Demonstrating Quantum Speed-Up with a Two-Transmon Quantum Processor

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The thesis work discusses the characterization of a two-qubit processor implemented using capacitively coupled tunable superconducting qubits of the Transmon type. Each qubit can be manipulated and read out individually using a non-destructive single-shot readout. In addition, a universal two-qubit gate can be implemented using the interaction between the qubits. The system implements therefore all basic building blocks of a universal quantum processor. Using it, we implement the universal sqrt(iSWAP) two-qubit gate, characterizing the gate operation by quantum process tomography and obtaining a gate fidelity of 90 %. We use this gate to create entangled two-qubit Bell states and perform a test of the CHSH Bell inequality, observing a violation of the classical boundary by 22 standard deviations after correcting for readout errors.

Using the implemented two-qubit gate, we run the so-called Grover search algorithm: For two qubits, this algorithm finds among four elements $x \in \{00,01,10,11\}$ the one element y that solves a search problem encoded by a function f for which $f(y)=1$ and $f(x\neq y)=0$. Our implementation retrieves the correct answer to the search problem after a single evaluation of the function $f(x)$ with a success probability between 52% and 67%, therefore outperforming classical algorithms that are bound to a success probability of 25%. This constitutes a proof-of-concept of the quantum speed-up for superconducting quantum processors.

Finally, we propose a scalable architecture for a superconducting quantum processor that can potentially overcome the scalability issues faced by todays superconducting qubit architectures.