BRAINMORPHIC ALGORITHM IMPLEMENTATION FOR A BIO-HYBRID SYSTEM

Landry Bailly, Timothée Levi
IMS, UMR5218, CNRS, University of Bordeaux, Talence, France

Machine learning algorithms are now used daily on a very large scale to perform diverse learning and classification tasks such as facial recognition or biological signal classification. As a result, the demand for computing power has been growing exponentially (×300,000 between 2012 and 2018). The associated energy cost is considerable: training a single complex neural network can require as much energy as a human consumes over 57 years. It has therefore become essential to explore energy-efficient alternatives.
Neuromorphic engineering, originally focused on replicating the biophysics of neurons and synapses in hardware, has progressively expanded toward novel computational principles, materials, and applications. Over the past few decades, it has been applied to develop innovative technologies in both neuroscience and artificial intelligence.
To harness the advantages of biological intelligence—most notably its plasticity and remarkable energy efficiency (around 20 W for a brain with billions of neurons)—a promising direction is the direct use of biological neurons for computational tasks. This has recently been enabled by the emergence of bidirectional hybrid systems and biologically realistic AI algorithms.
Our objective is to perform computational tasks such as pattern recognition using biological neurons. To achieve this, we develop a computational bio-hybrid closed-loop system that combines a Biological Neural Network (BNN) with a Spiking Neural Network (SNN). (fig 1)

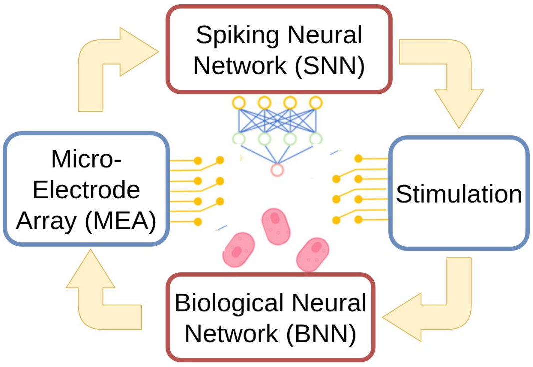

Figure 1 : Bio-Hybrid System

In this context of a bio-hybrid closed loop, the first step is to perform the biological signal processing. We did an FPGA-based implementation of an unsupervised SNN for pattern recognition. The model consists of a single layer of Leaky Integrate-and-Fire (LIF) neurons fully connected to the input with synapses following the Spike-Timing-Dependent Plasticity (STDP) rule, capable of recognizing repetitive hidden patterns.

The SNN is implemented on a Field-Programmable Gate Array (FPGA), leveraging its flexibility and parallel processing capabilities. This setup enables real-time execution, processing input signals from a Micro-Electrode Array (MEA) at a sampling rate of 20 kHz. We employ the AMD Kria KR260 development board, which integrates programmable logic and embedded software, with AXI-based control ensuring real-time communication between processing and I/O modules. The implementation manages serial and parallel computing, allowing the design to adapt to input size and real-time constraints. The implementation has been validated by performing several experiments and comparing results with FPGA implementations and Python simulations. We also compared precision and recall using different number representations.

Future work will include the integration of the spike detection and spike sorting stages, which are more computationally demanding. These stages will be adapted to our model to maintain overall system performance while ensuring compatibility with real-time processing requirements. This algorithm is the first step of the whole bio-hybrid system.