Simulation of a memristive device-based Reservoir Computing architecture

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High energy consumption in artificial intelligence (AI) systems is increasingly limiting device miniaturisation, where systems with power consumption constraints like health wearables, autonomous vehicle sensors and Internet-of-Things devices must be scaled down to be marketable. Within this context, the Reservoir Computing (RC) paradigm offers a promising alternative, as the development of hardware-based RC devices could result in significant reductions in energy consumption and device footprint compared with traditional computing devices [1].
Memristive devices are two terminal electronic elements whose resistance depends on the history of applied stimuli [2]. The process is also reversible and controllable (save for device degradation and cycle-to-cycle variation), which lends itself to many interesting uses including its applications in RC and neuromorphic computing.
The simulation work presented here is based on a volatile Resistive Random-Access Memory (ReRAM) device, a class of memristive device that does not retain its programmed state over time, and exhibits decaying conductance when excited. The device dynamics, together with an amplitude threshold detection scheme are incorporated to form the RC system, which achieves classification accuracies of up to 94% on the MNIST test set. A version of the memdiode model [3] was adapted to exhibit decaying conductance states, characteristic of volatile ReRAM behaviour. Device-to-device variation and cycle-to-cycle variation are also included in the simulation. The response of the device to stimulus is used as the reservoir module, providing the nonlinear dynamics and fading memory required for RC, shown in Figure 1. Pixel greyscale value is encoded temporally as pulse width to achieve high accuracies for an unbinarised and uncropped MNIST test set. This architecture demonstrates that adding a simple threshold detection scheme to a memristive device-based RC can improve classification performance. Moreover, the adaptation of the memdiode equations to demonstrate decaying conductance state widens the scope of the model, and allows for the model's use in a broader range of neuromorphic architectures.

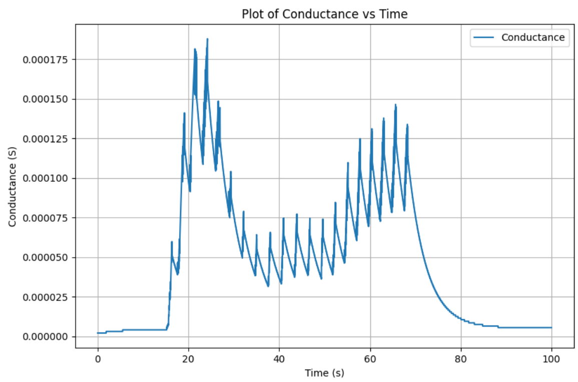

Figure 1: Example reservoir response to full MNIST figure.

[1] Christensen, D. V. et al., Neuromorph. Comput. Eng., 2, 022501, 2022.

[2] Yang, J. J. et al., Nat. Nanotechnol., 8(1), 13-24, 2013.

[3] Aguirre, F. L. et al., Micromachines, 13(2), 330, 2022.