Impact of device-to-device variability (D2D) of memristors on the Memristive Cellular Nonlinear Network (M-CNN) image EDGE detection task

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M-CNN is an emerging paradigm that enriches conventional Cellular Nonlinear Networks (CellNNs) with complex dynamics inherent to memristive devices. This is achieved by incorprating a non-volatile memristor into the core circuitry of the CellNN architecture [1, 2]. From a computational standpoint, the behaviour of M-CNN is governed by localized interactions with its neighbouring cells (M-CNN cells), encapsulated in a set of synaptic weights and a bias term. Governed by the Local Rules (LRs), every individual cell in the M-CNN contributes to the dynamics of the system. For the network to successfully execute a task, the collective system must converge from its initial state toward a stable global equilibrium. However, memristors are prone to device-to-device (D2D) variability due to the stochastic nature of their switching mechanisms [3]. Consequently, it is crucial to assess the impact of this stochasticity on the functional reliability of the M-CNN grid for applications.

In this work, we investigate the impact of D2D variability on the performance of a 16×16 image EDGE detection task implemented using M-CNN cells through circuit-level Cadence simulations. The simulation parameters capturing D2D variability are derived from experimental measurements of five distinct HOTO (HfO_2/TiO_x) device samples. These devices are integrated into the core circuitry of an M-CNN cell and evaluated under the worst-case local rules (LRs) for edge detection identified in [4].

The most influential parameters of the variability-aware JART Valence Change Mechanism (VCM v1b) model [5] affecting the convergence behavior of each worst-case LR are identified through extensive simulations. These parameters are subsequently utilized to calibrate the model against our experimental data. To incorporate D2D variability at the network level, model parameters for each M-CNN cell are sampled from a truncated Gaussian distribution, ensuring physically consistent bounds. Furthermore, to account for full-system non-idealities, a ±20% tolerance is applied to the passive resistors and capacitors, which are randomly assigned across the 16×16 grid. Despite these cumulative variations, the simulation results demonstrate the excellent robustness of the M-CNN edge detection architecture, maintaining functional integrity across the entire sampled parameter space.

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