ELECTRICAL, ELECTRONICS AND COMMUNICATIONS ENGINEERING

Reservoir Computing: theory, implementation and algorithms

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Context of the research activity	In the last decade, the pervasion of Artificial Intelligence (AI) within many everyday life aspects, like personal health monitoring, smart industry and smart city applications has generated a massive data explosion. The retrieval of relevant information from massive amounts of data will soon be impossible with conventional computers due to physical limitations. The need for local, or edge , computing systems to become faster and more energy-efficient is exponentially increasing.
Objectives	The proposed research activity addresses energy-efficient edge computing, developing theoretical foundations and hardware prototypes of reservoir computing (RC) based on a delay-free single-node that is empowered by memristive devices used as nonlinear, tunable, dynamical elements and computing/storage elements enabling in-memory vector-matrix multiplication (VMM) in one step. RC is a disruptive and conceptually low-power neuromorphic paradigm particularly suited for intelligent edge computing applications. A reservoir is a nonlinear dynamical system expanding the input temporal information towards a single readout layer that can be trained to perform complex tasks. Despite the several reported attempts, a convincing hardware platform for a RC is still missing. The proposed research activity provides low power solutions for both reservoir and readout. Memristor technology is leveraged (i) to realise a simple, yet versatile, compact single-node reservoir; (ii) to implement multiple readout layers with multi-tasking ability through in-memory VMM, thus avoiding heavy data transfer between processing and memory units. On one side, compactness and absence of delay elements in the reservoir enable theory-driven hardware optimisation and tuning on the onset of the edge of chaos, i.e. in between ordered and chaotic behaviour, where reservoirs maximise their computating efficiency. The dismissal of delayed

	feedback is possible thanks to the use of memristive technology, which can enrich the dynamics of oscillatory circuits through its nonlinearity and inherent dynamics. Indeed, memristors are two-terminal metal/insulator/metal devices, characterised by nonlinear conduction and nonlinear dynamics due to the voltage-driven ion rearrangement in the insulator. On the other side, memristors will be used as nonvolatile storage memory devices with information coded in programmable conductance levels arranged in a crossbar matrix. The simultaneous application of an array of voltage values at the bit lines of the crossbar results in the voltage-conductance VMM in one step and translates into an array of current values at the word lines, in a parallel fashion, in only one extremely efficient computational step. In summary, the proposed research activity will provide theory foundation, hardware implementation and benchmark to existing alternative proposals of a novel efficient and scalable RC platform enabling the next generation and green AI in edge computing devices.

Skills and competencies for the development of the activity	- A Master's degree in Electrical Engineering, Physical Engineering, Physics of Complex Systems, 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; - Prior publications and/or research activities in memristor technology, neural networks and machine learning are favourable for the development of the PhD activity.