Evaluating Performance of Quantum Computers with Cycle Benchmarking

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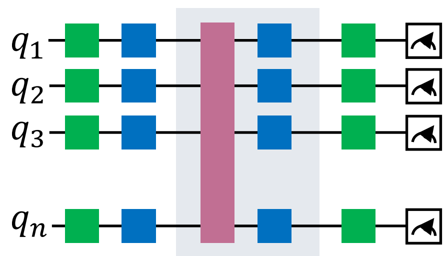
CYCLE BENCHMARKING

Cycle benchmarking (CB) is **a protocol for estimating the process fidelity of a clock cycle of operations on a quantum register**.

The process fidelity provides an estimate of the effect of all global and local error mechanisms on the clock cycle.

Protocol: Green gates indicate a change of basis, blue gates indicate Pauli twirling gates, and the red gate indicates the noisy process of interest. The grey box is repeated m times.



The estimated process fidelity is calculated by averaging overlap over a collection of these circuits constructed for a set of basis changes (n-qubit Pauli matrices; green):

$$F(\tilde{G}, G) = \sum_{P \in \mathrm{P}} \frac{1}{|P|} \left(\frac{\sum_{l=1}^{L} f_{P,m_2,l}}{\sum_{l=1}^{L} f_{P,m_1,l}} \right)^{\frac{1}{m_2 - m_1}}$$

RANDOMIZED COMPILING

Randomized compiling (RC) transforms a quantum circuit by injecting twirling gates around 'hard' gates, which are expected to have high error rates.

Twirling gates convert the noise processes experienced by the hard gate to a stochastic channel.

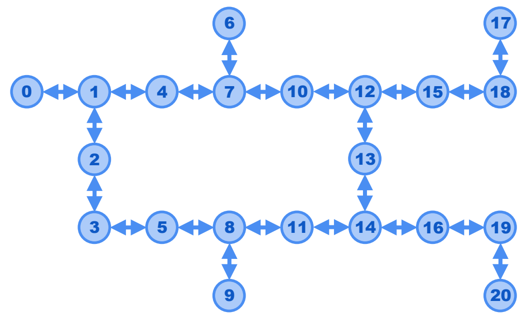
The results of cycle benchmarking provide estimates of performance for randomly compiled circuits.

Erhard, A., Wallman, J.J., Postler, L. et al. Characterizing large-scale quantum computers via cycle benchmarking. Nat Commun 10, 5347 (2019). https://doi.org/10.1038/s41467-019-13068-7

Wallman, J., & Emerson, J. (2016). Noise tailoring for scalable quantum computation via randomized compiling Phys. Rev. A, 94, 052325. https://doi.org/10.1103/PhysRevA.94.052325

EXPERIMENT PROCEDURE

IBM "toronto" QPU: a 27-qubit processor of which we use 20 qubits, with layout shown below.



True-Q software: developed by Quantum Benchmark to generate CB and RC results.

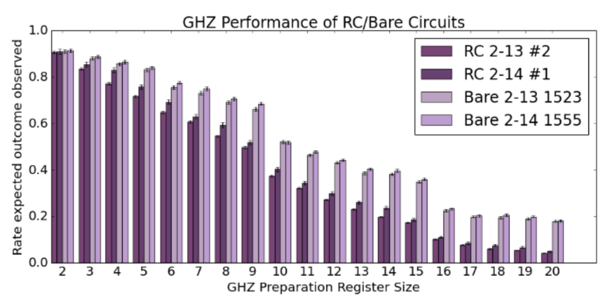
RC: Pauli twirling to compile GHZ-state preparation circuits into 32 logically-equivalent circuits. Results from these circuits are combined to represent the RC circuit output.

Cycles: different counts of CNOT gates used in the GHZ circuits to estimate their process fidelities.

Quantum Benchmark. True-QTM Documentation. https://trueq.quantumbenchmark.com/
IBM, "Qiskit Documentation." https://qiskit.org/documentation/, (19 December 2018).

RANDOMIZED COMPILING RESULTS

We execute RC GHZ circuits and uncompiled GHZ circuits on toronto.



CYCLE BENCHMARKING RESULTS

The results of the wider cycle are only predicted by the results of the smaller cycles for the A3 cycle. This most likely indicates that there are additional noise processes present in the larger cycle that are not observed in the smaller cycles.

Cycle	Gates	Experiment Process Fidelity
0	H(0)	0.99903
1	CNOT(0,1)	0.96539
2	CNOT(1,2)	0.98663
3	CNOT(2,3)	0.9855
4	CNOT(3,5)	0.98404
5	CNOT(5,8)	0.99011
6	CNOT(8,9)	0.98861
7	CNOT(8,11)	0.99088
8	CNOT(11,14)	0.98688
9	CNOT(14,13)	0.98395
10	CNOT(13,12)	0.97753
11	CNOT(12,10)	0.98632
12	CNOT(10,7)	0.98912
13	CNOT(7,6)	0.99267
14	CNOT(7,4)	0.98442
15	CNOT(12,15)	0.98174
16	CNOT(15,18)	0.9798
17	CNOT(18,17)	0.97658
18	CNOT(18,21)	0.98206
19	CNOT(21,23)	0.97807

Cycle	Gates	Experiment Process Fidelity	Experiment Process Fidelity	Multiplied Process Fidelity
A1	CNOT: (0,1) (2,3) (5,8) (10,7) (11,14) (13,12) (15,18) (21,23)	0.77743	0.64543	0.86137
A2	H(0) CNOT: (1,2) (3,5) (7,6) (8,9) (12,10) (14,13) (18,17)	0.62929	0.63838	0.90214
A3	CNOT: (7,4) (8,11) (12,15) (18,21)	0.92761	0.92792	0.94045

ACKNOWLEDGEMENT

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