# Embedded learning on neuromorphic systems: Towards a unified computing framework

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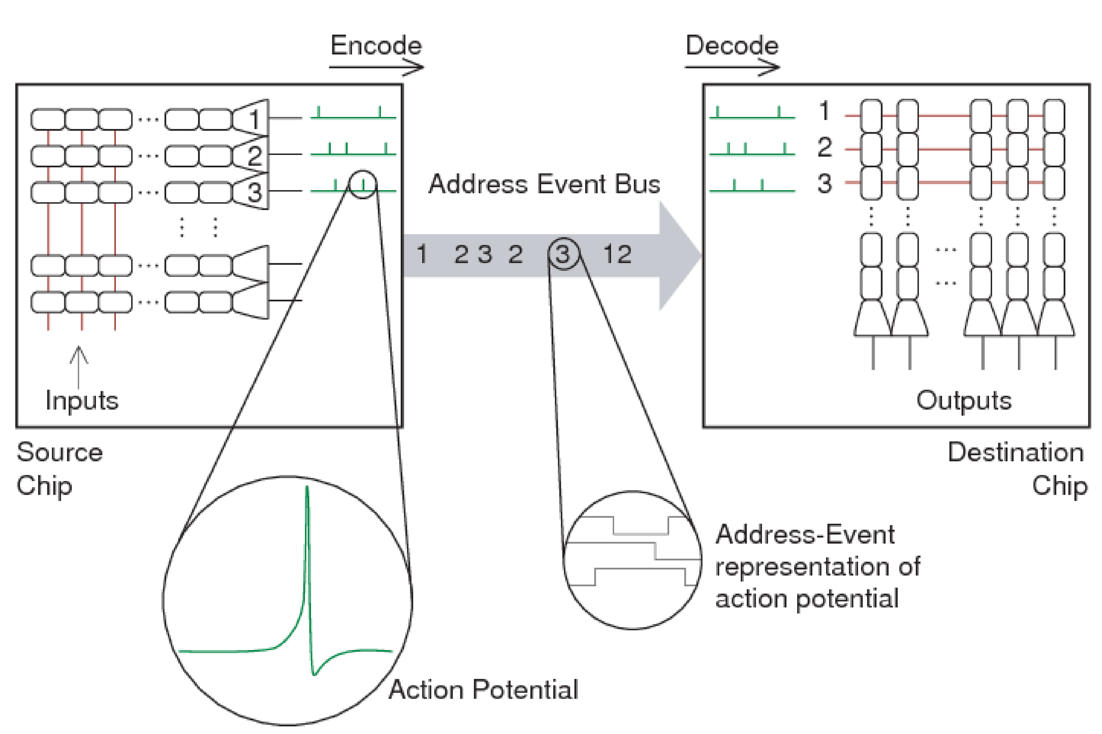
## Introduction

Neuromorphic systems are hardware modules able to mimic the dynamical and computational aspects of biological brains. In the recent years significant progress in the field has led to remarkable capabilities in simulating large-scale neural networks mainly used in Machine Learning field for accelerating computations and "run" massively parallel and distributed computations on large-scale data inputs. However, most neuromorphic devices do not offer embedded learning, implying that need to be calibrated or trained off-line (off-the-chip) neural networks.

In this work we introduce the neural synaptic array transceiver (NSAT), a generic neuromorphic framework capable of supporting embedding (and on-line) learning based on a three-factor, spike-driven learning rule compatible with STDP. NSAT supports a wide-range of neural models (such as compartmental models, Mihalas-Niebur neurons, etc) and multiple different supervised and unsupervised learning schemes based on event-based machine learning algorithms. As proof of concept in this work we show NSAT performing real-time, event-based deep learning of patterns in data streaming from a silicon retina (DAVIS camera), using a recently proposed event-based random back-propagation algorithm.

## Event-based Computations

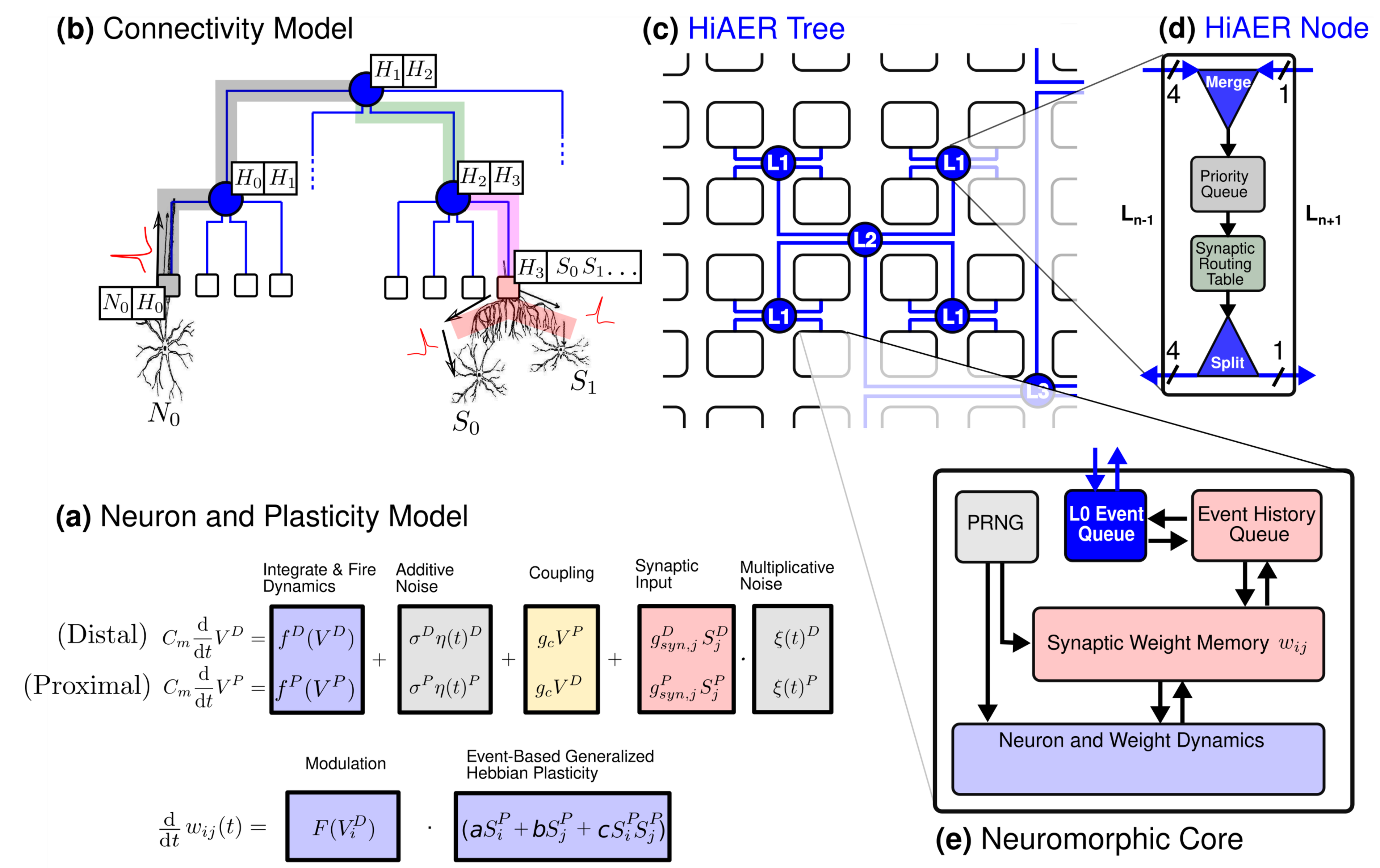
Brain's architecture is vastly different from standard digital computing (von Neumann architecture). It is mainly distributed, parallel, power efficient, and computations and memory are locally distributed on neurons and their components.




Neurons communicate via spike-events. Spike-events are routed in between neurons and facilitate communication between neurons. All other information necessary is local to neurons.

## The NSAT Framework

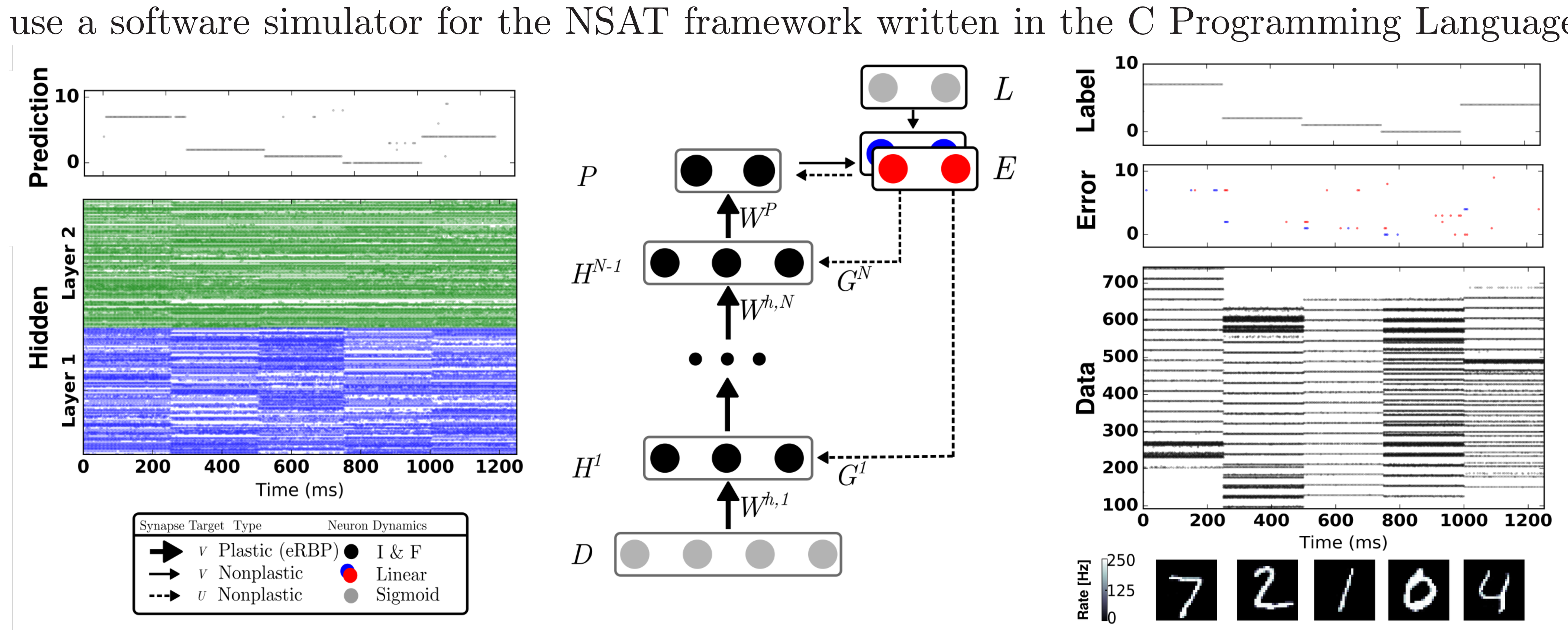
The Neural and Synaptic Array Transceiver is a digital brain-inspired computer architecture for embedded learning co-designed by UCI, UCSD and Intel Corporation.




The NSAT framework is designed to support large-scale (deep), on-line, spike-based learning while affording ultra-low power hardware implementation in custom or off-the-shelf hardware [1]. Industry collaborators are investigating custom digital hardware implementations of the NSAT.

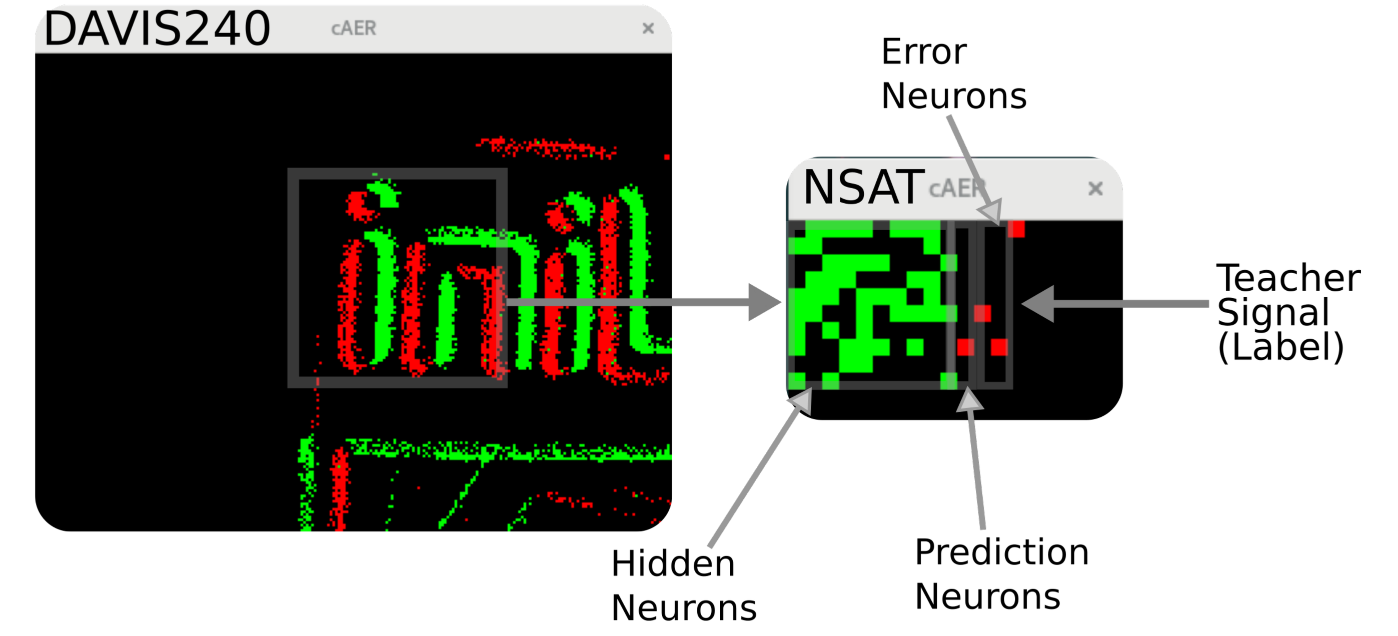
## Event-based Learning

Recent breakthroughs in event-driven learning algorithms enabled an error-modulated synaptic plasticity rule for fast and efficient spike-based deep learning in neuromorphic hardware. In this work we apply the event-based Random Back-Propagation (eRBP) algorithm [2] on the MNIST data set (handwritten digits from 0 to 9) in an on-line fashion. First we illustrate a case where MNIST digits have been converted to spike trains. The figure below illustrates the results as well as the network architecture. In all simulations we use a software simulator for the NSAT framework written in the C Programming Language.




## A real-time demo

We simulate the NSAT interfaced with a Davis retina camera (an event-based, asynchronous camera that generates spike-events when the intensity of a pixel changes). The camera focuses on a computer screen displaying MNIST digits. Davis retina camera feeds the spike-events to the neural network. The user feeds in real–time custom labels to the neural network via keyboard strokes.




The figure above illustrates the output from the Davis camera (left panel) and the visualization of the neural network output (right panel). On the right panel each green pixel represents the hidden neurons. Red pixels indicate prediction, error and label (teacher) neurons, respectively.

## References

[1] B. U. Pedroni, S. Sheik, S. Joshi, G. Detorakis, S. Paul, C. Augustine, E. Neftci, and G. Cauwenberghs, *Forward Table-Based Presynaptic Event-Triggered Spike-Timing-Dependent Plasticity*, BioCAS 2016.

[2] E. Neftci, C. Augustine, S. Paul, G. Detorakis, *Event-driven Random Back-Propagation: Enabling Neuromorphic Deep Learning Machines*, arXiv preprint arXiv:1612.05596, 2016.

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