Building a Quantum Synapse Paradigm

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We will present here our recent research on the development of quantum neural networks, including biologically inspired dynamic qubits interactions. Our motivation was to build quantum versions of synaptic processes as they occur in actual neural systems, that is, to build "quantum synapses" between qubits. In particular, we present our recent results concerning the study of a minimal model of two interacting qubits with an activity-dependent dynamic interaction as in classical dynamic synapses. This type of synaptic interaction induces the so-called synaptic depression, that is, synapses that exhibit synaptic fatigue after a strong presynaptic stimulation. Our study shows that such time-dependent interaction induces Rabi oscillations whose frequency decreases when synaptic depression is introduced, thus excitations can be trapped for a long period of time. This creates a population imbalance between the qubits even though the Hamiltonian is Hermitian. This imbalance can be maintained over time by introducing a small energy change between the qubits. We have also shown that long-time entanglement between the two qubits increases naturally in the presence of synaptic depression. Furthermore, we will describe the analysis of a plausible experimental setup of our two-qubit system that demonstrates that these results are robust and achievable experimentally in a laboratory, and I will illustrate preliminary results related to the extension of our system to larger quantum neural networks.

[1] J.J. Torres and D. Manzano, New J. of Phys. **24**, 073007 (2022).

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