# Non-equilibrium properties of memristive circuits

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Networks with memristive elements (resistors with memory) are being explored for a variety of applications ranging from unconventional computing to models of the brain. However, analytical results that highlight the role of the graph connectivity on the memory dynamics are still a few, thus limiting our understanding of these important dynamical systems. In our talk we discuss various aspects of the dynamics which analyzed in recent work. We derive an exact matrix equation of motion that takes into account all the network constraints of a purely memristive circuit, and we em- ploy it to derive analytical results regarding its relaxation properties. We are able to describe the memory evolution in terms of orthogonal projection operators onto the subspace of fundamental loop space of the underlying circuit. This orthogonal projection explicitly reveals the coupling between the spatial and temporal sectors of the memristive circuits and compactly describes the circuit topology, and provide a bound on the strength of interaction. For the case of disordered graphs, we are able to explain the emergence of a (universal) power law relaxation as a superposition of exponential relaxation times with a broad range of scales using random matrices, and derive a Lyapunov functional which is equivalent to a disordered Ising model. In the case of circuits subject to alternating voltage instead, we are able to obtain an approx- imate solution of the dynamics, which is tested against a speci

c network topology. These result suggest a much richer dynamics of memristive networks than previously considered. In particular, we show that the number of independent memory states in a memristive circuit is constrained by the circuit conservation laws, and that the dynamics preserves these symmetry by means of a projection on the physical subspace. Also, we are able to show that for the case of purely passive or active systems, the eigenvalues of the Jacobian are always real, implying that oscillations can emerge only for mixtures. Our last result concerns the weak non-linear regime, showing that the internal memory dynamics can be interpreted as a constrained gradient descent, and provide the functional being minimized.

[l] Caravelli, Traversa, Di Ventra, Phys. Rev. E (2017) to appear.
[2] Caravelli, Accepted in IJPEDS, Special Issue in Advances in Memr. Net. (2017).
[3] Caravelli, Barucca, to appear on arxiv (2017) to appear.