Noise, noise, and more noise

Delphine Martres

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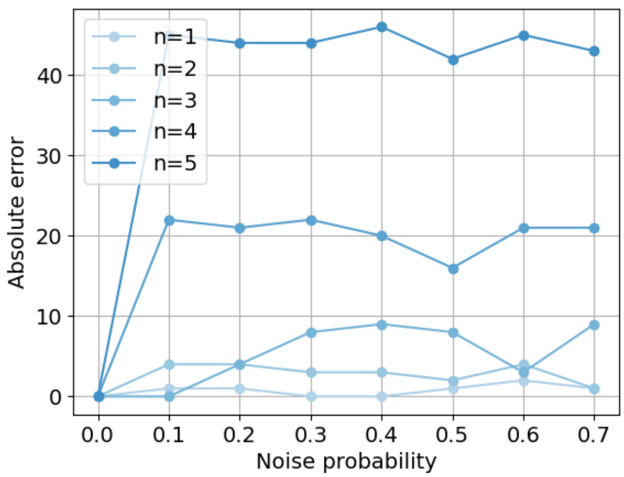
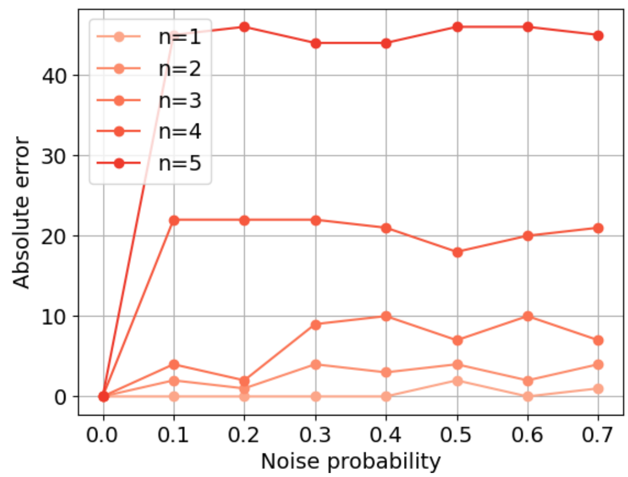
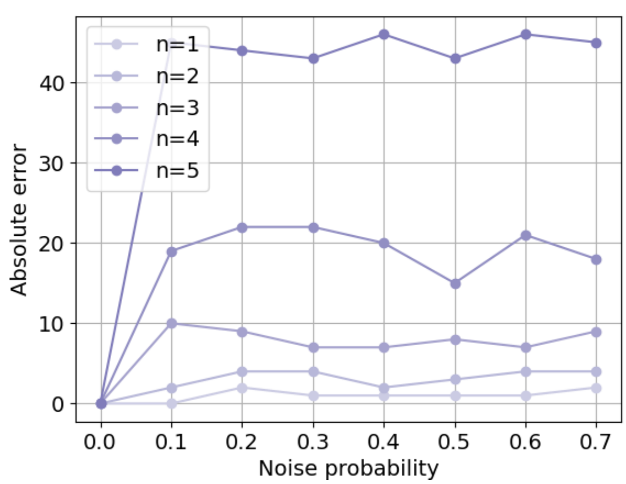
Here are presented the results for tests with the Pauli noise model described in the task, with the noise probability being the probability of having a random Pauli operator X, Y, Z act on the qubit after a 1-qubit gate, and on the target qubit after a 2-qubit gate.



(a) Increasing 1-qubit gate noise probability (2-qubit gate error probability kept at 0)



(b) Increasing 2-qubit gate noise probability (1-qubit gate error probability kept at 0)



(c) Increasing both 1-qubit and 2-qubit gate noise probability together

Figure 1: Absolute error on the result of the quantum adder for $a + b$ (taken to be the state with the most counts over 1024 shots) with respect to noise level, for different n the number of qubits used to represent a and b.

For $n = 1$ qubit used to represent a and b, the 2-qubit gate noise has less effect on the result than for other cases, because there are fewer 2-qubit gates in that circuit. For $n = 3$ qubits, in the first 2 plots the error increases to a maximum when the noise level is around $p = 0.3$. In all plots, for the higher numbers of qubits $n = 4$ and 5, the error is already maximal as soon as $p = 0.1$ because the bigger circuits have more gates. The maximum error also increases exponentially with respect to the number of qubits, which is expected because each added qubit is exponentially more significant in the binary representation of the number, so an error on that qubit will also be exponentially more significant compared to one on a lower qubit.

On NISQ devices there are noise mitigation techniques such as Zero Noise Extrapolation which can be effective to deal with such noise for small scale circuits. But for a scalable solution that could yield quantum advantage, one should build fault-tolerant quantum devices, and in particular use quantum error correction codes. For example the 9-qubit Shor code will encode 1 logical qubit into 9 physical qubits, and individual Pauli errors on the physical qubits can be detected and corrected.