Politecnico di Torino

ELECTRICAL, ELECTRONICS AND COMMUNICATIONS ENGINEERING

DET - REservoir COMputing with MEmristive Nonlinear Dynamics: Theory, Design and Applications (RECOMMEND)

Funded By	Dipartimento DET
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Context of the research activity	The project consists of three cross-disciplinary pillars that allow an efficient realization of the Next Generation Reservoir Computing (NGRC) paradigm: (i) Memristors, (ii) Nonlinear Circuit and System Theory, and (iii) Neuromorphic Computing Systems. The research activity combines complementary expertise across three different domains, namely memristor fabrication and modeling, nonlinear circuit- and system-theoretic paradigms to electronic circuit design and analysis, and development of memristor-based neuromorphic systems.
	The overall goal of the RECOMMEND project is to demonstrate at the modeling and hardware level an energy-efficient adaptable RC platform. Special attention is paid to the implementation of the NGRC concept, for which the highly-nonlinear resistance switching dynamics of memristors are to be exploited. For this purpose, scalable nonlinear circuits with a few electronic components shall be designed and built, which allows a suitable nonlinear transformation of the input data according to the NGRC paradigm. Furthermore, a holistic circuit-theoretic modeling approach, augmented with nonlinear system-theoretic concepts, shall be used to work out a transformation of the input data as efficiently as possible, leading to a compact and powerful RC platform. The RC platform is completed by a memristor-based readout layer, which, supporting in-memory VMM, will feature multitasking capability. Therefore, the research shall develop across three main levels: (i) at the computational level we will develop computational models for mapping signal prediction and data classification problems on an innovative RC platforms, outperforming standard hardware structures by extending their functionalities, as enabled by the tunable dynamics of memristors; (ii) at the system level a hybrid neuromorphic system, consisting of physical memristor-based nonlinear dynamic circuits, will be developed. The hybrid system will be endowed with the versatility to implement different computing schemes, as well as to operate under time-varying conditions, allowing,

Objectives	furthermore, its energy/speed efficiency to be quantitatively assessed through appropriate testing circuitry; (iii) at the nanotechnology level a technological approach, aiming at the fabrication of tailor-made memristive materials and devices, at the development of compact physics-based device and circuit-theoretic models, and at the set-up of flux-charge-domain-based numerical simulators, shall be pursued for a large-scale exploitation of the novel computational paradigm to be proposed. An experimental proof-of-concept for the realizability of the NGRC concept in hardware shall be finally presented, through the fabrication of a compact physical demonstrator, exploiting analogue dynamics of memristor in the reservoir circuit and MVM in a passive crossbar array-based read out layer, and its comprehensive testing, including a quantitative evaluation of energy and speed efficiency relative to alternative state-of-the-art hardware solutions, for time series prediction and optimization problem solution. In order to provide proof of evidence for the adaptability of the hardware platform to solve multiple problems or to execute a very same task under time-varying conditions, we shall adopt Recursive Least-Squares (RLS) Methods to experimental data, so as to estimate the kernels of the nonlinear operator, associated to the hardware system, under specific operating conditions. Then, comparing these estimates to the analytical formulas for the kernels, earlier derived, allows to infer how to tune the nonlinear dynamics of the memristive reservoir circuit, so as extract appropriate nonlinear functions of the input data at relevant nodes, to allow the read-out layer to solve a certain problem under the specified operating conditions.

Skills and competencies for the development of the activity	- A Master’s degree in Electrical Engineering, Physical Engineering, Physics, or related field; - A strong background in nonlinear circuits and/or machine learning; - Strong analytical skills and technical skills; - Excellent programming skills preferably in Matlab/Python; - Excellent mathematics foundations, especially nonlinear dynamics, statistics and probability theory - An interdisciplinary mindset and an open and proactive personality in interacting with researchers from different disciplines; - Strong communication, presentation and writing skills and excellent command of English.