Project Report (Quantum Computation, Problem-2)

Ayanava Dasgupta, M. Tech. (CS), ISI Kolkata
Premanshu Chatterjee, M. Sc. (CS), RKMVERI, Belur

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1 Problem Statement

Current quantum devices are noisy, and are not yet capable of applying error correction techniques. Therefore, various mitigation techniques have been proposed in the literature which try to lower the effect of error on the system. In this project we shall look into one such technique to mitigate the effect of noise on idle qubits. In general when storing a qubit $\rho = |\psi\rangle\langle\psi|$, where $= cos(\frac{\theta}{2})|0\rangle + sin(\frac{\theta}{2})|1\rangle$, it is subjected to errors on the channel E, leading to an erronous state ρ_{noise}. From the method of unitary padding mentioned in [Mas+22], we pad U and V before and after ρ respectively. The output state is now $\rho_{out} = VE(U\rho U^{\dagger})V^{\dagger}$. Our goal is to find optimized U and V such that the fidelity $\mathcal{F} = \langle\psi|\rho_{out}|\psi\rangle$ is maximized. The necessary criteria is $\langle\psi|\rho_{out}|\psi\rangle \geq \langle\psi|\rho_{noisy}|\psi\rangle$. For the sake of simplicity we will define the fidelity as follows

$$\mathcal{F} = \Big\{ \sum_{s\in\{0,1\}^n} \sqrt{p_{in}(s).p_{out}(s)} \Big\}$$

where n is the number of qubits we are incorporating in our circuit and p_{in} p_{out} are the probability distribution of the state ρ and ρ_{out} respectibely. In this project we investigate following things.

1. Given the structure of U and V propsed in [Mas+22], what would the optimum angle be for R_y gate for different types of noise channels given in [Mas+22] [which are *Depolarization noise, Biased pauli noise(Dephasing noise), Thermal Relaxation(Amplitude Damping)*].
2. Instead of using R_y we will also try with R_x and R_z.
3. We will increase the number of qubits, and check whether at any point the extra $CNOT$ gates incur more noise than the case without any padding, i.e., this method would lead to extra error.

2 Results

2.1 Depolarization Noise

For depolarization noise, we can see as number of qubit increasing with the increment of probability of error (p_{err}) fidelity decreases with a higher rate of decay(which seems to be exponential). We also performed the whole experiment using R_x and R_z instead of using R_y. But we coudn't notice any better result.

2.2 Dephasing Noise

For dephasing noise, we can see as number of qubit increasing with the increment of probability of error and bias (p_{err} and b) fidelity decreases with a higher rate of decay(which seems to be exponential). We also performed the whole experiment using R_x and R_z instead of using R_y, but we couldn't notice any better result.

2.3 Amplitude Damping

For amplitude damping(or thermal relaxation), we notice that using R_y we could see a random pattern implying that using R_y gate in the circuit doesn't help much to capture the noise pattern wrt delay in the circuit. Whereas, if we use R_x and R_z we can see a pattern that with increasing delay the fidelity descreases in exponentioal rate. All the detailed results can be seen in the code section.

3 Final Conclusion

Using R_y in the padding unitary we can capture the noise pattern for depolarization noise and dephasing noise but not for thermal relaxation. But using R_x and R_z we can capture the noise pattern of all the 3 different noise models. Although R_x and R_z does'nt have much difference in their performance in capturing the noise models.

References

[Mas+22] Alena S. Mastiukova et al. *Suppressing decoherence in noisy intermediate-scale quantum processors with unitary operations*. 2022. DOI: 10.48550/ARXIV.2208.04926. URL: https://arxiv.org/abs/2208.04926.