Adaptive properties of stochastic memristor networks: a computational study

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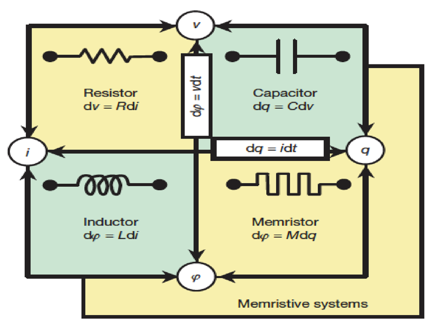
ABSTRACT

A 'memristor' is a passive two-terminal circuit element the electric resistance of which depends on the history of the charge that has passed through it. Given this fundamental property, memristors can store and process information at the same time. Recently, a polymer-based material has been developed which is able to accomplish basic memristor's functions and can also build self-assembled random memristor networks.Here, we implemented a platform to simulate and evaluate adaptive properties of stochastic memristor networks. In this platform, network dynamics can be parametrically simulated with the control at different granularity levels, going from a single memristor to large-scale configurations. Using this simulation platform we have shown that memristor networks stimulated with random noise follow a stable (or semistable) behavior that diverges from its initial state depending on the stimulation history. Interestingly, by changing the connectivity patterns (from random to distance-dependent), we observed differences in the dynamics of the network that depend on the type of input used. The results have demonstrated the possibility of adaptations and learning in complex statistical memristor networks.

INTRODUCTION

A 'memristor' (portmanteau from "memory resistor") is a passive two-terminal circuit element the electric resistance of which depends on the history of the charge that has passed through it [1].



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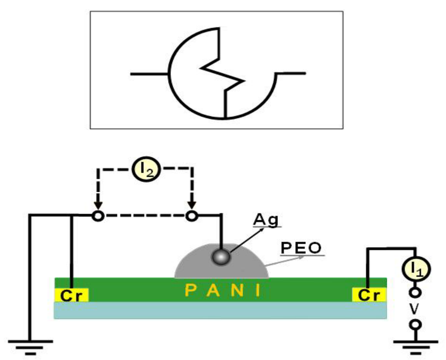
Despite the conceptual importance of memristors, there are still few electronic devices that implement their basic functions. Recently, a polymer-based material has been developed which is able to accomplish basic memristor's functions [2].



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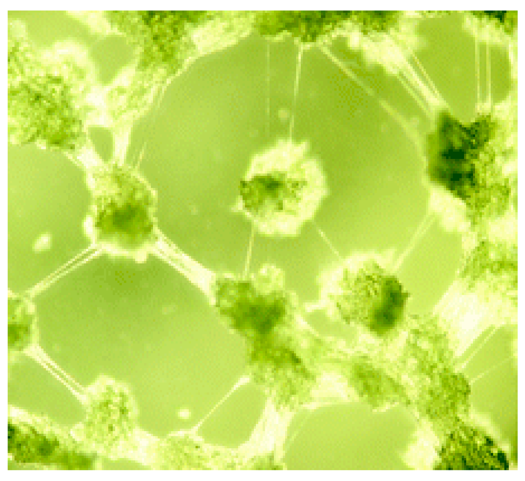
Recently, it has been shown that networks of memristors with few elements and a deterministic connectivity can implement some features observed in the neuronal circuits of a simple biological system, like the Lymnea stagnalis pond snail [3].

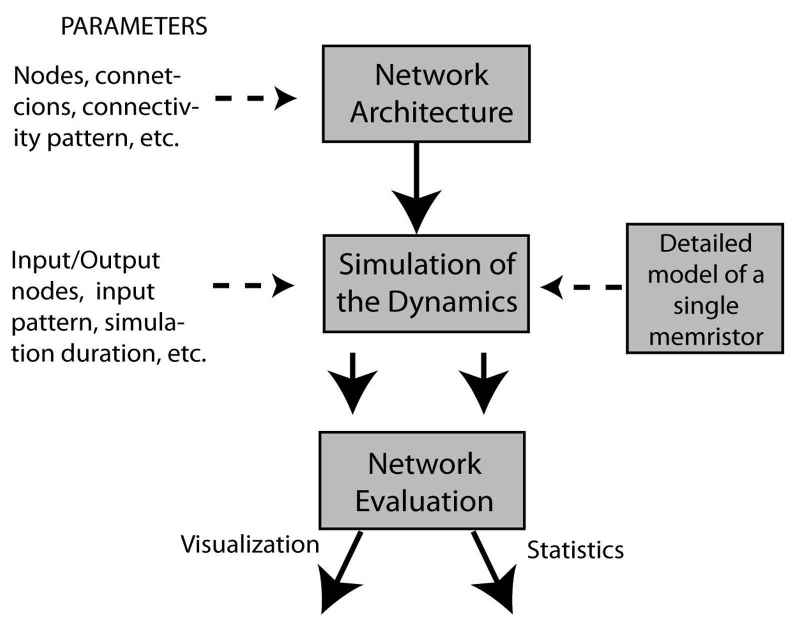


Interestingly, polymeric-based memristors can also build self-assembled random memristor networks , which allows to create self-assembled networks of memristors at a nanoscale level [4] (*see also poster No. 23 for more details*).

Optical microscopy images of fibrillar networks (image sizes are 0.6 6 0.5 mm).

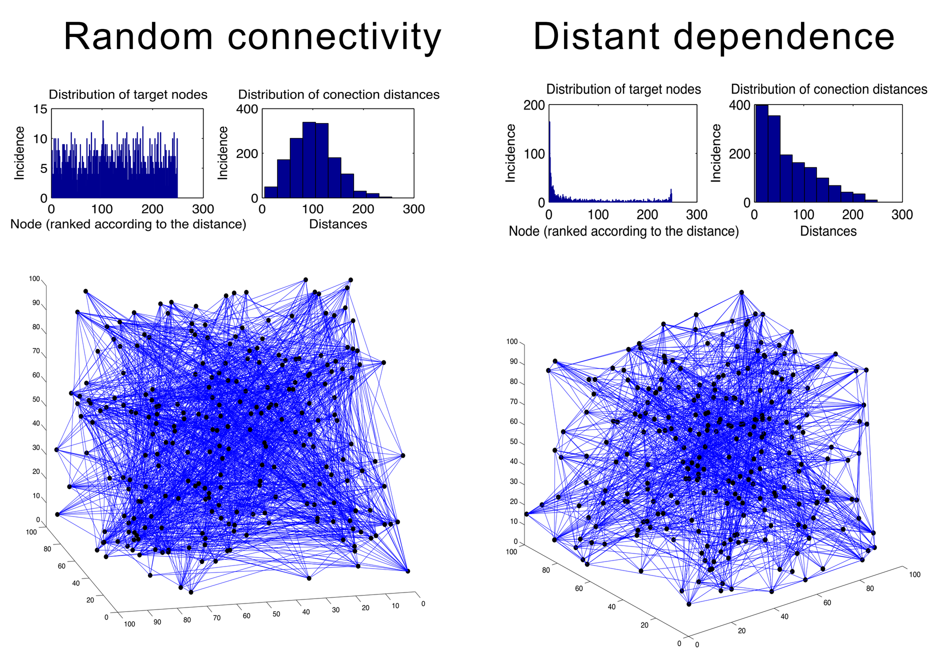
Our central goal is to simulate and study the adaptive properties of the self-assembled memristor networks. Such networks contain a much greater number of nodes with an unknown connectivity pattern.

METHODS



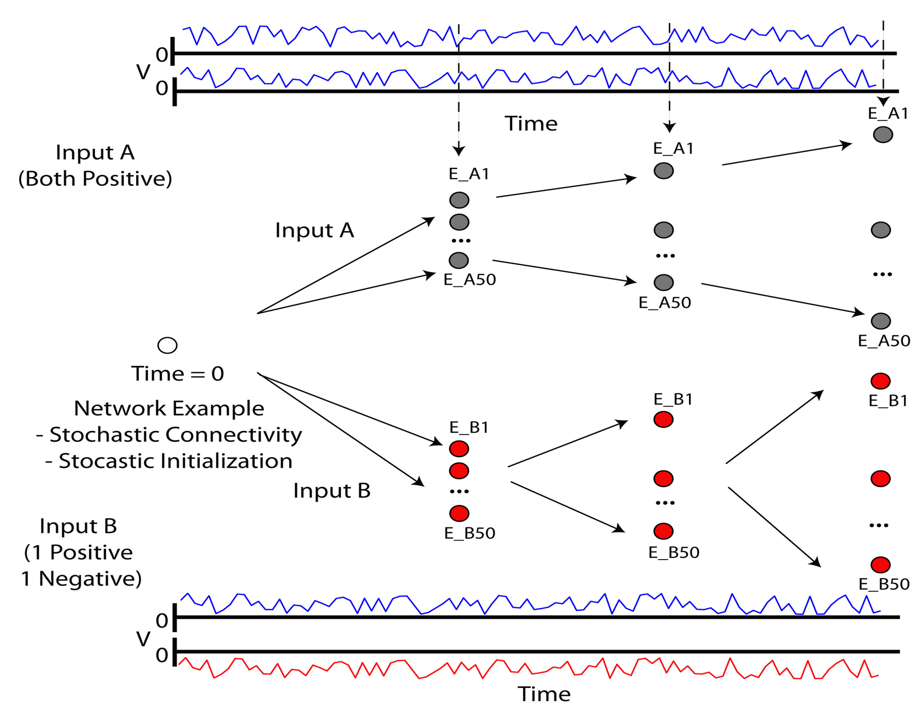
The model is divided in three modules: (a) The architecture module generates a 3D arrangement of nodes and defines the connections between them. (b) The dynamical module calculates the values of all memristors at each time step. (c) The evaluation module computes an "offline" analysis (after simulations are finished) to evaluate the activity of the network and to display it in a three-dimensional (3D) environment.

A) Network Architecture

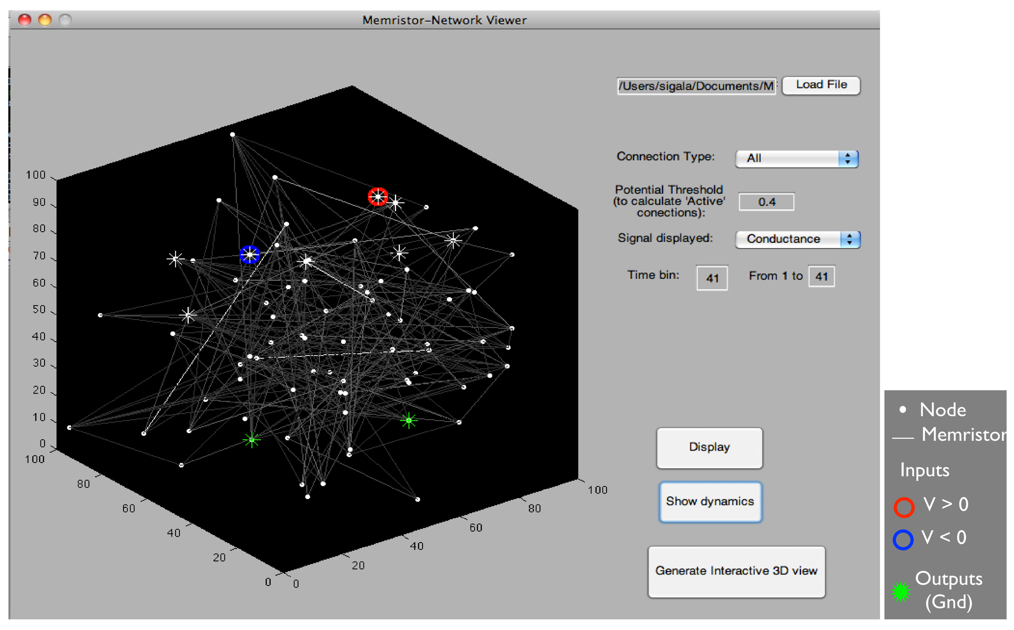


Exapmples of two memristor networks created different connecitivy rules: "Randomly connected" and "Distance dependent" (neighboring nodes are more frequently connected).

B) Dynamics



In this step of the simulatins memristor networks are stimulated by applying voltage to the input nodes. The figure ilustrates how different networks 'develope' different properties depending of the history of stimulation



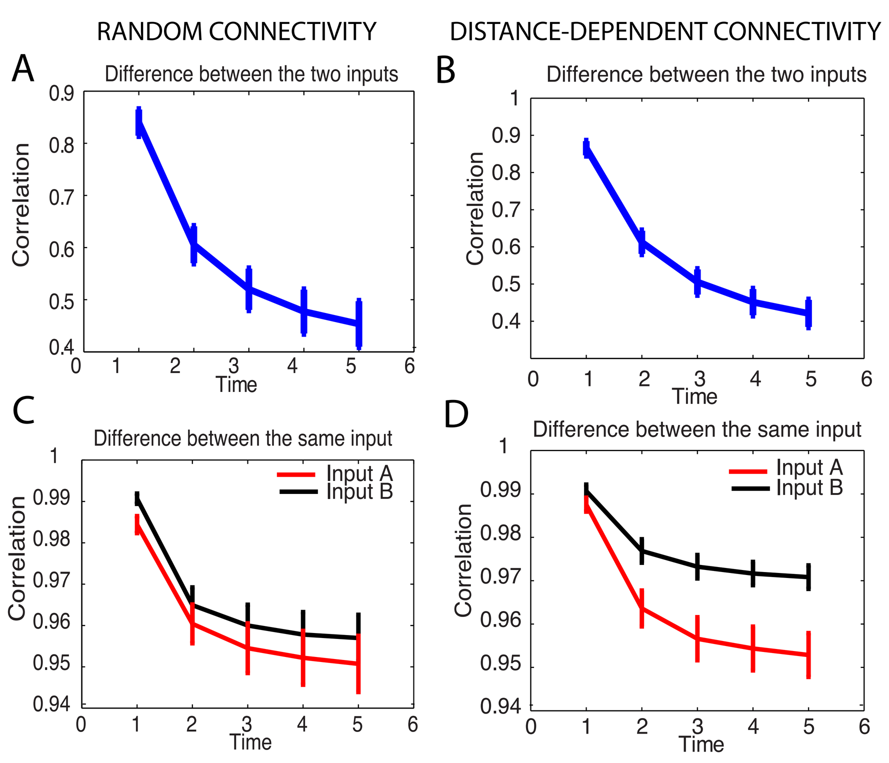
Simulation platform for visualization of the 3D random networks.

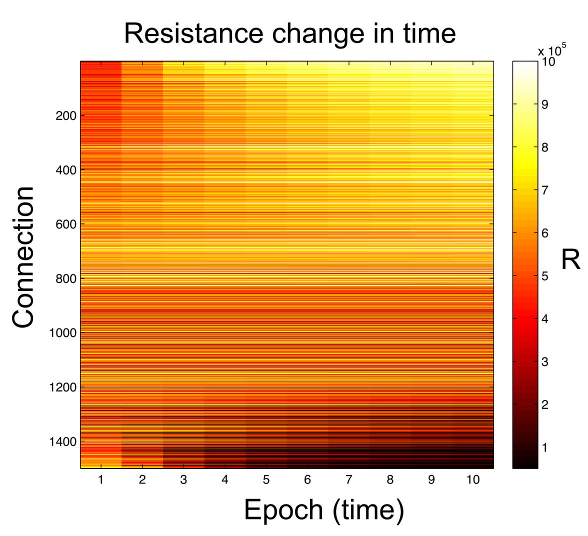
C) Evaluation

To measure how different two networks are at a given time we use the Pearson correlation. The similarity between two given epochs i and j of a network stimulated with independent random patterns of the type A, is defined by corr(E_Ai, E_Aj), where the dimension of the vectors E_Ai and E_Aj is defined by the total number of connections. In general, the overall similarity (S) after a stimulation with the input pattern A during a time t, is given by the average correlation across all possible paired comparisons: S(t) = <corr(E_Ai, E_Aj)>

RESULTS

Mean correlation value (20 different networks) as a function of time. The monotonic and decreasing correlation values as a function of time indicate that the network epochs tend to diverge the longer we stimulate. This behavior is stable regardless of the type of input used and of the networks architectures simulated. Networks with a distance-dependent connectivity decorrelate faster when the input is positive in one node and negative in the other, than when both inputs are positive (D). This is not the case for the randomly connected networks (C). This suggests a relation between the input pattern and the type of connectivity that impacts the adaptive properties of the network.





The plot shows the resistance change of each connection of a given network. Connections are sorted from top to down according to the total change in resistance. The majority of connections (top of the panel) became resistive. A smaller fraction (middle of the panel) almost didn't change and few of them became conductive (bottom part).

CONCLUSIONS

- A simulation platform was implemented based on detailed information about single memristors
- First simulations on memristors networks are in agreement with experimental data.
- These results show that the connectivity profile as well as input configuration impact the learning capaabilties of the networks.
- In general, our results show that memristor networks have adaptive properties that depend on their structure and the input pattern of stimulation applied.

References

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