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The Photon Shell Game and the Quantum von Neumann Architecture with Superconducting Circuits[1]

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Superconducting quantum circuits have made significant advances over the past decade, allowing more complex and integrated circuits that perform with good fidelity. We have recently implemented a machine comprising seven quantum channels, with three superconducting resonators, two phase qubits, and two zeroing registers. I will explain the design and operation of this machine, first showing how a single microwave photon $|1\rangle$ can be prepared in one resonator and coherently transferred between the three resonators. I will also show how more exotic states such as double photon states $|2\rangle$ and superposition states $|0\rangle + |1\rangle$ can be shuffled among the resonators as well [1]. I will then demonstrate how this machine can be used as the quantum-mechanical analog of the von Neumann computer architecture, which for a classical computer comprises a central processing unit and a memory holding both instructions and data. The quantum version comprises a quantum central processing unit (quCPU) that exchanges data with a quantum random-access memory (quRAM) integrated on one chip, with instructions stored on a classical computer. I will also present a proof-of-concept demonstration of a code that involves all seven quantum elements: (1), Preparing an entangled state in the quCPU, (2), writing it to the quRAM, (3), preparing a second state in the quCPU, (4), zeroing it, and, (5), reading out the first state stored in the quRAM [2]. Finally, I will demonstrate that the quantum von Neumann machine provides one unit cell of a two-dimensional qubit-resonator array that can be used for surface code quantum computing. This will allow the realization of a scalable, fault-tolerant quantum processor with the most forgiving error rates to date.

[1] M. Mariantoni *et al.*, Nature Physics **7**, 287-293 (2011.)
[2] M. Mariantoni *et al.*, Science **334**, 61-65 (2011).

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