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Technology, Social Impact

Quantum Circuit Transformation using Reinforcement Learning

ABSTRACT

Quantum computer in the NISQ era (Noisy Intermediate Scale Quantum) suffer from limited qubit connectivity for two qubit operations (only physically adjacent qubits can interact) and high error rates, which compound when increasing the depth of the circuit, making execution of deep quantum circuits an unfeasible task.

To make an arbitrary quantum circuit executable on a given target architecture, a quantum compiler has to insert SWAP gates so that gates in the original circuit only ever occur between qubits located at adjacent nodes, a process known as *Qubit Routing*[1]. The process produce a new circuit, possibly with a greater depth, that implements the same unitary function as the original circuit while respecting the topological constraints

OBJECTIVE

Classical Greedy routing approaches are currently in use, while a couple of combinatorial RL approaches are also used, which learn the value function and attempt to perform simulated annealing runs on them. We aim to improve the speed and efficiency (depth overhead) of these methods by using RL in an autoregressive setting.

METHOD

We use Policy Gradient methods in reinforcement learning and tree searches through them to find efficient methods of quantum compilation. It's easier to attempt to learn the policy directly than a value function.

The Combinatorial function is achieved using an autoregressive setting, where each action (for each qubit) in each step is dependent on the operations in the previous step.

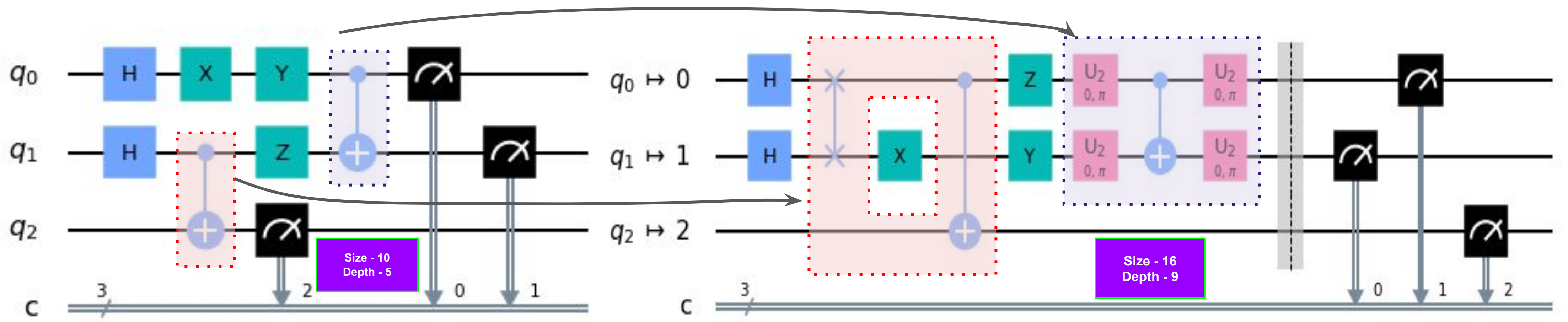

Fig. 1 *An example of qubit routing. Our framework will incorporate a strategy to perform qubit routing - (1) Qubit Movement, and (2) Qubit Allocation, such that the final transformed circuit (i.e., the one mapped to the topology) has the lowest depth (or size).*

RL FORMULATION AND RESULTS

$$V(s) = \max_{s'} Q(s,a)$$

$$Q(s,a) = \sum_{s'} R(s,a,s') + \gamma V(s')$$

$$UCT_s(a) = Q(s,a) + \sqrt{\frac{n(s,a)}{1+n(a)}} \times p(s,a)$$

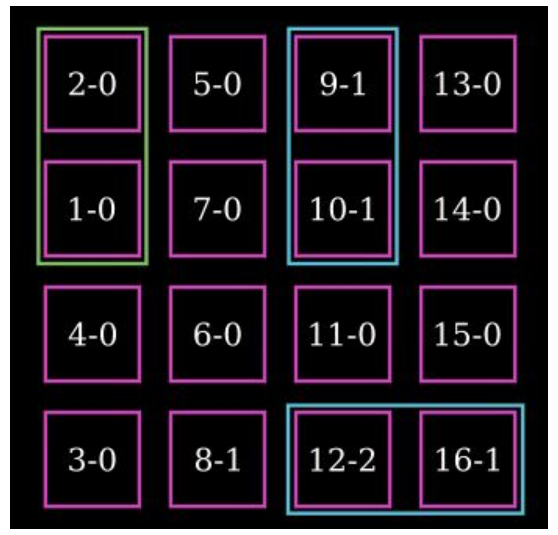

Fig. 2 A snapshot of the *qubit grid computation by the RL-based framework.*

Circuit	Gate Count	MCTS Depth
rd84_142	154	154
adr4_197	1498	2016
radd_250	1405	1864
z4_268	1343	1833
sm66_145	1701	2357
misex1_241	2100	2883
rd73_252	2319	3143
cycle10_2_110	2648	3595
square_root_7	3089	3967
sqn_258	4459	6067

Table 1 *Results of the circuit transformation - depth and size, by our RL-based framework.*

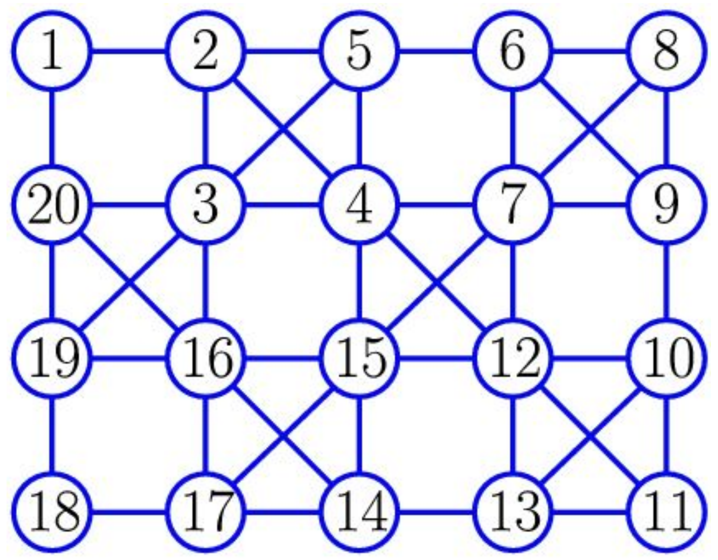

Fig. 3 *Hardware layout of IBM's 20 qubit machine, each edge represents a possible 2-qubit operation.*

References:

1. On the qubit routing problem, Alexander Cowtan et al., **arXiv:1902.08091**

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