Error Mitigation in Quantum Approximation Algorithms

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Problem Statement + Roadmap

Can we mitigate physical noise enough to make quantum computational gains in the near future (NISQ)?

- NISQ projected to provide computational gains in solving optimization problems
- *Recent results: **cost function gradients decay exponentially!**

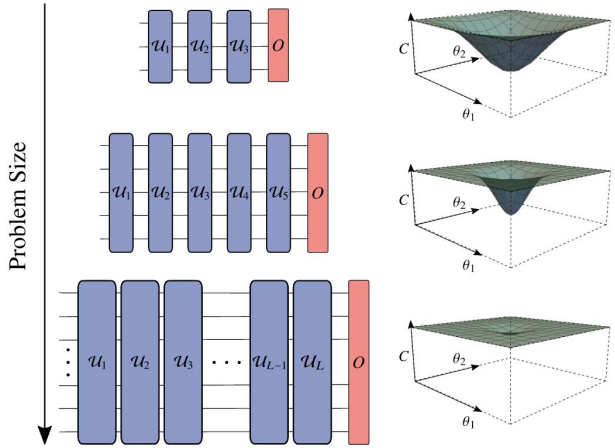


*Figure 1 in [arxiv: 2007.14384]

Background → QAOA → ZNE → Results

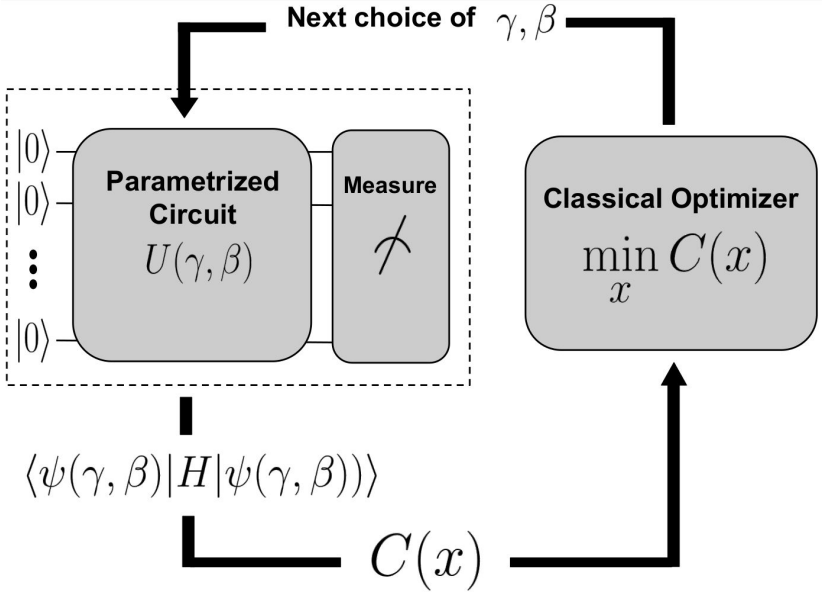
Background

- **(Digital) Quantum Computing:** computing with superpositions + entanglement
- **Qubit:** storage / processing of superpositions (two-level system)

  Implementation: superconducting transmon, trapped ion, photonic qubit, etc.
- **Noise (Decoherence):** loss of information due to interaction with environment
- **NISQ - Noisy Intermediate Scale Quantum:** quantum devices projected to be large (and reliable) enough to make computational gains

QAOA: Quantum Approximate Optimization Algorithm

- Hybrid quantum-classical approximation algorithm to perform optimization



$$H = \sum_{x\in\{0,1\}^n} C(x)|x\rangle\langle x|$$

$$f(\gamma^*, \beta^*) = \sum_{x\in\{0,1\}^n} C(x)|\langle\psi(\gamma^*, \beta^*)|x\rangle|^2$$

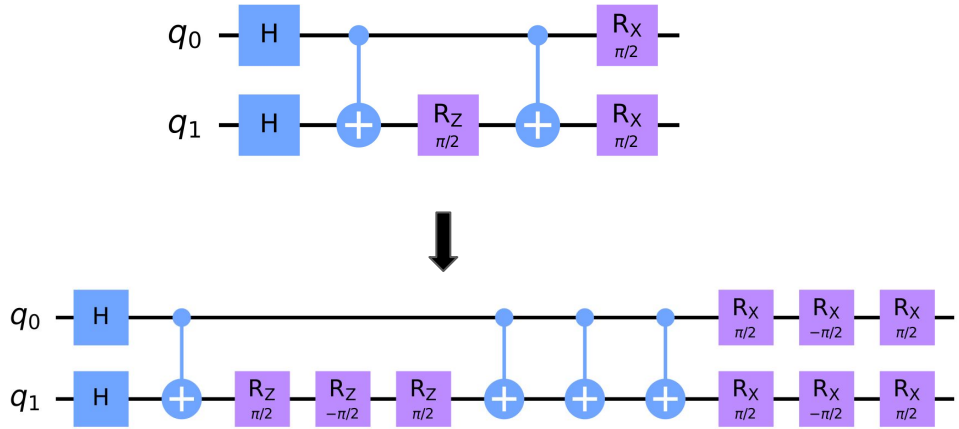
$$= \sum_{x\in\{0,1\}^n} C(x)|\langle x^*|x\rangle|^2$$

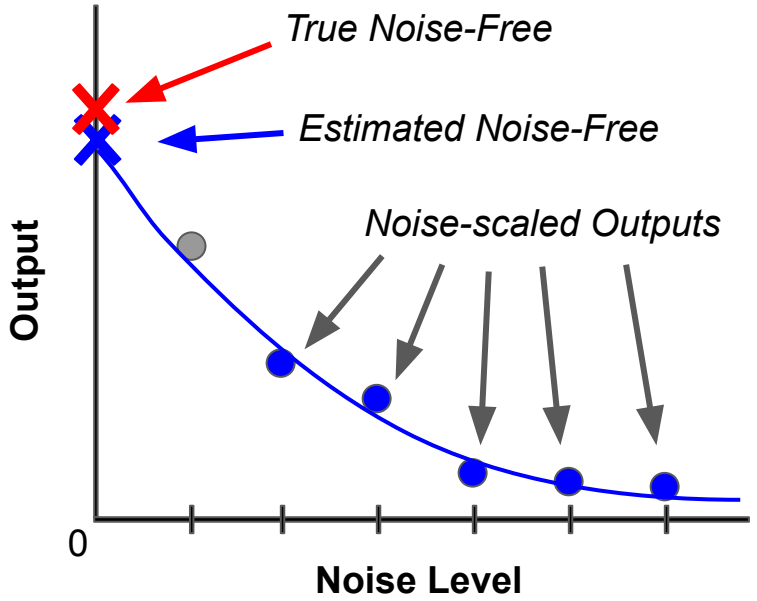
$$= C(x^*)$$

$$\min_x C(x) = \min_{\gamma,\beta} f(\gamma, \beta)$$

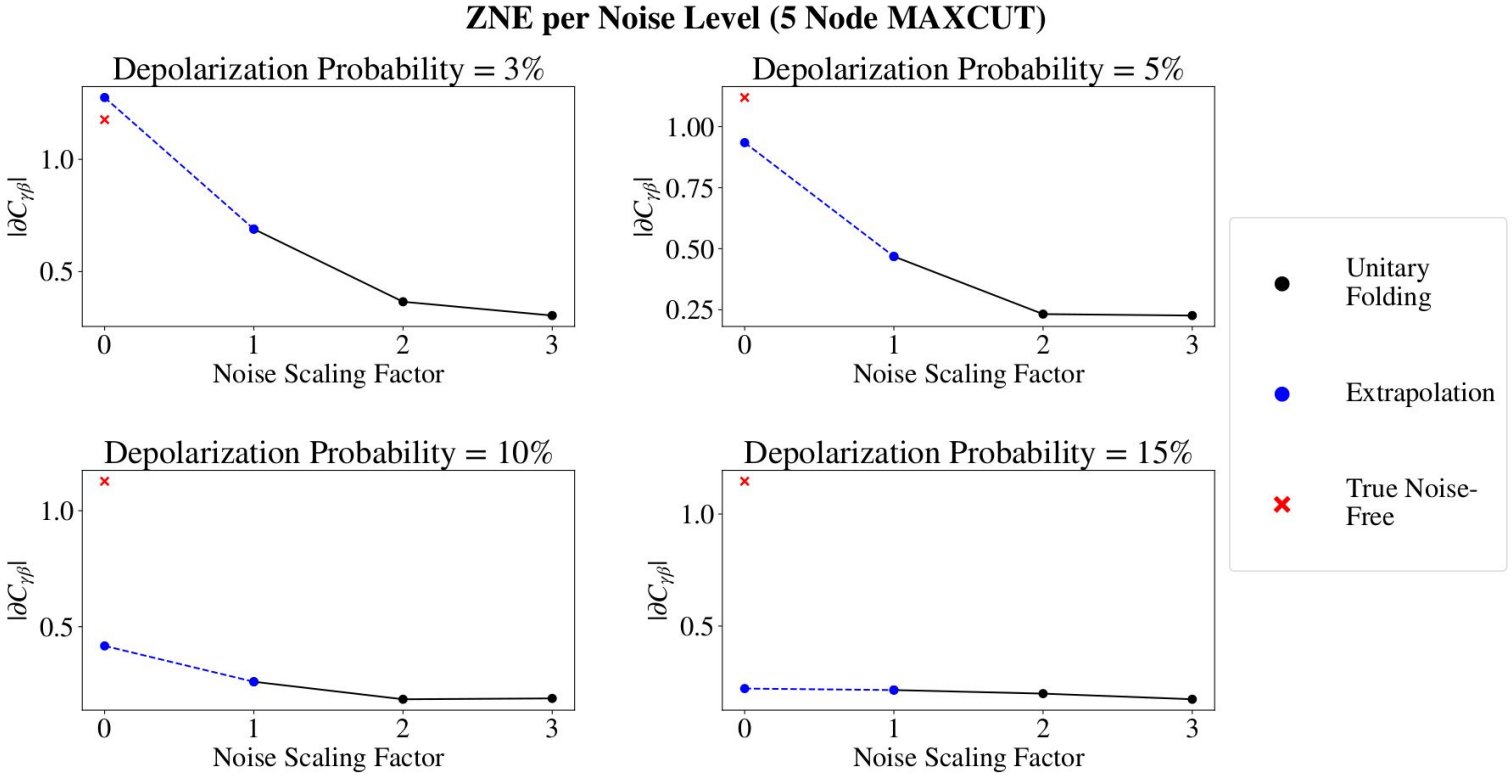
ZNE: Zero Noise Extrapolation

- ZNE = (1) noise scaling + (2) extrapolation to zero noise
- Unitary Folding: $U \mapsto U(I)^n = U(U^\dagger U)^n$

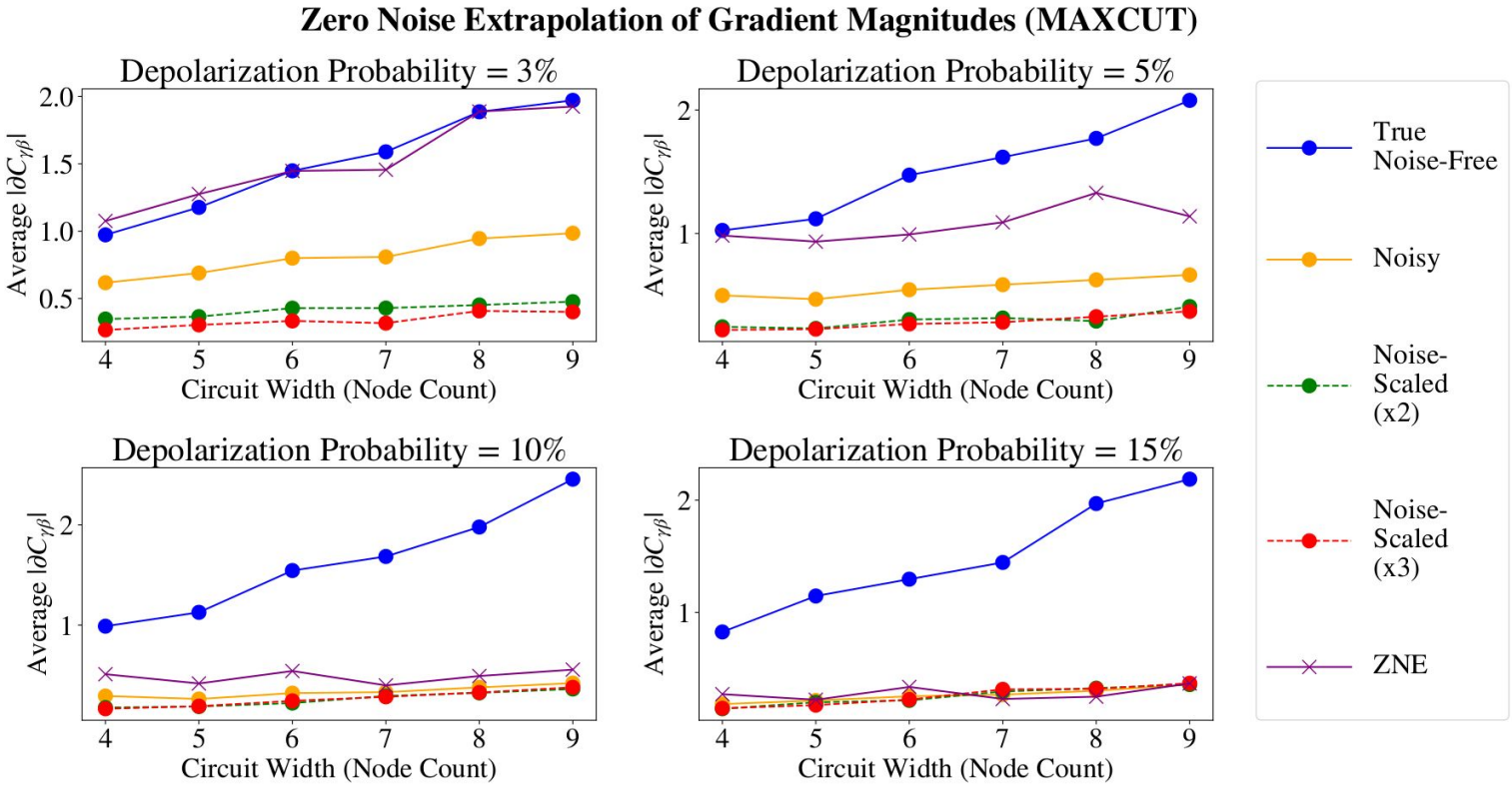




Results


ZNE per Noise Level (5 Node MAXCUT)
Depolarization Probability = 3%
Depolarization Probability = 5%
Depolarization Probability = 10%
Depolarization Probability = 15%
$|\partial C_{\gamma\beta}|$
Noise Scaling Factor
Unitary Folding
Extrapolation
True Noise-Free

Results


Zero Noise Extrapolation of Gradient Magnitudes (MAXCUT)
Depolarization Probability = 3%
Depolarization Probability = 5%
Depolarization Probability = 10%
Depolarization Probability = 15%
Average $|\partial C_{\gamma\beta}|$
Circuit Width (Node Count)
True Noise-Free
Noisy
Noise-Scaled (x2)
Noise-Scaled (x3)
ZNE