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Development of Electronic System Interface for Neuromorphic Arrays in In-Sensor Computing

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Introduction

Neuromorphic and in-sensor computing integrates sensing and processing, removing the von Neumann bottleneck. It enables real-time, low-power neural networks for IoT, clean energy, and edge AI, with dedicated hardware offering faster, more efficient computation than FPGA or GPU."

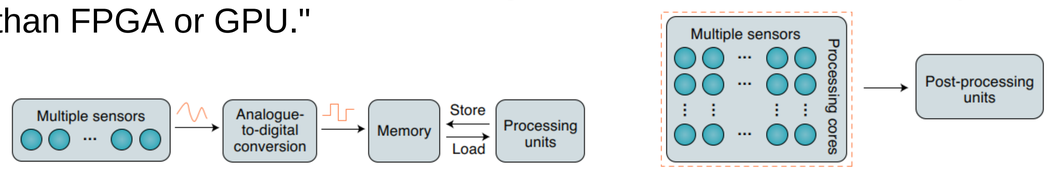


Figure 1. Von Neuman vs in-sensor neuromorphic architecture [1].

Materials for Neuromorphic Hardware

Memristive materials:

- Combine resistance + memory in one device
- Programmable, non-volatile states
- Tunable conductance
- Emulate synaptic plasticity

Found in oxides, phase-change alloys, MTJs, ferroelectrics, 2D & polymeric materials

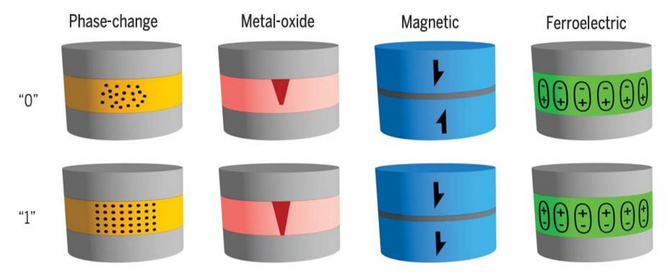


Figure 2. Memristive material schematics [2].

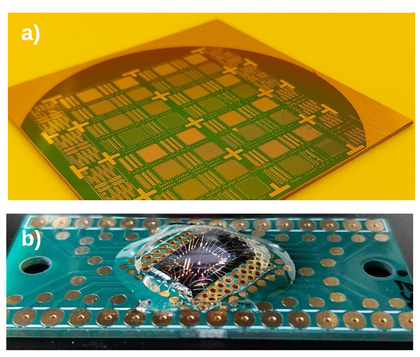


Figure 3. a) Arrays of Memristors b) Crossbar array bonded on carrier board

In-Sensor Computing:

- Provides rectified, ultra-sensitive detection
- Act as sensors + computing nodes via I–V response
- Supports optical, gas, and multi-modal sensing in crossbar designs

Concept

- Driving Neuromorphic Chips
- Neuron & Synapse Functions
- Connecting Layers
- Power and Processing

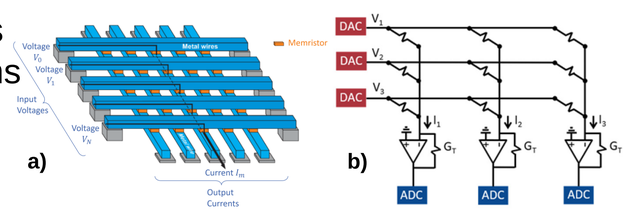


Figure 4. a) Physical schematic b) Electrical schematic of an array [3].

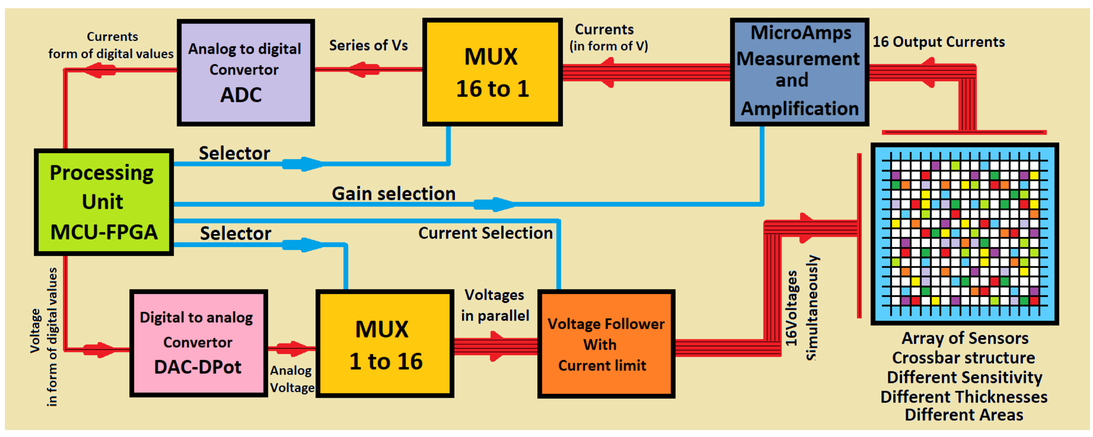


Figure 5. Block diagram of crossbar array electronic interface

- Absolute operation condition finder
- Single device characterization
- Array characterization up to 32 connection (simultaneous feed)
- Maximum 16x16 array
- Modular (Memristive array - Sensor array)
- Digital control and processing (DAC-ADC)
- Signal generator (Sin-Pulse-Triangle-Impulse-Square)
- 12-bit resolution
- Automatic gain control

References

[1] Zhou, F. and Chai, Y., 2020. Near-sensor and in-sensor computing. *Nature Electronics*, *3*(11), pp.664-671.

[2] Lanza, M., Sebastian, A., Lu, W.D., Le Gallo, M., Chang, M.F., Akinwande, D., Puglisi, F.M., Alshareef, H.N., Liu, M. and Roldan, J.B., 2022. Memristive technologies for data storage, computation, encryption, and radio-frequency communication. *Science*, *376*(6597), p.eabj9979.

[3] Pedretti, G. and Ielmini, D., 2021. In-memory computing with resistive memory circuits: Status and outlook. *Electronics*, *10*(9), p.1063.

[4] Ielmini, Daniele, and H-S. Philip Wong. "In-memory computing with resistive switching devices." *Nature electronics* 1, no. 6 (2018): 333-343.

Characterization and Computation

Characterization:

- I-V and C-V measurement
- Endurance and Retention Test
- AC - DC analyzer
- Analog, Digital driving/measurement
- Single-array device measurement
- Digital / Analog memristor

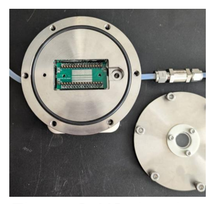


Figure 6. H2 chamber with array connection

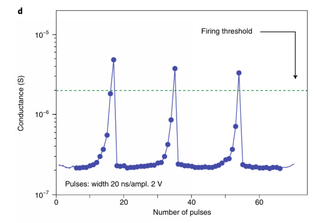
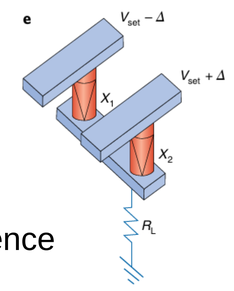


Figure 7. conductance vs pulses[4].

Operations:

- Programmable Signal output
- Programmable Tuning
- Programmable Measurement sequence
- Logic operations
- In-sensor Computation
- Hard-Coded and Soft-Coded Array
- Data Logging



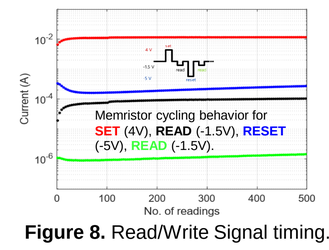


Figure 8. Read/Write Signal timing.

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X_1	X_2	$Y = X_2'$
0	0	1
0	1	1
1	0	0
1	1	1

Figure 9. memristor based logic diagram [4]

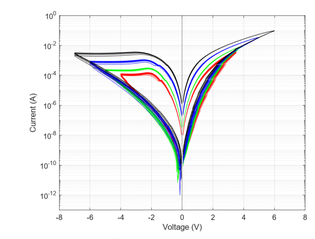

Figure 10. I-V test.

Main-board and Module

Main-board

- 550MHz clock speed
- USB Interface to PC
- 32bit ARM Cortex M7
- 16-bit ADC
- 3 State Relay Array
- Parallel Control of the modules
- Synchronization
- Display
- Power supply

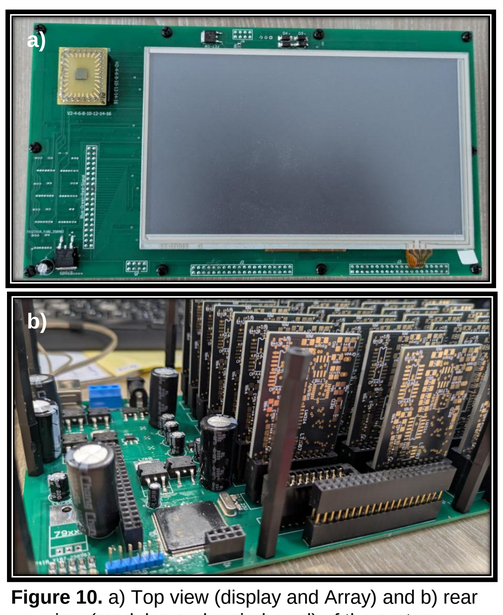

Figure 10. a) Top view (display and Array) and b) rear view (modules and main-board) of the system.

Module

Figure 11. Input/Output Module

Output mode:

- mV DC generator
- Wide Output (-24 to 24v)
- Signal Gen (72MHz)
- 12-bit DAC
- Output PID
- Current limiter

Input mode:

- µA measurement
- Amp to Volt
- Auto/Selectable Gain
- 12-bit ADC
- 1MS/s
- 10MΩ

Summary and key points

- **Driving and validating neuromorphic arrays** is enabled by a modular **Electronic System Interface (ESI)**, designed as a flexible platform for both device **testing** and **real-time** neuromorphic **computation**.
- A **microcontroller and FPGA** work in tandem: Manages timing, control logic, precise synchronization, parallel processing, and reliable multi-channel data handling.
- **32 re-configurable I/O channels**, switchable between input and readout, with integrated DACs, waveform generators, amplifiers, ADCs, and memory for precise signal delivery and response acquisition.

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