Compilation of algorithm-specific graph states for quantum circuits

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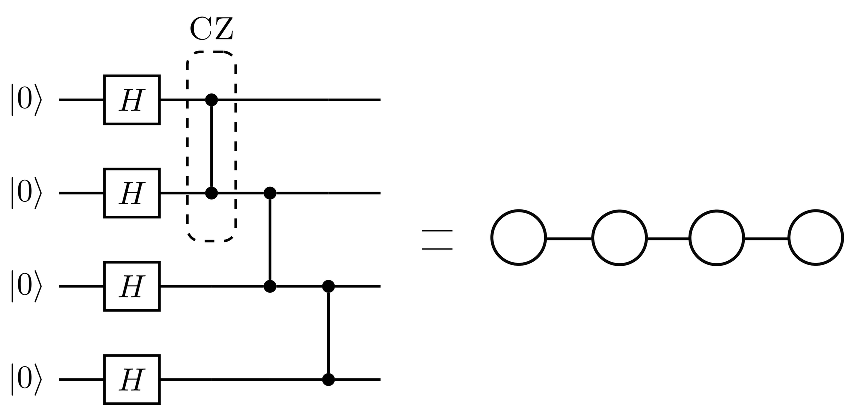
1. Introduction

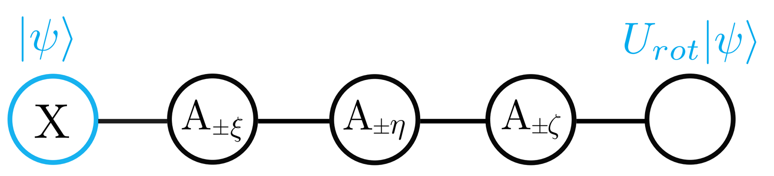
Graph states are a basic resource in measurement based quantum computation (MBQC). Traditionally circuits are embedded into lattice graph states based on the topology of the circuit. Here we present an alternate approach where we simulate the Clifford part of the circuit classically to generate an algorithm specific graph state for the computation.

2.MBQC

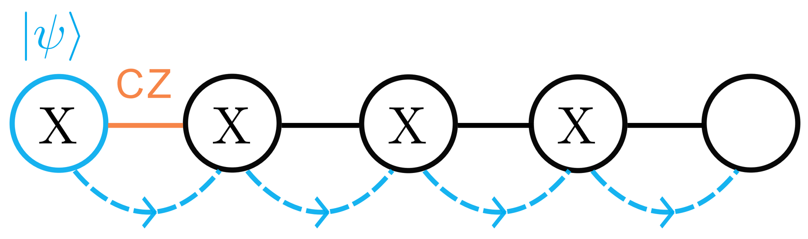
In measurement based quantum computing [1], computation is performed by generating a graph state and measuring each qubit in a specified manner often depending on previous measurement outcomes. The elements required for universal quantum computing with MBQC are desribed below.



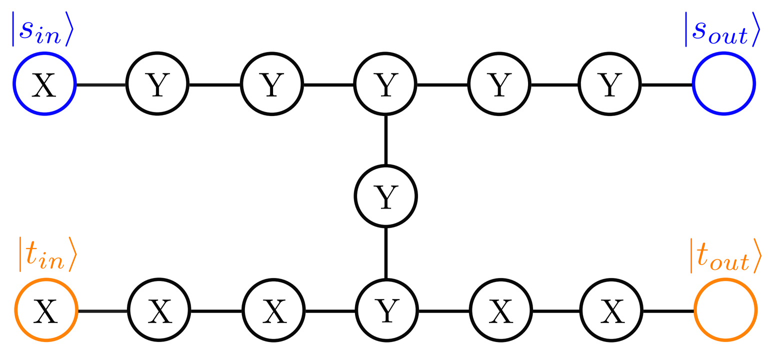
Graph states are generated by initialsing the nodes (qubits) to the $|+\rangle$ state and applying a CZ operation between connected nodes. The circuit above generates a 4 qubit linear graph state.



Single qubit rotation: An arbitrary one qubit unitary in the Euler representation $U_{rot} = e^{-i\frac{\zeta}{2}X}e^{-i\frac{\eta}{2}X}e^{-i\frac{\xi}{2}X}$ is implemented above by measuring the first qubit in Pauli X basis and the other three qubits in the $A_\phi = \cos\phi X + \sin\phi Z$ basis, with ϕ being ξ, η and ζ respectively for the second, third and fourth qubits from the left. The sign of the measured angle is determined by the previous measurement outcomes.

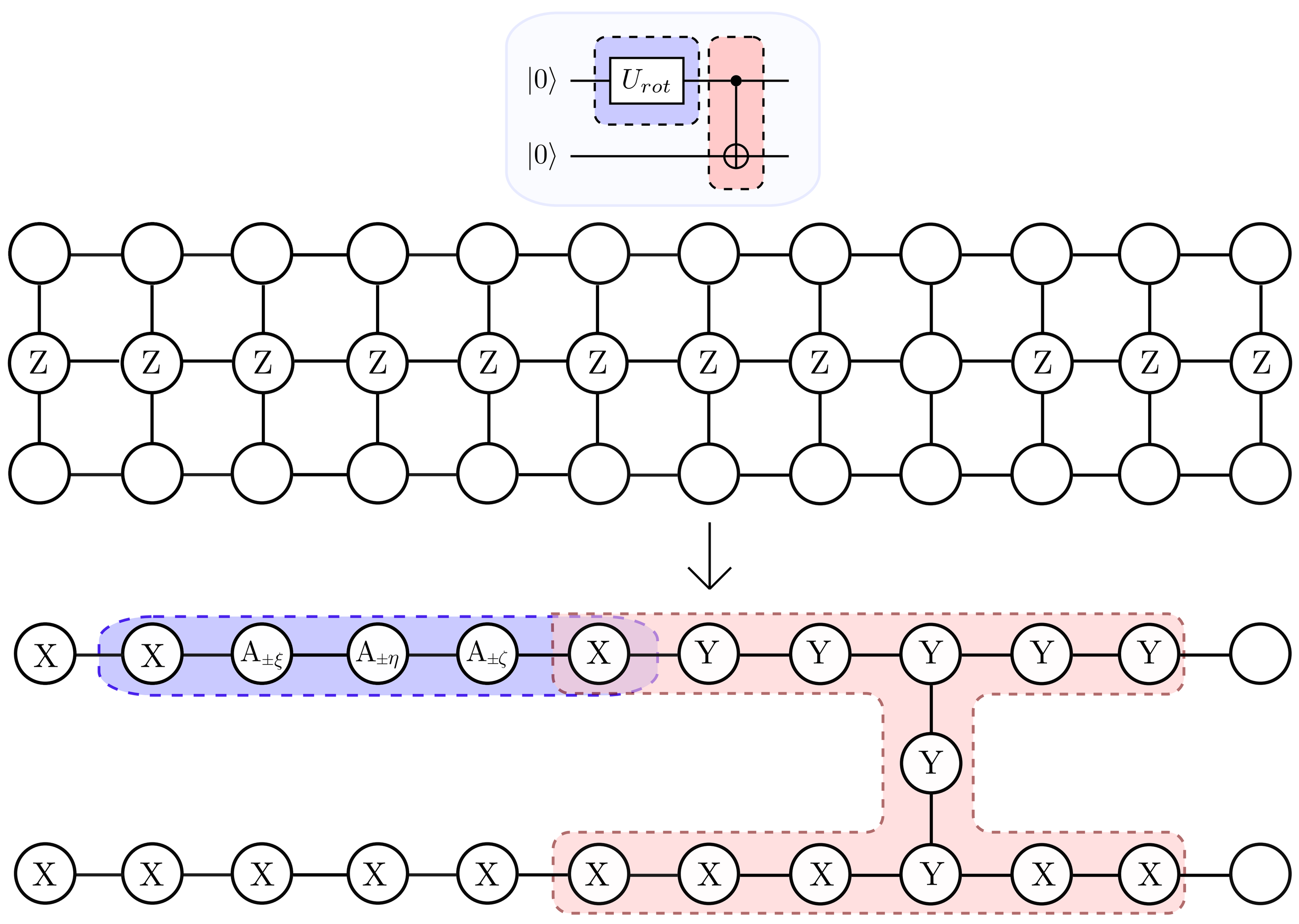


State propagation: Qubits can be encoded into the graph state using a CZ operation and propagated to the right by sequential Pauli X measurements. Each time the state is teleported from one node to the next, there can be a Pauli error that must be adjusted for in the next measurement.



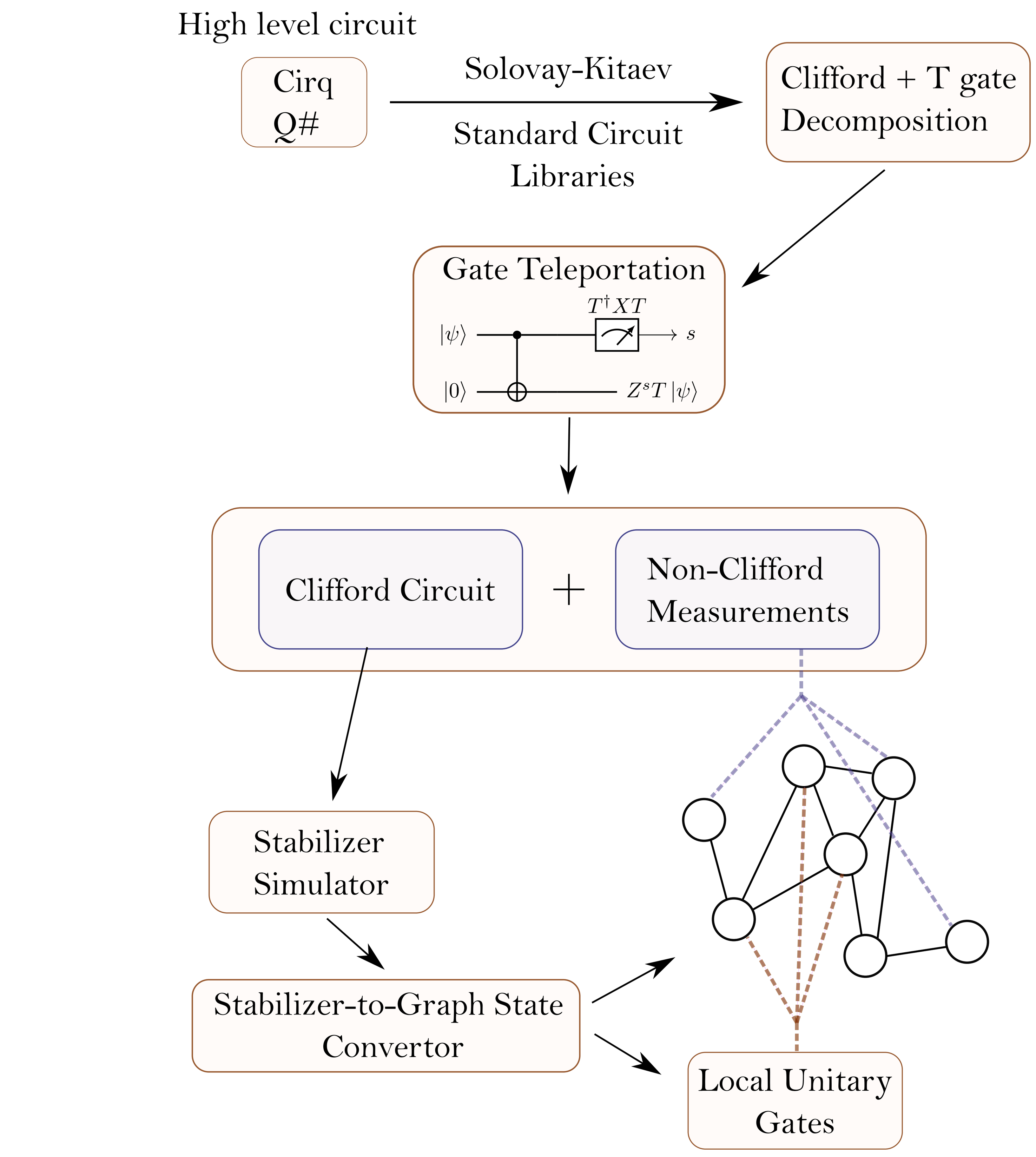
CNOT : A CNOT gate can be implemented between a source qubit and a target qubit using the graph structure shown above.

3. Circuit embedding (Standard method)



A circuit is simulated in MBQC by first creating an **algorithm specific graph state** from a standard square lattice graph state by using Pauli Z measurements which disconnect nodes from the graph state. The circuit is then simulated using the gate equivalences described previously.

4. Graph Compiler (Our method)



Instead of using the circuit layout, our compiler exploits the fact that a) any circuit can be implemented as a Clifford circuit followed by non-Clifford measurements and b) all stabilizer states have a locally equivalent graph state, to generate an algorithm specific graph state. The workflow is as listed below —

1. A high level circuit description in Cirq or Q# is input into the compiler.
2. The circuit is decomposed into Clifford + T gates using standard libraries and the Solovey-Kiatev algorithm [2].
3. The T gates in the circuit are now implemented as a teleported gate, leaving the circuit with only Clifford gates and rounds of non-Clifford measurements at the end.
4. The Clifford circuit is simulated using a stabilizer simulator [3] and the output stabilizer state is found.
5. An efficient algorithm [4] is used to convert the stabilizer state into a graph state (list of nodes and edges). The compiler also determines the local unitary operations that convert the graph state to the output of the Clifford circuit.
6. Quantum hardware can now generate the graph state, apply the local unitary gates followed by the non-Clifford measurements to implement the circuit.

5. References

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[4] Van den Nest, M. et al. Phys. Rev. A, 70(3), p.034302 (2004).