

Università degli Studi di Cagliari

Bio and Cyber Neural Network Interaction: Toward Hand Kinematic Decoding

Gianluca Leone, Paolo Meloni



# ZyON: Enabling Spike Sorting on APSoC-based Signal Processors for High-Density Microelectrode Arrays

High-Density Multi-Electrode Arrays are a key instrument in neuroscience research. For realexperiments, in-place low-latency time processing is required. This poses the need for embedded high-performance computing platforms capable of processing in real-time the stream of samples produced by the acquisition front-end to extract higher-level information. Our system, implemented on a Xilinx Z7020 All-Programmable System-On-Chip is capable of executing online spike sorting up to 5500 acquisition channels, 43x more than state-ofthe-art alternatives, supporting 18KHz acquisition frequency. We present an experimental study on a commonly used reference dataset, that uses an online refinement of the sorting clusters to improve the accuracy up to 82%, with only 4% degradation with respect to offline analysis.



#### **ZYON** spike sorter

work	year	channels	accuracy	DSP	BRAM
Valencia	2019	1	87%	130	29
Schäffer	2020	128	86%	60	98
Our work	2020	4096	82%	61	104

**SPIKE SORTING** is a neural engineering signal processing task that consists into recognize when the sensed spikes are fired by the same neuron. It is carried out by executing three fundamental steps:

- Spike detection: spikes are detected by relying on their typical pointy shape;
- **Feature extraction**: spikes fired by the same neuron are recognized because of their similar shape. Spike shapes are classified by means of features such as width, slope, etc.
- Spike classification: the spikes are classified depending on the generated feature vector.

Neural activity mapping can sometimes provide more complete information than spike detection or local field potential analysis for neural decoding tasks, such as hand kinematic decoding.





my/www.

## A Bandwidth-Efficient Emulator of Biologically-Relevant Spiking Neural Networks on FPGA

ADC

Closed-loop experiments involving biological and artificial neural networks would improve the understanding of neural cells functioning principles and lead to the development of new gen. neuroprosthesis. This work focuses on the development of a real-time spiking neural network emulator addressing fully-connected neural networks on the Xilinx Zynq 7020 All-Programmable SoC and can emulate fully connected spiking neural networks counting up to 3,098 Izhikevich neurons and 9.6e6 synapses in real-time, with a resolution of 0.1 ms.

work	year	synapses	neurons	DSP	BRAM
Gupta	2020	1.25e4	800	64	16
Sripad	2018	2.00e4	12,800	100	213

HP PORT 1	SYNAPTIC CURRENT COMPUTATION MODULE FPGA	SPI MEN REAI	MEMBRANE POTENTIAL COMPUTATION MODULE	
HP PORT 2	SYNAPTIC CURRENT COMPUTATION MODULE FPGA	SYNAPTIC CURRENT MEMORY WRITER FPGA		
HP PORT 3	SYNAPTIC CURRENT COMPUTATION MODULE FPGA	SPIKE MEMORY FPGA	MEMBRANE POTENTIAL MEMORY FPGA	CONTROL
54	SVNADTIC			

### Hand Kinematic Decoding

SIGNAL PROCESSING CHAIN

MULTIUNIT SPIKE BINS SINGLE UNIT SPIKE BINS LOCAL FIELD POTENTIAL The chosen neural signal requires real-time low-latency processing. Once ready, the neural decoding is usually made by means of Kalman filters or neural network based decoders.

Neural decoding is a mapping

from the neural activity to the

outside world. The hand kinematic

decoding problem aims to rebuild

the dozens of joints' positions that

Prosthetic implants rely on a wide

range of signals, non-invasive

strategies make use of sEMG and

EEG signals, invasive strategies can

directly collect the neural activity

characterize the hand state.

from the motor cortex.

Pani	2017	2.07e6	1,440	408	392	PORT	CURRENT	IZHIKEVICH PARAMETERS	SYNAPTIC CURRENT	
Our work	2022	9.6e6	3,098	140	130.5	H	MODULE FPGA	FPGA	FPGA	

It is possible to **increase the number of synapses** that can be emulated in real-time by taking advantage of a physiological delay that affects the spike propagation along the cell's axon. This phenomenon, called **axonal delay**, makes possible to relax the spike propagation deadline, reuse multiple times the same set of synaptic weights, and **exploit the off-chip memory** to store them.







ARM

**Single cell behavior** Fixed- and floating-point Izhikevich single-cell membrane potential superimposition at the varying of the fixed-point data width. The waveforms have been captured within a time window of 200 ms.

On the left side of each row of the plot is indicated the fixedpoint data format. Each column depicts a different kind of neuron, from left to right regular spiking, chattering, intrinsically bursting, fast-spiking, and low-threshold spiking cells.

#### Let's keep in touch!

NEURAL SIGNAL DECODER

HAND JOINTS POSITION VELOCITY ACCELERATION The data to test such devices is made of two parallel recordings: the neural activity and the hand kinematic. However, it is hard to find, especially in the case of invasive neural recording. In fact, every dataset requires months of work to be recorded, since the subjects need training for accomplishing the experimental task.

work	year	signal	electrodes	decoder	accuracy	
Batayneh	2022	sEMG	10	FFNN	79.8%	
Ahmadi	2021	Single-unit	96	QRNN	86%	
Ahmadi	2021	Multi-unit	96	QRNN	84%	
Du	2022	sEMG	8	SNN	87%	
Nason	2020	Multi-unit	96	Kalman	76%	
State of the art neural decoder						





CPS Summer School 2022, 19-23 September 2022, Pula, Sardinia, Italy