Appendix: Unpacking the Quantum Supremacy Benchmark with Python

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A small appendix to the blog post "Unpacking the Quantum Supremacy Benchmark with Python" by M. Sohaib Alam and Will Zeng, outlining how to obtain the expressions for the theoretical values of the cross-entropy benchmark fidelity (F_{XEB}) used in the blog post.

Appendix A: Ideal F_{XEB}

Following the supplementary material of [3], we first note that the probability of some fixed bitstring's sampling probability equaling p when a random unitary is sampled is given by

$$Pr(p) = (D-1)(1-p)^{D-2} \tag{1}$$

where $D = 2^n$ is the dimensionality of an n-qubit space. Following the reasoning in the supplementary material[2] of [1], we find that the probability of sampling a bitstring with sampling probability p is given by

$$\langle P(x_i)\rangle = \int_0^1 p^2 D(D-1)(1-p)^{D-2} dp = \frac{2}{D+1} \tag{2}$$

which is approximately $2/D$ as $D \to \infty$.

Appendix B: Noisy F_{XEB}

In the presence of the depolarization channel, $\rho \to p\,U|0\rangle\langle 0|U^\dagger + (1-p)\frac{I}{D}$, the probability of sampling a bitstring with sampling probability p is given by

$$\langle P(x_i)\rangle = \langle P(x_i)\rangle_0 + \frac{1-p}{D} \tag{3}$$

where $\langle P(x_i)\rangle_0$ is the expression in Eq. 2. The expression above simplifies to

$$\langle P(x_i)\rangle = p\left(\frac{D-1}{D+1}\right) \tag{4}$$

which is approximately p as $D \to \infty$.

References

[1] Arya K. Babbush R. et al. Arute, F. Quantum supremacy using a programmable superconducting processor. *Nature*, 574:505–510, 2019.

[2] Arya K. Babbush R. et al. Arute, F. Supplementary information for quantum supremacy using a programmable superconducting processor. *arXiv:1910.11333*, 2019.

[3] Isakov S.V. Smelyanskiy V.N. et al. Boixo, S. Characterizing quantum supremacy in near-term devices. *Nature Phys*, 14:595–600, 2018.