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Mentees: Sebastian Brandhofer, Philip Kim, Jakub Mrożek, Siyuan Niu
Mentor: Nicholas T. Bronn

Circuit/Pulse Optimization Across Different Quantum Hardware Modalities

Quantum computing can be realized on different quantum hardware modalities. Superconducting circuits are used in quantum computers of IBM and Google. Other approaches use neutral atoms or *spin qubits*. Constructing optimized quantum circuits for one of these hardware modalities requires understanding its underlying physics and typically involves adapting quantum circuits that have been constructed for a different hardware modality or on a logical level for abstract gate primitives such as Clifford+T.

In this QAMP project we focused on adapting and optimizing quantum circuits for semiconductor quantum dot spin qubits. Our approach consisted of two parts. First, we learned the state of the art for spin qubits based on different technologies to derive potential requirements and gate primitives of the spin qubit platform. Second, we developed an algorithm based on template matching to construct optimized quantum circuits for spin qubits that satisfy the requirements specified in the state of the art.

Semiconductor quantum dot spin qubits (*spin qubits*) do not yet have a standard qubit device, unlike in superconducting circuit community where the transmon qubit is serving as a workhorse. Instead, the state of the art for spin qubits is based on various schemes such as electron spin, singlet-triplet, and hole spin. Candidate two-qubit gates for these schemes include CROT, CPHASE, SWAP, iSWAP and $\sqrt{SWAP}$ with each having different gate runtimes and gate fidelities depending on their exact realization. Each of these candidate two-qubit gates, except the SWAP gate, can be used for universal quantum computation in conjunction with a suitable set of single-qubit operations. This poses novel requirements on quantum circuit optimizations based on template matching since every qubit operation now has a multitude of realizations using different two-qubit gate primitives and an optimal template may not solely be determined by its cost but also by its position in the quantum circuit. For instance, it may be beneficial to choose a two-qubit gate primitive with a lower fidelity but shorter runtime for the realization of a qubit operation if that operation has an impact on the overall runtime of the quantum circuit, hence decreasing the circuit decoherence at the cost of a lower gate fidelity for that qubit operation.

To that end, we developed an algorithm that takes a quantum circuit C, a set of templates T and a set of two-qubit gate primitives P including their characteristics as an input and outputs an *optimized* quantum circuit that is realized using the specified two-qubit gate primitives and templates. The output quantum circuit will have an optimal value

$$\alpha \cdot r + \beta \cdot f, \qquad (1)$$

where r is the total runtime of the quantum circuit, f is the product of individual gate fidelities and α and β are constants that define the tradeoff between the decoherence time and gate fidelities.

In the remainder of the mentorship program, we will implement this algorithm and define suitable templates for the spin qubit platform.