A modular modeling approach for memristors with synaptic-like plasticity and volatile memory

Daniel Habart *et. al.*

Institute of Physiology, Czech Academy of Sciences

Compact memristor models are essential for circuit- and system-scale neuromorphic simulation, yet widely used frameworks (e.g., TEAM/VTEAM) typically do not capture two behaviors that are central in neuromorphic settings: long-tailed volatile conductance relaxation and synaptic- like plasticity with timing dependence. Our work introduces a modular, computationally efficient framework that unifies a voltage-driven memristive core with an STDP-like plasticity module formulated via eligibility-trace dynamics and a volatility module implemented as a hereditary convolution with a power-law memory kernel, followed by a saturation nonlinearity.

The modularity of the model allows device-specific modifications without changing the underlying modeling framework. Furthermore, using an appropriate measurement protocol, the distinct effects of the individual components may be effectively separated, enabling near-independent optimization of each functional component of the model.

We also introduce a technique based on the Laplace transform to determine the functional form of the conductance mapping for a given device. Owing to the simplicity of the model framework, this form may provide useful insight to the characteristic macroscopic behavior of the device, replacing ad hoc voltage-current relationships with principled construction.

The model reproduces both volatile memory and synaptic plasticity observed in polymeric memristors. We quantitatively validate the complete model against a comprehensive set of experimental data exhibiting potentiation, synaptic-like plasticity and volatile decay.

Our work presents a new paradigm for memristor modeling that is both practical for large-scale neuromorphic simulation and rich in explanatory power, providing a principled tool for the design of next-generation neuromorphic hardware.