

# Self-organized criticality in neuromorphic nanowire networks

PhD Thesis Summary

Fabio Michieletti

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In recent years, the demand for big data elaboration and complex tasks execution has represented an exponentially increasing challenge for standard computing systems based on Von Neumann architecture. Among the several applications, the spreading use of artificial intelligence led to a huge power consumption, expected to become unbearable in the near future. Indeed, the intrinsically analog nature of these brain-like algorithms represents a difficult task for current widespread digital systems. To tackle this issue, innovative hardware substrates have been explored aimed to mimic neural and synaptic features. Among the possible implementations, self-organizing networks of memristive elements demonstrated to be promising candidates thanks to the inherent complex interconnection of nonlinear devices resembling synaptic plasticity properties. In particular, memristive nanowire networks (NWNs) showed relevant emerging behavior that enables their fruitful implementation as physical reservoir in the framework of *in materia* neuromorphic reservoir computing. Furthermore, the reported emergence of self-organized criticality (SOC) and the relative enhancement of specific tasks performance resulted promising for the optimization of the reservoir substrates. However, the experimental control of critical dynamics and the understanding of its impact on information processing still represents a challenge.

In this work, an experimental study of NWNs self-organized criticality tuning and of its impact on information processing is reported. In detail, the critical state programming is investigated both in two-terminal and multi-terminal configu-

rations. Results unveiled the possibility of manipulating SOC emergence both by changing network structural topology and by electrically modulating system connectivity. Moreover, a relationship between critical dynamics and network computational capabilities is demonstrated. In the following, the outlook of this work is outlined.

In the first chapter, the research context is exposed. The characteristic properties of biological neural systems are initially described, highlighting the mechanisms at the basis of brain information processing. Successively, the state of the art realizations of self-organized bio-inspired systems are reported, together with their observed brain-mimicking behavior. The second part is devoted to the description of self-organized criticality fingerprints through the analysis of the standard sandpile model. Next, the main evidences of SOC arising in both biological and self-organizing systems are summarized. Finally, a complete summary of scientific literature studies of memristive nanowire networks properties is provided. Individual elements memristive behavior is detailed by focusing on the physical resistive switching mechanisms. Moreover, the emerging brain-like properties induced by the inherent topology complexity are discussed. To conclude, the reported self-organized criticality observations in NWNs are discussed.

In the second chapter, the experimental methods used for the achieving of this work results are described. Electrical characterization setup and protocols, together with the relative networks fabrication processes are reported for both two-terminal and multi-terminal measurements. In the last section, the statistical tools employed for the assessment of self-organized criticality are explained. The characterization results are finally reported in the third chapter. In a first section, criticality is assessed in two-terminal configuration on networks with different topological properties, unveiling the correspondence between percolation onset and critical dynamics. In the second section, networks electrical programmability in terms of spatial voltage distribution and dynamics is demonstrated through multi-terminal characterization. Moreover, local critical dynamics are observed and their impact on nonlinear transformation task performance is evaluated, demonstrating a correlation between the emergence of criticality and the generation of significant features for temporal complex transformations. These results represent a relevant improvement in the understanding of the relationship between network connectivity, local dynamics and specific information processing.