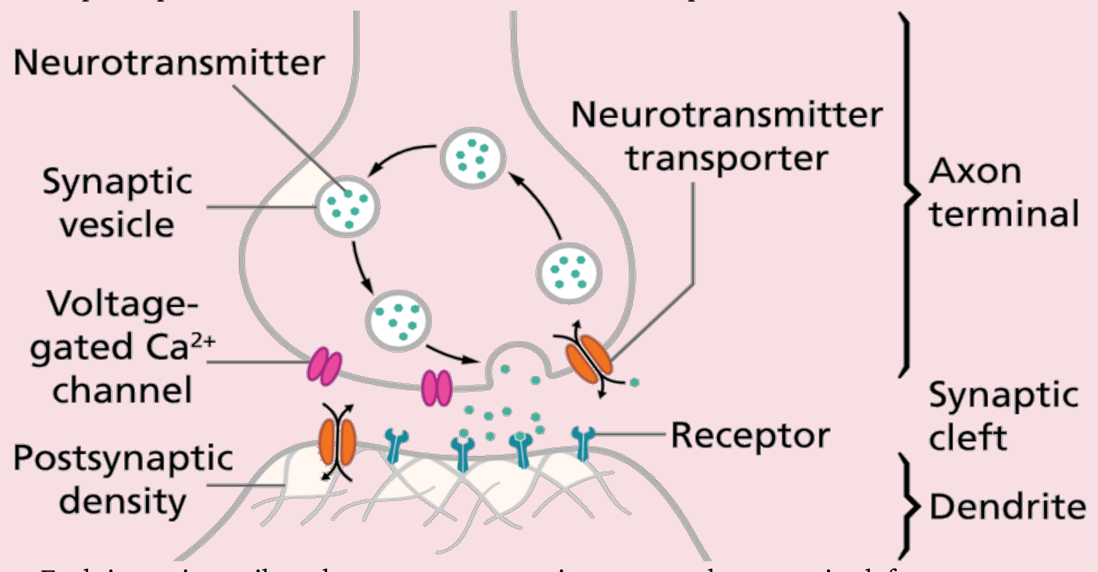
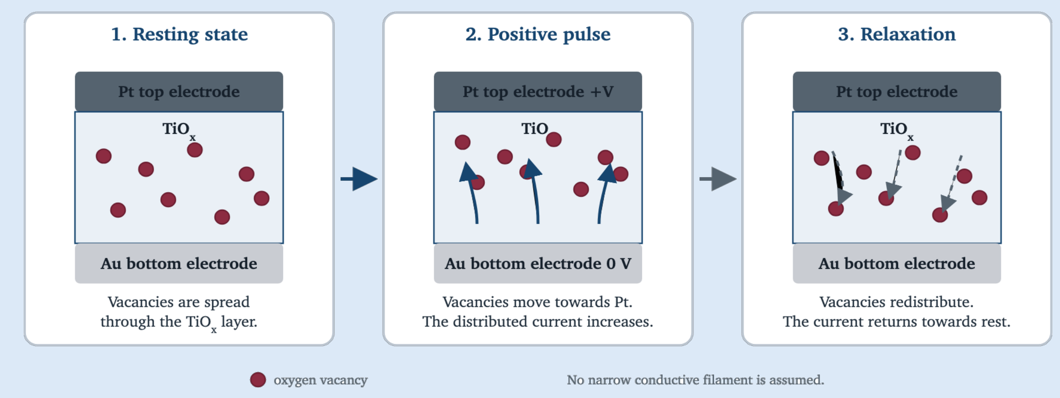


Figure 2. Chemical synapse. Thomas

- Each incoming spike releases neurotransmitter across the synaptic cleft.
- The resulting postsynaptic conductance lasts for milliseconds.
- Vesicle depletion and calcium accumulation mean that each spike in a train can produce a different response.
- An artificial synapse must reproduce this short-term plasticity.

2 Why memristors?

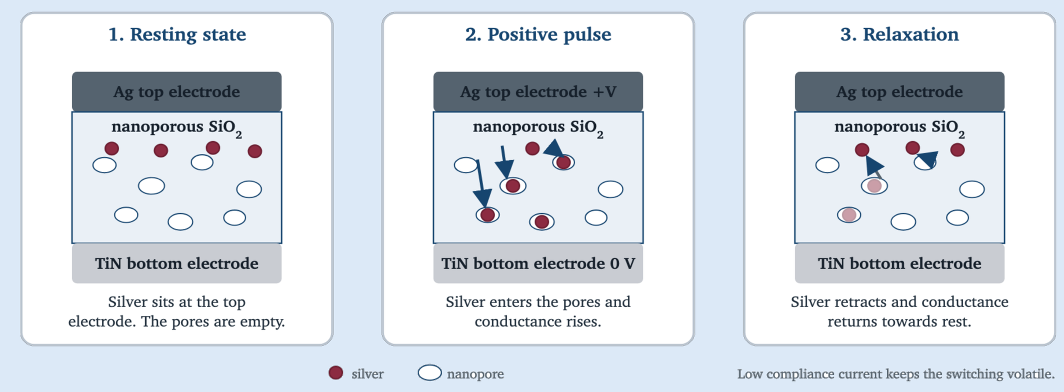
Fan device: distributed oxygen-vacancy movement



Fan device

- A voltage pulse moves oxygen vacancies through the TiO_x layer.
- This movement increases the device conductance.
- After the pulse, the oxygen vacancies redistribute and the conductance decreases.

Bohao device: volatile silver movement through nanopores



Bohao device

- A voltage pulse moves silver into the nanoporous SiO_2 layer.
- The silver forms or extends a conductive path, which increases conductance.
- After the pulse, the conductive path weakens and the conductance decreases.

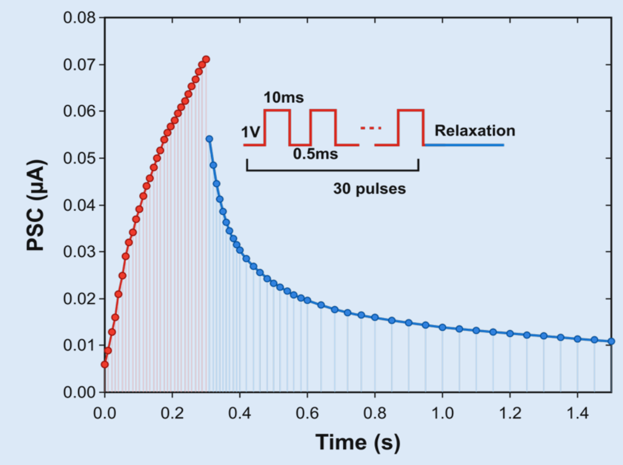
Why this behaves like a synapse

- Closely spaced pulses produce a larger accumulated response.
- Longer gaps allow more of the response to decay.
- The conductance therefore depends on recent pulse timing; giving the device temporal memory.
- This behaviour can reproduce short-term synaptic plasticity.
- Importantly computation and memory storage occur in the same device.

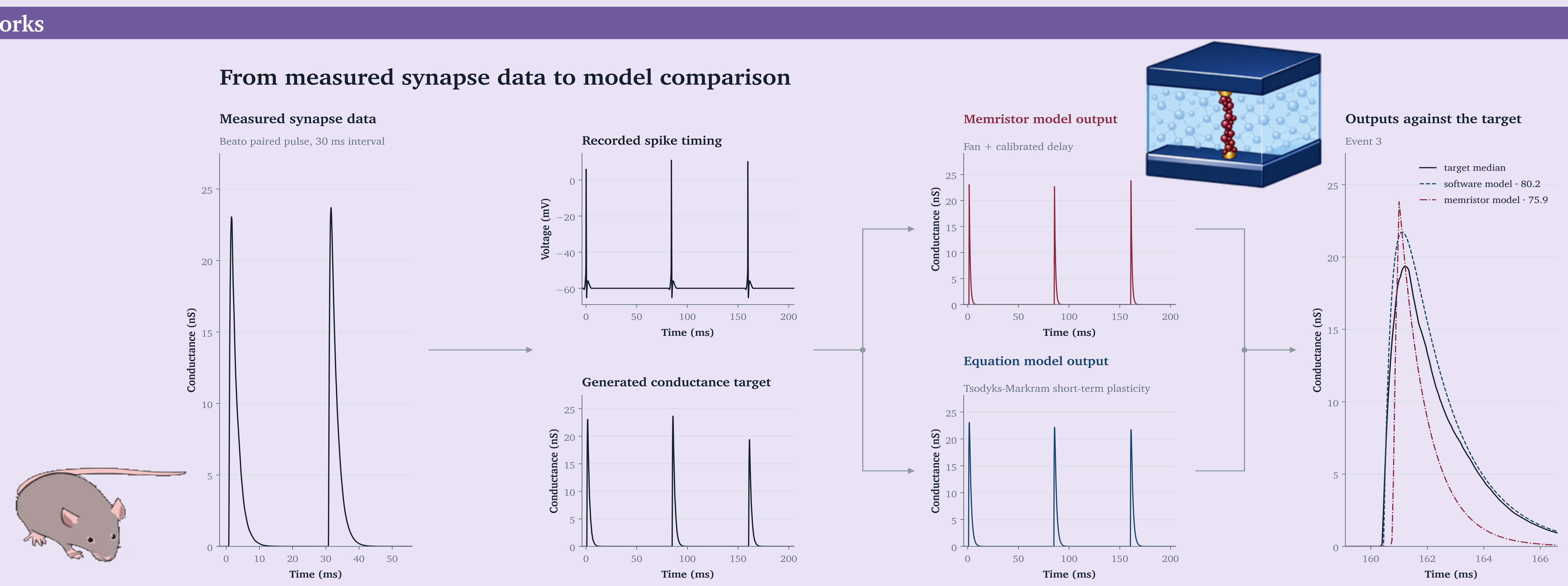
Project boundary

- This project reconstructs both devices into models using actual measurements.
- The project did not test any physical memristor directly.

Figure 3. Memristor potentiation and relaxation cycle. Ding et al. (2026), Fig. 4d



3 How the project works



1 Measured synapse data

The Beato dataset contains recordings from connected mouse spinal motoneurons. These measurements provide the biological basis for the semi-synthetic data generated in the next step.

2 Generate the semi-synthetic data

The measured spike timing forms the model input, while Beato-derived response measurements generate 1,000 conductance targets.

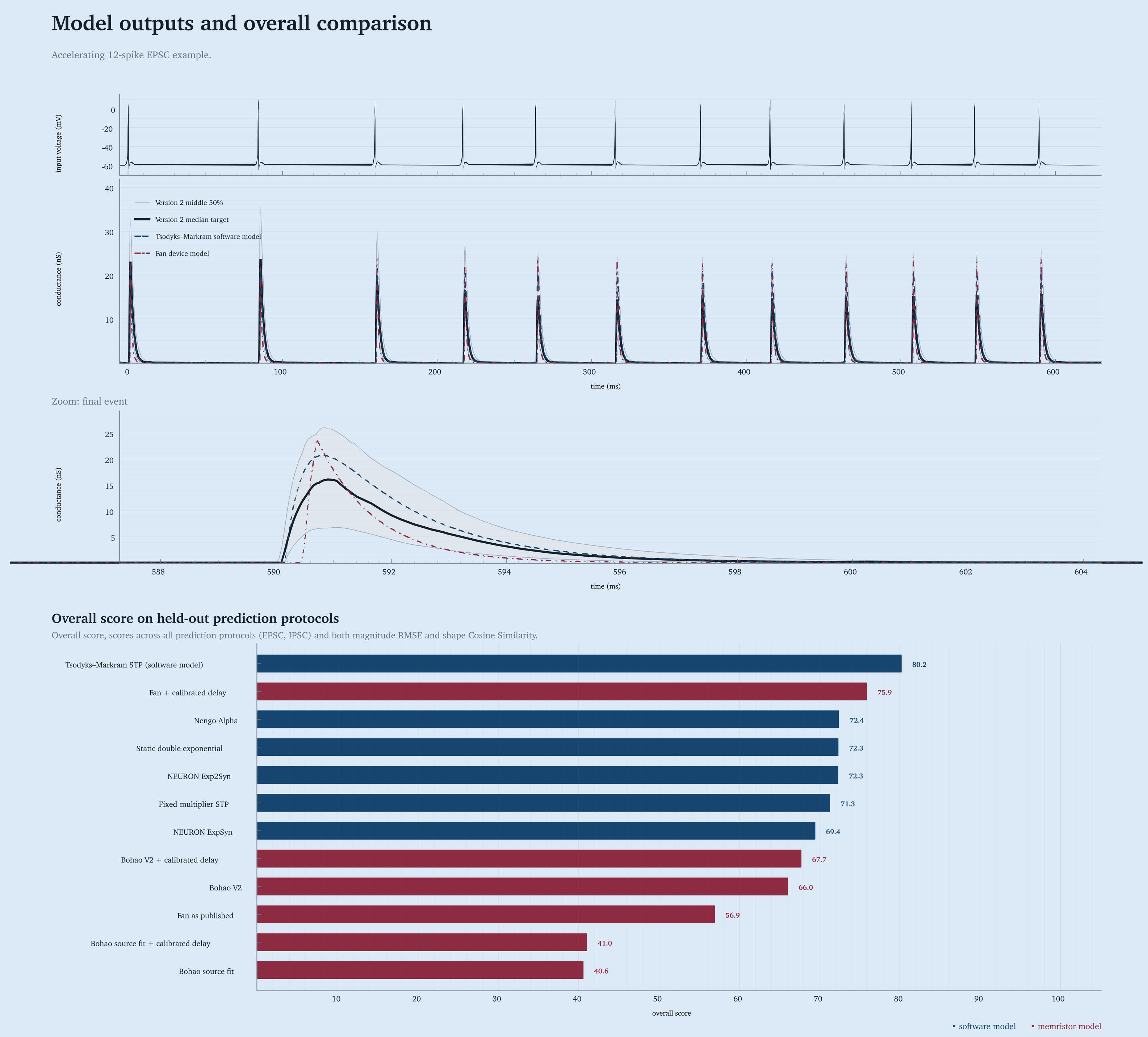
3 Artificial synapse models

All models take the same presynaptic input and are compared with the same target conductance. Six software models receive detected spike times, while five memristor models process voltage sampled at 20 kHz.

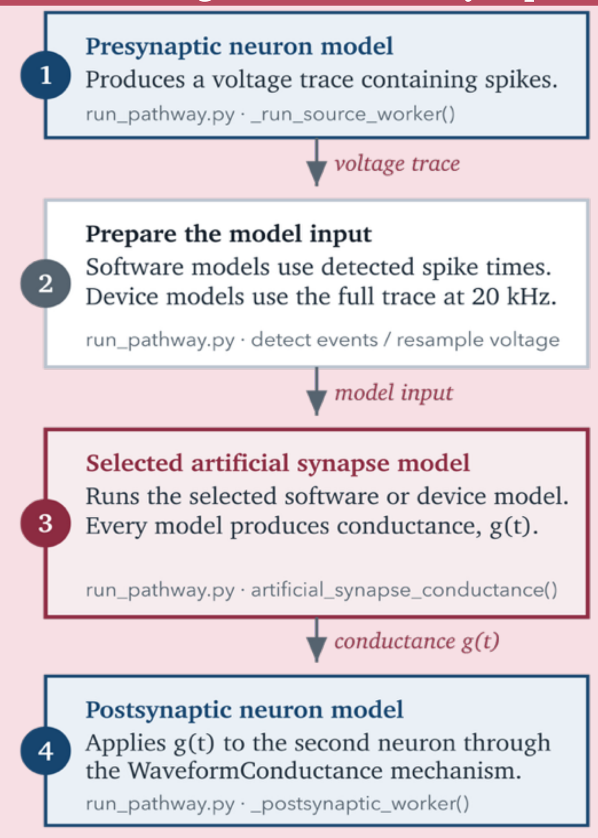
4 Score models against the target

The overall score combines response size and waveform shape on a 0–100 scale. An output with no response scores 50, while a perfect match scores 100.

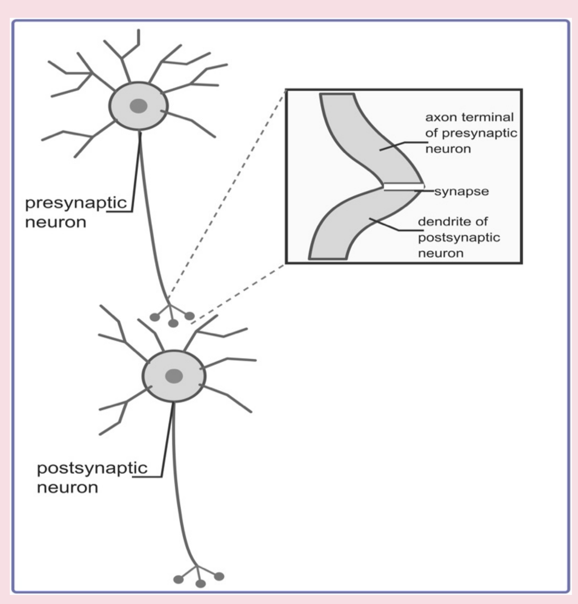
4 What we found



5 Connecting neurons through an artificial synapse



- Each artificial synapse model is placed between two copies of the published Lombardo–Harrington mouse motoneuron model.
- This provides a basic neuron–synapse–neuron connection for a future CPG network.
- The current test is limited because both motoneurons and the artificial synapse remain simulated.



What this means

- Reconstructed memristor models can approximate short-term synaptic responses under biologically derived spike trains.
- Fan memristor came a close second to Tsodyks–Markram.

Limitations

- The targets combine measured biological data with generated conductance waveforms rather than complete end-to-end recordings.
- The comparison uses fixed calibrated delays to reproduce biological response latency.
- The physical memristors were reconstructed in software rather than tested directly.

Next step

- Run the same pathway using physical memristors.
- Collect full end-to-end traces that record presynaptic activity and the resulting postsynaptic response in the same experiment.

Explainer Animations

1. Beato et al. OSF tw9pu 2. Ding et al. dataset D3940 3. Wang et al., J. Phys. D 59, 015101 (2026), DOI: 10.1088/1361-6463/ae23de 4. Lombardo & Harrington, ModelDB 217882 5. Tsodyks & Markram, PNAS 94:719 (1997). 6. Ding et al., Advanced Science (2026), Fig. 4d.