# Environment Aware Memristive Oscillatory Circuit towards ELM Emulation


I. Tompris[1], I. K. Chatzipaschalis[1,2], Th. P. Chatzinikolaou[1], I. - A. Fyrigos[1], A. Adamatzky[3], Phil Ayres[4], G. Ch. Sirakoulis[1]

1. Department of Electrical and Computer Engineering, Democritus University of Thrace (DUTh), Xanthi, Greece
2. Universitat Politecnica de Catalunya, 08034 Barcelona, Spain
3. Department of Computer Science and Creative Technologies, University of the West of England, Bristol, UK
4. Institute of Architecture and Technology, Royal Danish Academy, 1435 København K, Denmark

*Emails: {itompris, ichatzip, tchatzin, ifyrigos, gsirak}@ee.duth.gr, andrew.adamatzky@uwe.ac.uk, phil.ayres@kglakademi.dk*


## 1. Overview

**Motivation:**

- **Engineered Living Materials** (ELMs), especially the Mycelium, possess unique properties yet to be harnessed:
  1. **Mechanical** and **Structural** Properties
  2. **Low-Cost** Manufacturing
  3. **Biodegradability**
  4. **Bio-Inspired Computation** through Complex Electrical Activity

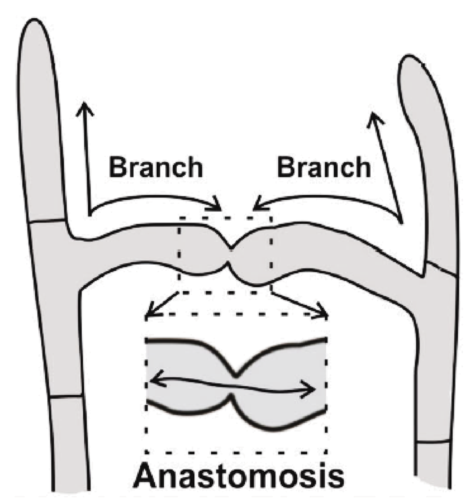
**Our Proposal:**

- ***A Digital Twin (DT) optimizing mycelium-based ELM development, while also dynamically adjusting the designed circuit by incorporating external stimuli through environmental sensors***
- Implementing Wave Cellular Automata, supported by memristor-based circuitry, to mimic wave propagation within a cellular-like architecture

## 2. ELM Mechanisms and Environmental Stimuli to be Modelled

**Essential Features:**

- Tip Extension
- Branching (Lateral/Apical)
- Anastomosis
- Environmental Conditions




**Environmental Stimuli:**

- Moisture
- Temperature
- pH Levels
- Nutrient Availability
- Substrate Composition
- Light

## 3. Modelling Mechanisms with CBRAM Devices

**Model:**

- **Reaction-Diffusion** Processes
- **Activator-Suppressor** System

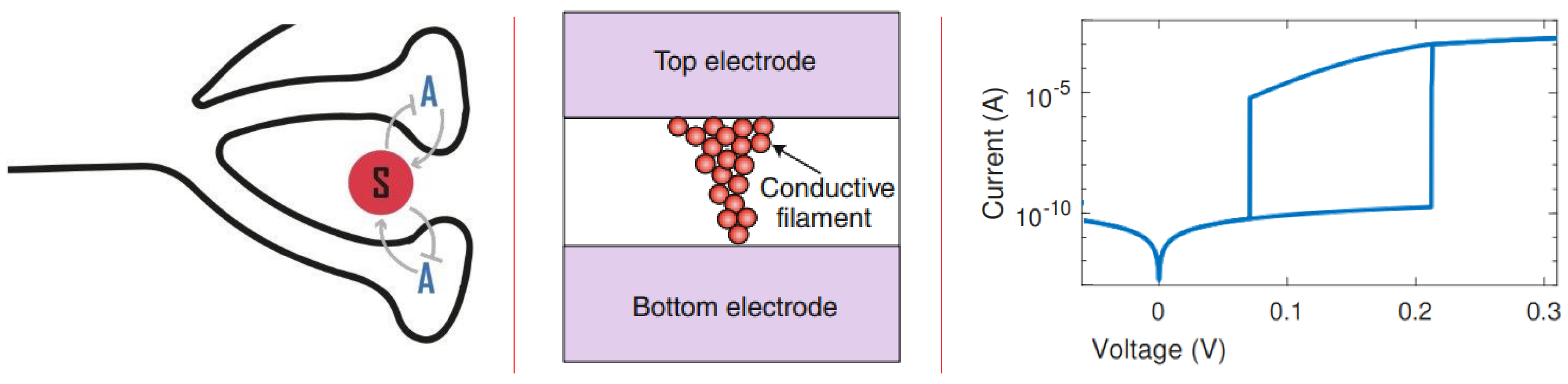
$$\frac{\partial u}{\partial t} = \nabla^2 u + \zeta(\kappa u + u^2 - \lambda u v) \in \Omega_c$$

$$\frac{\partial v}{\partial t} = d\nabla^2 v + \zeta(\mu u^2 - v) \in \Omega$$

$$\frac{dc}{dt} = \zeta \nu c(a(u) - c)(c-1) \in \Omega$$

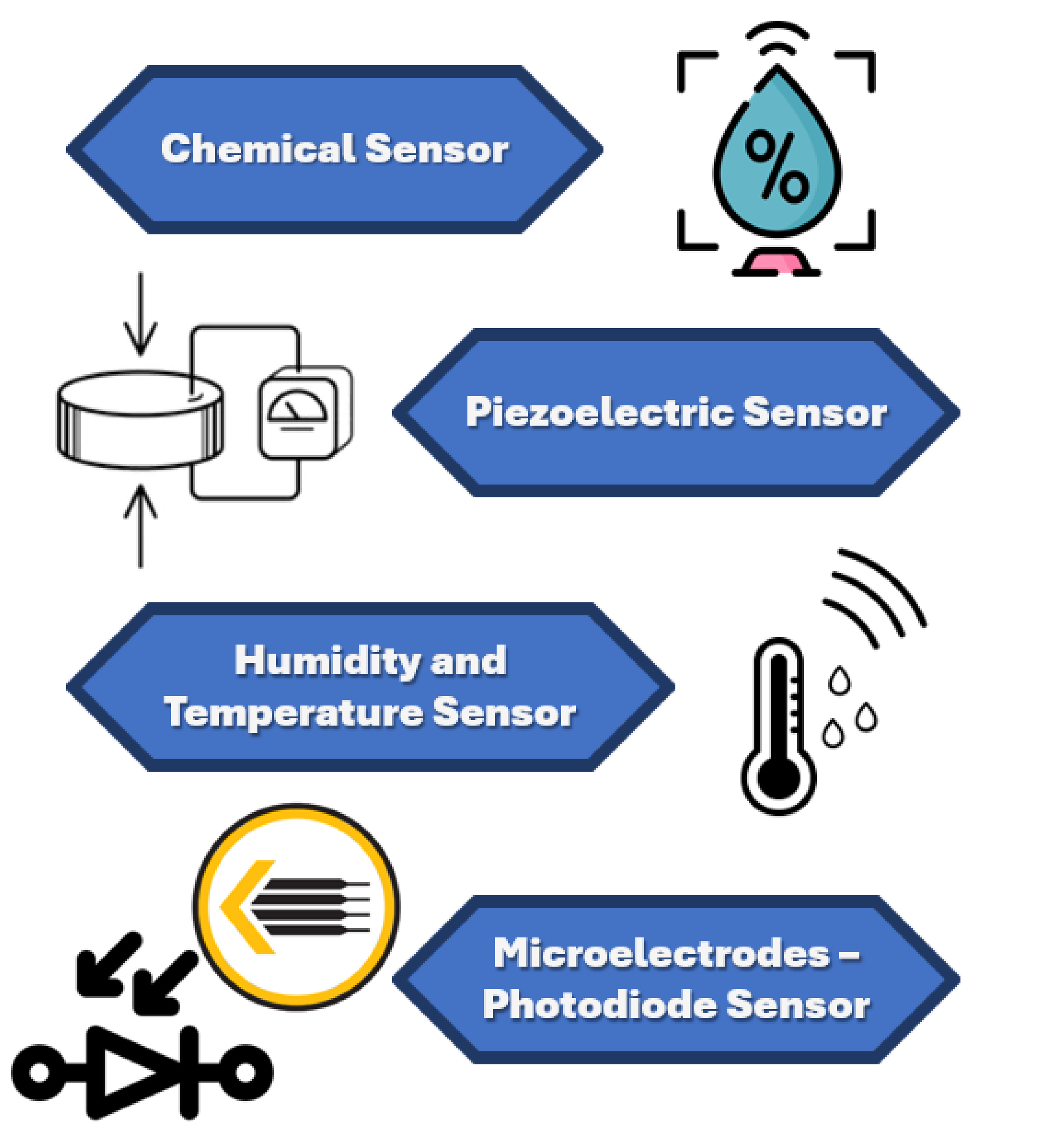
**Conductive Bridge Random Access Memory:**

- Incorporates both **computation** and **storage** capabilities
- Can be used for **bio-inspired computation** due to its conductive filament (CF) dynamics
- Exhibits rapid **unipolar switching** capability



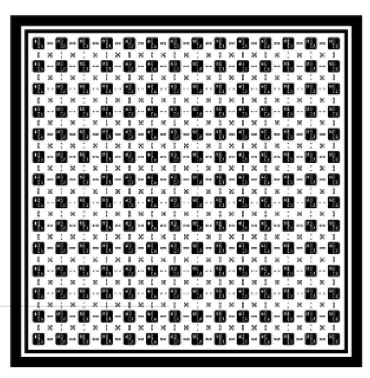

## 4. Incorporating External Stimuli

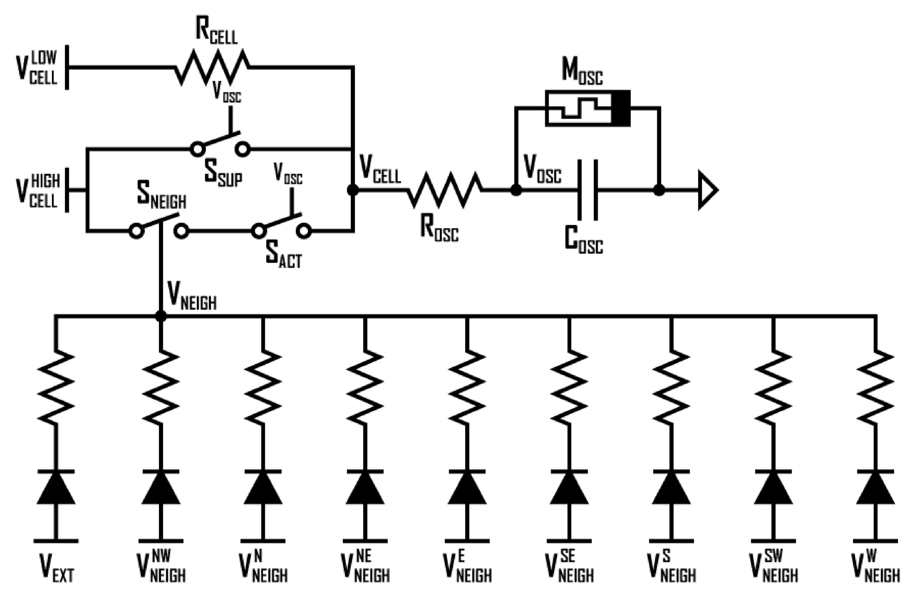
- Reacts to changes in **chemical compositions**, similarly to mycelium's response to **nutrients or toxins**
- Responsive to **temperature variations**, reflecting mycelium's adaptive growth to **heat or cold**
- Alters behavior **under physical force or pressure**, mimicking mycelium's growth direction changes around obstacles
- Sensitive to **light intensity and wavelength**, simulating mycelium's **phototropic** responses
- Conductive to **electrical currents and alterations**, reflecting **bioelectrical signals** in mycelium networks



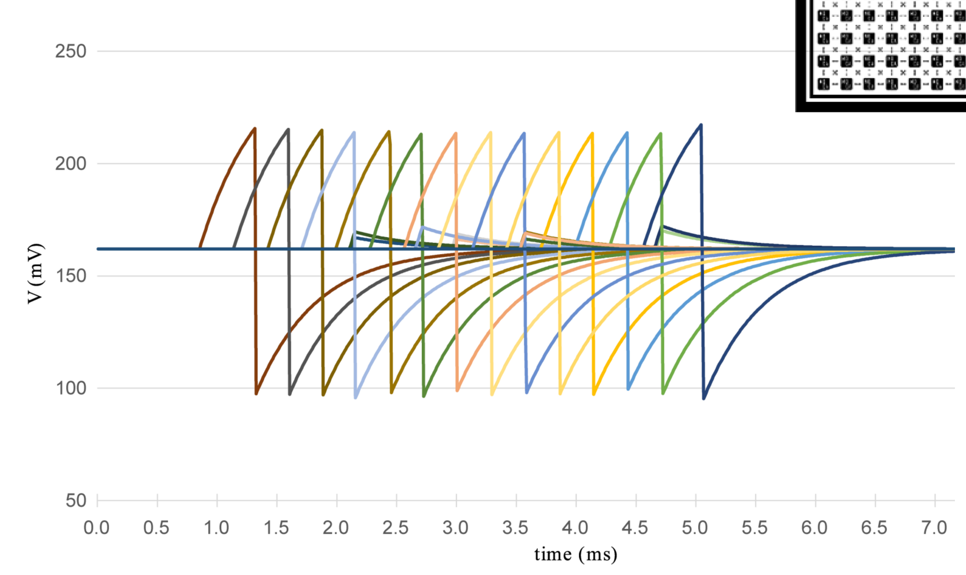

## 5. Memristive Oscillating Cellular Automata Circuit and Operation

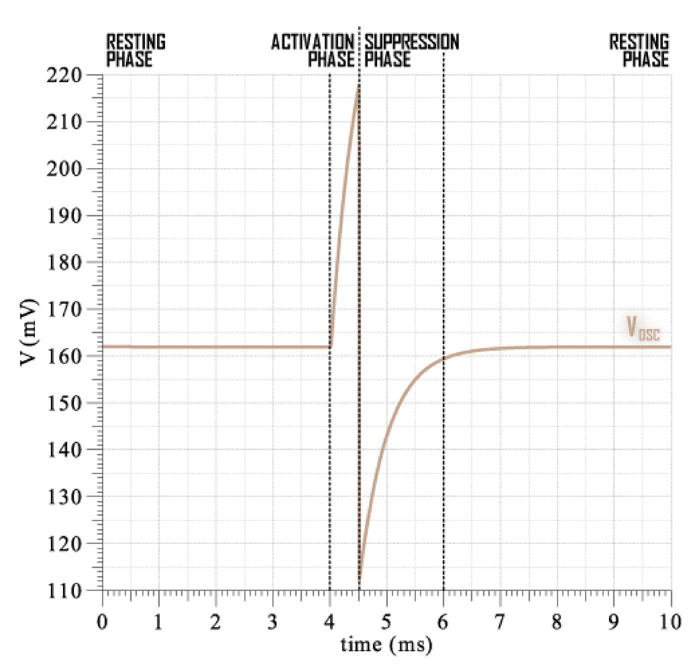
- The oscillation is triggered by its **Moore** neighbors, along with an **external source ($V_{EXT}$)** corresponding to hyphae evolution due to **external stimuli**
- Its operation includes **resting**, **activation**, and **suppression** phases, triggered by external stimuli and controlled by resistor and capacitor values

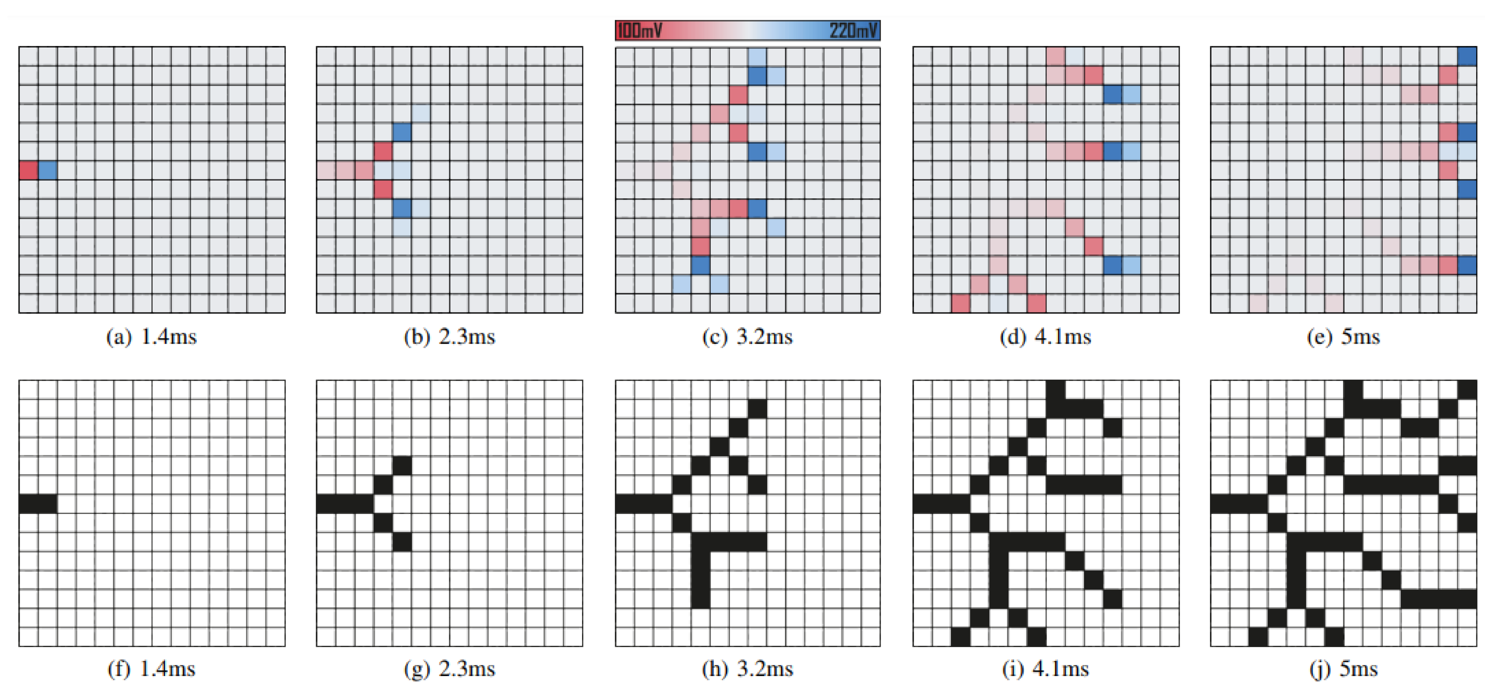





**14x14 Simulation Results:**




(a) 1.4ms (b) 2.3ms (c) 3.2ms (d) 4.1ms (e) 5ms

(f) 1.4ms (g) 2.3ms (h) 3.2ms (i) 4.1ms (j) 5ms

## 6. Conclusions and Future Work

- Potential of memristive devices for efficient digital twins of biological systems is showcased
- Research avenues are explored in bio-materials, smart materials, and environmental sustainability
- Integration of additional environmental variables and increase in circuit scale

## References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