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XXXIV Cycle

Memristor-based Recurrent Neural Networks

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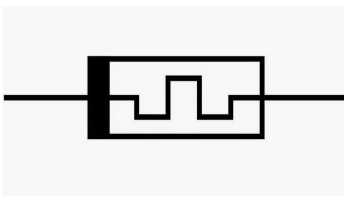
Research context and motivation

- In the last few decades, the search of **innovative computing platforms** that could offer new, ultra–low power processing methods and architectures has intensified.
- A **neuromorphic computing** approach aims to go beyond the current conventional digital processing by **exploiting complex dynamics and nonlinear phenomena emerging from the physics of non-volatile memory devices** (e.g. memristors).
- Recently, **memristors** have played a key role as synaptic devices for bio-plausible neural networks: their peculiar switching properties and signal storing capability are well suited for emulating synapse functionality of biological neural networks.
- **Neurological research suggests that neural representation is highly dynamic**, encoding multiple kind of tasks and stimuli by the joint activity of interconnected populations of neurons. Models based on **recurrent neural networks** seem well suited to capture similar dynamics and therefore have been used to investigate the mechanisms by which neural populations solve various computational problems.
- Since neuromorphic computation attempts to imitate the biological complex system of the brain, each part of the neuronal network is modelled and implemented into hardware with the aim of running machine learning algorithms.



Addressed research questions/problems

- Artificial neural networks are powerful computing models able to tackle difficult problems in artificial intelligence. Unfortunately, a deep mathematical explanation of their exceptional efficiency is still missing.
- Researchers have proposed that deep learning, which is providing important progress in a wide range of complex tasks, might inspire new insights into learning in the brain. However, **the methods used for deep learning by ANNs are biological implausible** and would need to be substituted by biologically realistic approaches.
- Their particular non-biological aspect is the supervised training process by means of the backpropagtion algorithm. This powerful technique requires massive amounts of labelled data and a nonlocal learning rule for changing the weights.
- From an unsupervised point of view, Hebb's rule is instead assumed to be closely associated with biological learning but unfortunately, it has not been to date a source of powerful learning algorithms for ANN.
- Therefore, **the current research aims to find local learning rules that could reach higher levels of efficiency** which are comparable to the one obtained using the backpropagation algorithm.

Submitted and published works

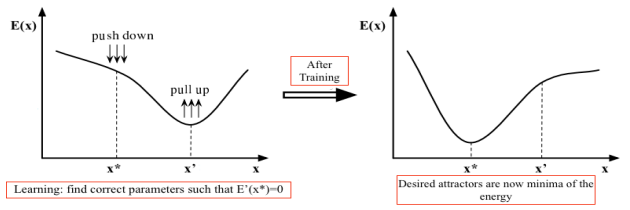
- Zoppo G., Marrone F. and Corinto F. (2019). "*A Continuous-time Learning Rule for Memristor-based Recurrent Neural Networks*". 26th IEEE International Conference on Electronics, Circuits and Systems, Genova (Accepted).
- Marrone F., Zoppo G., Corinto F. and Gilli M. (2019). "*Second Order Memristor Models for Neuromorphic Computing*". Midwest Symposium on Circuits and Systems, Dallas (USA).
- Zoppo G., Marrone F., Pittarello M., Farina M., Demarchi D., Secco J., Corinto F. and Ricci E. (2019). "Wound Viewer, a novel telemedicine method for chronic wound assessment through artificial intelligence, clinical trial and results". Journal of Wound Care. (Submitted)
- Zoppo G., Marrone F. and Corinto F. (2019). "*Equilibrium Propagation for Memristor-based Recurrent Neural Networks*". Emerging Technologies and Systems for Biologically plausible Implementations of Neural Functions. (Submitted)

Novel contributions

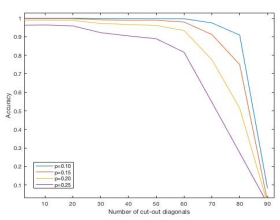
- Analysis of two different learning rules which are suitable for training continuous-time recurrent neural networks in solving binary images reconstruction.
- VLSI adaptability's analysis of the proposed neural network.
- Analysis of possible novel analogue computing architectures based on memristor devices and recurrent neural networks that exploit the memristor device physics to implement training algorithms in situ.

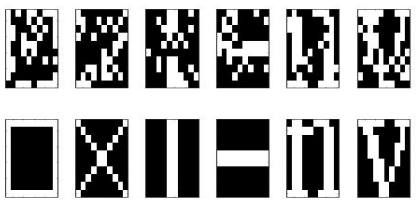
Adopted methodologies

- Given a scalar energy function *E*, the associated gradient system is characterized by a natural evolution into states which corresponds to minimal energy. Therefore, the aim of the inference process is to **find the correct parameters defining the energy function that assigns low energy values to the desired targets**.



- **This is achieved by additionally minimizing an external cost function defining the optimization problem**. Two techniques were considered in order to train recurrent neural networks for pattern reconstruction task: **Recurrent Backpropagation** and **Equilibrium Propagation**.
- During the learning process, the parameters of the models (i.e. weights) are continuously updated according to the considered learning rules. Therefore, memristors' peculiar switching properties and signal storing capability are perfectly matching this scenario allowing to train networks in situ.
- Unfortunately, **fully connected recurrent neural network are not really suited for VLSI implementation due to the enormous number of connections**. Therefore, a short analysis on the number of connections needed to achieve a desired level of accuracy was conducted.





Future work

- Consider the two previous techniques for solving other kind of tasks such as image classification, speech and sequence recognition.
- Consider recurrent neural networks for statistical inference.

List of attended classes

- 01TEHRV – Data Science for Networks (15/02, 6)
- 01QORRV – Writing Scientific Papers in English (28/03, 3)
- 01SFURV – Programmazione scientifica avanzata in Matlab (15/05, 4)
- 01TEVRV – Deep Learning (4/06, 6)
- 01TFGKG – Oxide Electronics: from conventional to multifilamentary conduction (4/07, 4)
- 02IUGKG – Il metodo Monte Carlo (12/07, 6)
- 01SCSIU – Machine learning for pattern recognition (22/07, 4)

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