Random Quantum Circuits with Varying Topologies and Gate Sets

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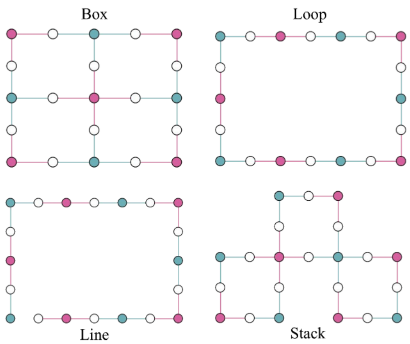
Abstract

We build on recent results [1] using sampling from the output of random unitary matrices as a metric for quantum supremacy. We first investigate the relationship between the choice of gate set and the circuit depth required to converge to an exponential distribution. In particular, we note that convergence is possible using iSWAP gates in place of CZ gates. Next we explore the effects of varying qubit connectivity on the convergence behavior of random circuits.

[1] Sergio Boixo, Sergei V. Isakov, Vadim N. Smelyanskiy, Ryan Babbush, Nan Ding, Zhang Jiang, John M. Martinis: "Characterizing Quantum Supremacy in Near-Term Devices", 2016; arXiv:1608.00263

Gate Sets and Topologies

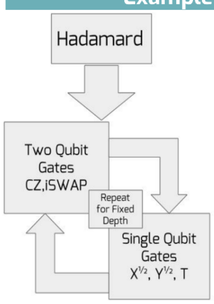


- Upper Transmon
- Lower Transmon
- Fluxonium

GS1: CPHASE, $X^{1/2}$, $Y^{1/2}$, T

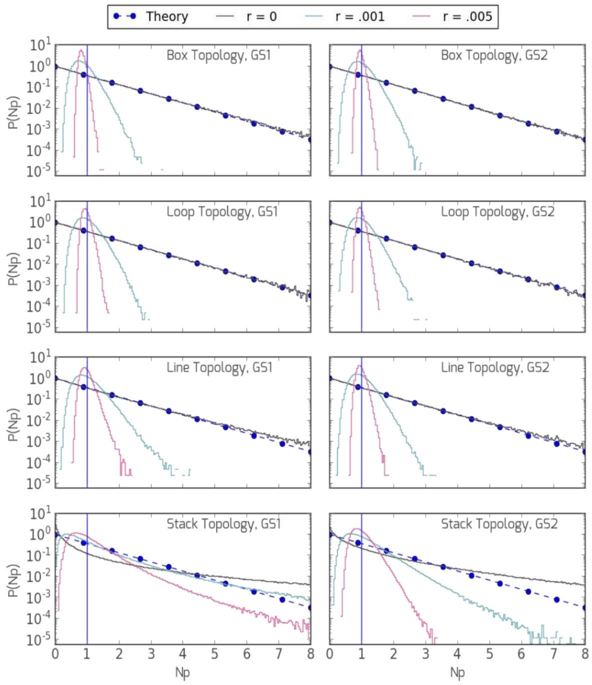
GS2: iSWAP, CPHASE, $X^{1/2}$, $Y^{1/2}$, T

Example Quil Program



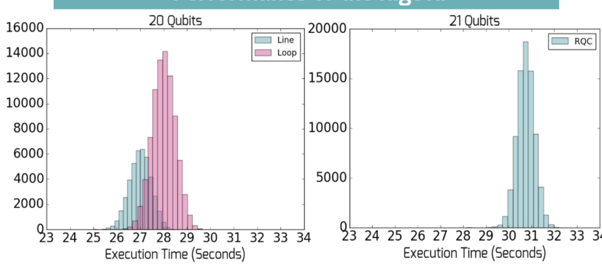

```
H 0          CPHASE(3.14) 2 0
H 1          CPHASE(3.14) 5 3
H 2          T 1
H 3          T 4
H 4          T 6
H 5          T 7
H 6          CPHASE(3.14) 5 1
H 7          CPHASE(3.14) 2 6
ISWAP 0 7    RX(1.57) 0
ISWAP 3 4    RX(1.57) 3
ISWAP 1 7    ISWAP 0 7
ISWAP 4 6    ISWAP 3 4
T 0          RX(1.57) 1
T 3          ...
```

Convergence to an Exponential Distribution



Results are from averaging over the bitstring probabilities of 1000 noisy circuit simulations, with circuit depths of 50. r is the two qubit gate error rate and r/10 is the single qubit gate error rate.

Performance of the Rigetti

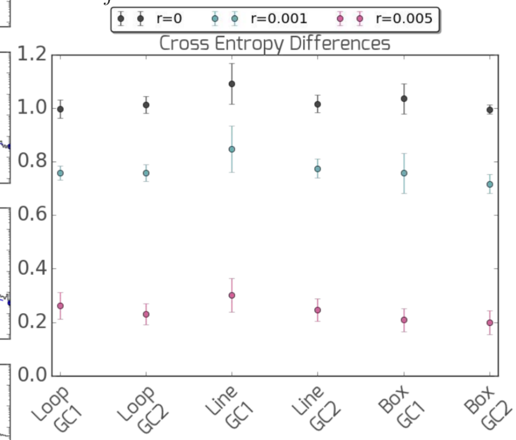


Results are for Amazon EC2 m4.16xlarge instances with 64 cores and 256 GiB of memory. Each machine had eight QVMs running, each with eight workers.

Measuring the Cross-Entropy Difference

Take p_A to be the distribution over bitstrings observed from sampling from a (possibly noisy) circuit, and take p_U to be the true bitstring probabilities. Then we define the cross entropy difference as:

$$\sum_j \left(\frac{1}{N} - p_A(x_j|U)\right) \log \frac{1}{p_U(x_j)}$$



Above we see the cross entropy differences for the topologies and gate sets being considered. The error bars are over 28 random circuits, each sampled 1000 times. (Except in the case of the Line topology on GC1, which is over 20 random circuits.)

Conclusion

We see that convergence to an exponential distribution is possible for the Box and Loop Topologies, extending the results from [1]. Convergence is also observed for GS2, a gate set that is applicable to architectures currently designed by Rigetti Computing [2]. Unfortunately, as compared to the cross entropy differences found in [1], these topologies seem to suffer more from noise in the system. In the future, we hope to continue to investigate the systems described here for larger numbers of qubits, more noise values and different topologies.

[1] Sergio Boixo, Sergei V. Isakov, Vadim N. Smelyanskiy, Ryan Babbush, Nan Ding, Zhang Jiang, John M. Martinis: "Characterizing Quantum Supremacy in Near-Term Devices", 2016; arXiv:1608.00263

[2] Sete, E. A., Zeng, W. J., & Rigetti, C. T. (2016). A functional architecture for scalable quantum computing. 2016 IEEE International Conference on Rebooting Computing (ICRC). doi:10.1109/icrc.2016.7738703