Realizing non-Abelian statistics using graph gauge theory on a quantum processor

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The indistinguishability of particles is a fundamental principle of quantum mechanics. For all (quasi)particles observed to date - including fermions, bosons, and Abelian anyons this principle guarantees that the double-exchange of identical particles leaves the system unchanged. However, an intriguing possibility exists in two spatial dimensions: double-braiding of non-Abelian anyons transforms the multi-anyon state. Such anyons can non-locally encode quantum information, which can be processed through pair-wise exchanges. Despite numerous theoretical proposals, experimental realization of non-Abelian anyon exchange, i.e., braiding of their space-time trajectories, has remained elusive. We propose a simple and systematic prescription to construct unitary protocols for braiding, manipulation, and readout of non-Abelian anyons and preparation of their entangled states on a digital quantum processor. We define the plaquette surface code as a stabilizer code on a generic planar graph of qubits with vertices of degrees 2, 3, and 4. By mapping each qubit to four Majoranas and recognizing that each degree-3 vertex (D3V) carries a new discrete Z2 flux of "Kasteleyn" field, we prove non-Abelian statistics of D3V's. In our approach, all the experimentally relevant operators are unambiguously fixed by locality, unitarity, and gauge invariance. Our specific prescriptions for experiments on a near-term digital quantum processor have been carried out to create and braid D3Vs on a superconducting quantum processor. Further, we created an entangled state of three logical qubits by braiding D3Vs. I will discuss the prospect of employing these anyons for quantum computation.