CONTROL AND THE CHARACTERIZATION OF BIOMIMETIC ARTIFICAL NEURONAL NETWORKS

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The brain is the central organ of the nervous system. It controls and coordinates all the activities of the human brain, by acquiring an enormous amount of data coming from the inside and the outside of the body, processing them and taking decisions. The basic unit of the brain are the neurons, excitable cells connected in complex networks. Neurons communicate through the synapse. During such events an electrical signals propagated along the axon of the pre-synaptic neuron (action potential) is transduced into a chemical signal, sensed by the post-synaptic neuron and transduced once again in a new electrical signal (post synaptic potential). The whole mechanism is highly dynamic: existing synaptic connection may strengthen or weaken and brand new ones may rise, while old ones might. This behavior is called neural plasticity and is at the base of learning and memory. Likewise, the computation of the data travelling along a network made of such cells is continuously changing, since each neuron will be assigning a different synaptic weight to the very same electrochemical input signal.

Neurons are not the only cells constituting the brain. Non-excitable cells, known as glial cells, outnumber neurons in the nervous tissue and perform very important functions. Among them astrocytes have been shown to play a crucial role in the control and the regulation of the synaptic communication and plasticity[1,2].

In order to recapitulate the efficiency of biological synapses, brain-inspired computing models have been proposed and develop through the years[3].

However, as conventional silicon based computing techniques have reached their limits in terms of energy consumption and density[4], organic electronics and neuromorphic platforms are emerging as new computational paradigm[5]. Such devices are analogic platforms able to mimic the structure and the functionality of the brain, therefore performing parallel computation, while showing plasticity and learning capabilities[6,7]. Among the plethora of the available materials and structure, organic electrochemical transistors (OECTs) have emerged for their natural ionic-to-electronic signal transduction, biocompatibility and possibility of operating in aqueous environment[8,9]. Such platforms are three terminal devices, in which a conductive polymer represents the channel of the transistor. The connection with the gate is obtained through an electrolyte solution. The voltage applied on the gate modulates the conductivity of the channel, through an ion flow.

In particular, PEDOT:PSS based OECTs have been exploited to recapitulate neurotransmitter-mediated synaptic plasticity[10]. In brief, upon the application of a voltage pulse on the gate, the oxidation of a neurotransmitter modulates the doping state of the PEDOT:PSS channel of the transistor, resulting in a change in device conductivity, *de facto* emulating the synaptic reinforcement naturally occurring in biological synapses, as shown in the figure below.

This PhD thesis focuses on the fabrication and the optimization of OECTs-based neuromorphic platforms, able to recapitulate the highly dynamic and plastic behavior of biological synapses, while carrying out information propagation and computation tasks, ultimately leading to the integration with biological systems. The control of the dynamic behavior of such devices was identified as a critical task, in order to allow for the implementation of networks of artificial neurons. Each neuromorphic device will indeed be locally controlled, allowing for the direct connection of several devices with different “synaptic weights”.

Furthermore, the study of the artificial network behavior and its interface with biological neural networks will be conducted through the complex system modelling approach, in order to: infer topology-induced network dynamics; and to control the overall network steady state, by solving consensus and synchronization problems.

The first year of work was primarily spent on the study of existing neuromorphic platforms and on the fabrication and characterization of PEDOT:PSS-based OECTs. In particular, either dry and wet etching techniques were studied and tested to precisely pattern the above-mentioned conductive polymer, dealing with the trade-off between easy processability and electrochemical properties of such material. The obtained devices normally works in depletion mode, meaning that the application of an input voltage stops the output current. The fabrication of enhancement mode devices, in which the input voltage enables the passage of the output current, was carried out. Possible control strategies, recapitulating the self-regulation naturally occurring in the brain, were designed.

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