Classical and quantum memristive devices for neuromorphic computing

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Neuromorphic computing (NC) is nowadays a highly active research field, changing the paradigm of classical computer architectures. NC allows for training models from examples, while it benefits in terms of processing speed and low power consumption from new compact designs that use in-memory computing.

Starting from the initial proposal of a memristor device introduced by Chua [1] and a practical implementation in TiO2 devices by Strukov et al. [2], where the migrating oxygen vacancies have the essential role, several other mechanisms for resistance modulation have been proposed, like the formation of metallic filaments, phase change or involving spintronic or ferroelectric effects. More recently, hybrid perovskite materials have been proposed for the realization of memristive devices [3], owing to their peculiar capacitive and inductive behaviors in the context of ion migration [4]. In this context, we review the major concepts and some particular implementations.

However, the continuous downscaling of electronic devices has prompted a discussion about quantum implementations of memristive devices. We approach this subject from the perspective of coherent scattering in multi-terminal neuron-like devices [5]. For this kind of systems, we establish connections between the synaptic weights and the scattering matrix elements. A possible implementation of a non-linear activation function is discussed. Next, a few-electron neuromorphic system is investigated, focusing on charge commutation effects on different terminals under the action of applied potentials on external gates [6]. Here, we employ machine learning (ML) techniques in form of conditional generative-adversarial networks (cGANs) [7] to predict charge density maps and deconvolute tunneling current maps given the scattering potentials. The ML-based image translation procedure enables an efficient design of such quantum neuromorphic devices. Further examples include the implementation of quantum sorters, as a mirrored neuron geometry, which enable a direct identification of quantum states [8]. In the end, we present future perspectives concerning memristor implementations using quantum many-body systems.

References

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