

# Fully-Digital Associative Memories Enabled by Non-Volatile Magnetic Logic



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Neurocomputing is considered an intriguing alternative to computing based on traditional von Neumann architectures due to its brain-inspired massive parallelism. In essence, a neurocomputer performs pattern recognition via associative memory instead of having general purpose computation by executing a list of commands. Hence, it is a powerful component for such applications as pattern recognition and image processing.

Neurocomputers constructed as associative memories consist of a network of coupled dynamic units, referred to here as artificial neurons, that process information in parallel. They are analogous to the nervous system in human brain in a way that each brain neuron corresponds to a computational unit in neurocomputer, and a connection between two artificial neurons represents a synapse connecting two brain neurons. The strength of this synapse is the connection coefficient (i.e., synaptic weight) that relates one artificial neuron to another.

Since CMOS is ineffective for constructing associative memories based on neural networks (NNs) from both power and area standpoints, in this work we propose a novel approach for them whereby the non-volatile storage of state offered by *mCell* devices is exploited to build various classes of *fully-digital* NNs with great efficiency. The inherent storage is exploited to *digitize* the relationships between neurons, thereby enabling efficient control of the *reconfigurable* connection coefficients. In addition, the non-volatile storage enables highly-efficient logic *pipelining* without requiring D flip-flops, which can significantly reduce the area and power required for NNs.

Fig. 1 depicts an example implementation where the phase relationships between neurons and neural computations are discretized by means of non-volatile logic. This system with  $n$  neurons would otherwise require  $n$  voltage-controlled oscillators (VCOs) to represent neural oscillations,  $n$  phase-locked loops (PLLs) to synchronize artificial neurons to each other, and  $n^2$  variable gain amplifiers (VGAs) to enable the programming of connection coefficients.

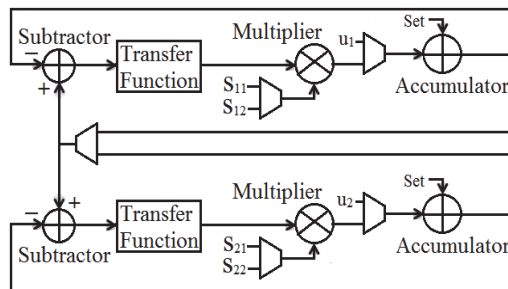


Fig. 1: High-level circuit representation of the proposed digital oscillatory NN with two neurons.