

QUANTUM ERROR CORRECTION WITH SUPERCONDUCTING QUBITS

by

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A Doctor Thesis

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ABSTRACT

Superconducting qubits are among the leading platforms for quantum computing, but their errors occur far too often for long computations. Quantum error correction protects information by encoding it redundantly and decoding the resulting error syndromes faster than errors accumulate. This thesis studies decoding for the surface code on superconducting hardware. It proposes a decoder that combines minimum-weight perfect matching with a learned correction for correlated errors caused by leakage and crosstalk, and an implementation that meets the one-microsecond syndrome cycle of current devices. On simulated noise calibrated to device measurements, the decoder lowers the logical error rate of a distance-seven code by 38% compared with standard matching.

論文要旨

超伝導量子ビットにおける量子誤り訂正

田中由紀

超伝導量子ビットは量子計算の有力な実装方式であるが、その誤り率は長い計算を行うには高すぎる。量子誤り訂正は情報を冗長に符号化し、誤りが蓄積するより速く誤りシンδροームを復号することで情報を保護する。本論文では、超伝導デバイス上の表面符号の復号を研究する。リーケージやクロストークに起因する相関誤りを学習により補正する項を最小重み完全マッチングと組み合わせた復号器と、現行デバイスの1マイクロ秒のシンδροーム周期に間に合う実装を提案する。デバイスの測定値に基づく雑音モデルの下で、距離7の符号の論理誤り率を標準的なマッチングに比べて38%低減した。

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Chapter 1

Introduction

A useful quantum computation may require billions of operations, while today's physical qubits fail roughly once in a thousand. Quantum error correction bridges this gap by encoding one logical qubit in many physical ones [1]. The encoding works only if the classical decoder that interprets error syndromes is both accurate and fast.

Chapter 2

Background

The surface code arranges data and measurement qubits on a lattice and detects errors through repeated stabilizer measurements [2, 1]. Below a threshold physical error rate p_{th} , the logical error rate of a distance- d code decreases as

$$p_L \approx A \left(\frac{p}{p_{\text{th}}} \right)^{\lfloor (d+1)/2 \rfloor}, \quad (2.1)$$

so each increase in distance suppresses errors further, provided the decoder is good enough.

Chapter 3

A Matching Decoder with Learned Corrections

Minimum-weight perfect matching finds the most likely set of independent errors consistent with the syndrome. We adjust its edge weights with a small neural network that recognizes syndrome patterns typical of leakage and crosstalk, and run the matching on programmable logic next to the control electronics.

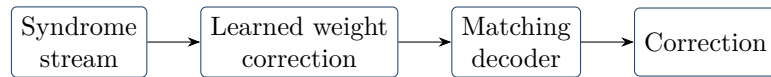


Figure 3.1: Decoding pipeline with learned corrections to matching weights.

Chapter 4

Results

Table 4.1 reports logical error rates per round for three code distances.

Table 4.1: Logical error rate per round under device-calibrated noise.

Decoder	$d = 3$	$d = 5$	$d = 7$
Standard matching	3.1×10^{-2}	9.4×10^{-3}	2.9×10^{-3}
Matching with corrections	2.6×10^{-2}	6.5×10^{-3}	1.8×10^{-3}

Chapter 5

Conclusion

Correlated errors are a large part of what separates real devices from textbook noise models, and a decoder that learns them recovers much of the lost performance within the time budget of the hardware.

Appendix A

Noise Model Calibration

Single- and two-qubit error rates, readout errors and leakage rates were taken from randomized benchmarking and readout calibration of a 17-qubit device.

Bibliography

- [1] Austin G. Fowler, Matteo Mariantoni, John M. Martinis, and Andrew N. Cleland. Surface codes: Towards practical large-scale quantum computation. *Physical Review A*, 86:032324, 2012.
- [2] A. Yu. Kitaev. Fault-tolerant quantum computation by anyons. *Annals of Physics*, 303:2–30, 2003.