Error Mitigation With Mitiq

Coloquio de Cómputo Cuántico

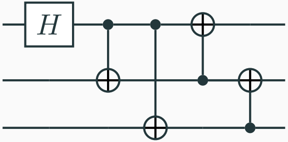
Nate Stemen

Nov 29, 2022

Overview

1. Overview of Quantum Error Mitigation (QEM)
    - Zero-Noise Extrapolation (ZNE)
    - Probabilistic Error Cancellation (PEC)
2. Overview of Mitiq
3. Unitary Fund

What is error mitigation?



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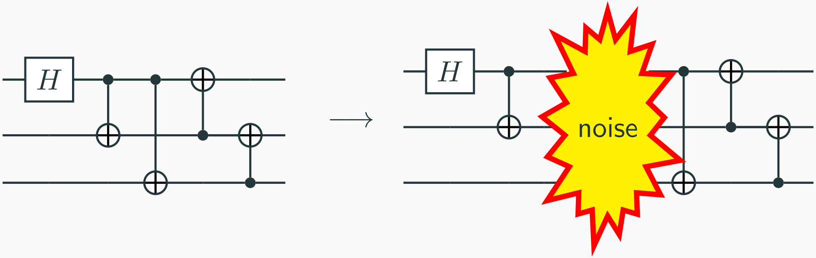

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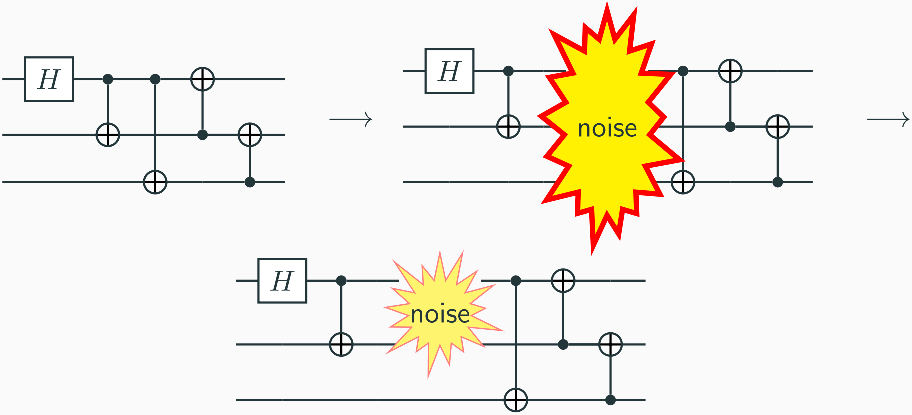

What about error correction?

Scheme for reducing decoherence in quantum computer memory

Peter W. Shor*

AT&T Bell Laboratories, Room 2D-149, 600 Mountain Avenue, Murray Hill, New Jersey 07974

(Received 17 May 1995)

Recently, it was realized that use of the properties of quantum mechanics might speed up certain computations dramatically. Interest has since been growing in the area of quantum computation. One of the main difficulties of quantum computation is that decoherence destroys the information in a superposition of states contained in a quantum computer, thus making long computations impossible. It is shown how to reduce the effects of decoherence for information stored in quantum memory, assuming that the decoherence process acts independently on each of the bits stored in memory. This involves the use of a quantum analog of error-correcting codes.

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- Intermediate measurements produce syndromes
- Use syndromes to correct errors

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- Collect results
- Infer ideal expectation values

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Scalable, but unfeasible

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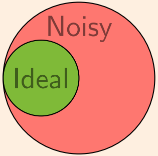
Unscalable*, but feasible

QEM Methods

Zero-Noise Extrapolation

$$\partial_t \rho = -i[H,\rho] + \lambda \mathcal{L}(\rho)$$

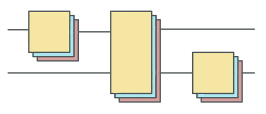
Symmetry-based techniques



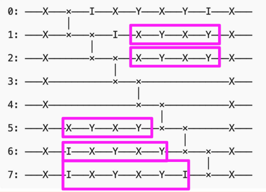
$$M\left|\psi\right\rangle = \left|\psi\right\rangle$$

$$\rho = \frac{M\rho M}{\mathrm{tr}(M\rho)}$$

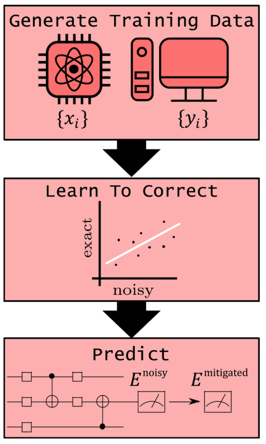
Probabilistic Error Cancellation



Dynamical Decoupling/Randomized Compiling



Learning-based methods



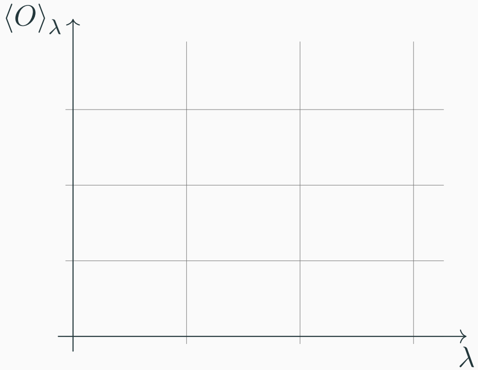
Zero-Noise Extrapolation (ZNE)

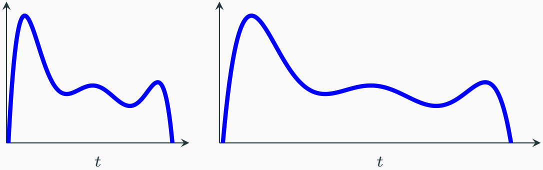
Key Idea

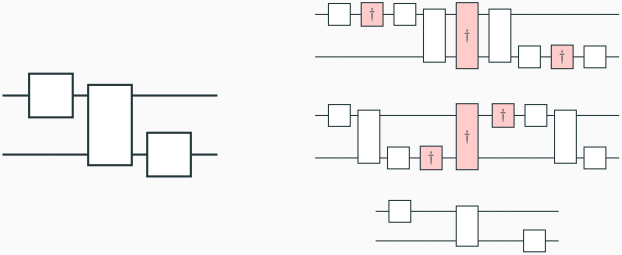
Scale noise up, extrapolate back to zero-noise value.

How do we scale the noise **up**?

$$\partial_t \rho = -i[H, \rho] + \lambda \mathcal{L}(\rho)$$



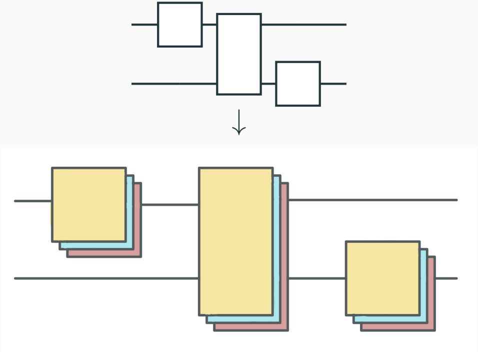




Probabilistic Error Cancellation (PEC)

Key Idea

Use noisy operations to build up noiseless ones by selective cancellation and sampling.



$$\mathcal{U} = \sum_{i=1}^{n} a_i \mathcal{O}_i$$

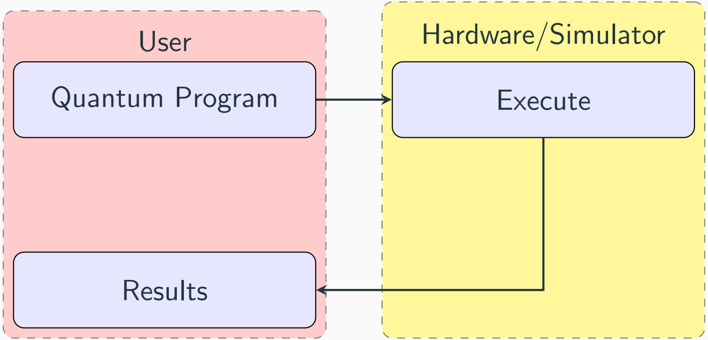
$$\langle A \rangle_{\mathsf{PEC}} = \frac{\gamma}{M} \sum_{i=1}^{M} \sigma_i \langle A \rangle_i$$

- $\mathcal{O}_i$: implementable operations
- σ_i: Sign of i^{th} circuit
- M: # of circuits
- γ: overall negativity (product of representation one-norms)

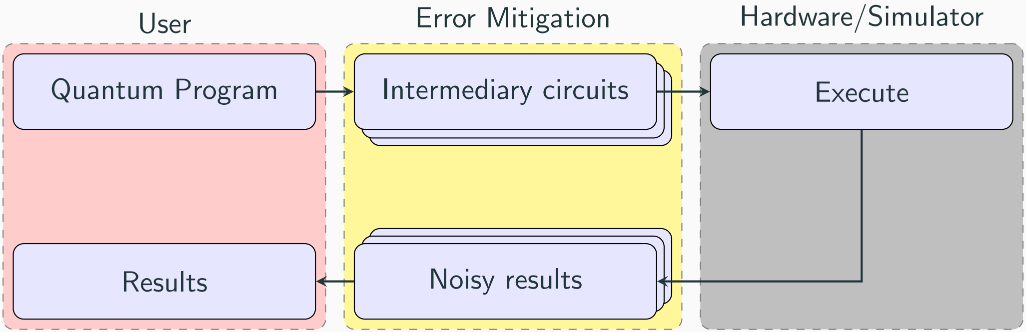
Mitiq

```
import cirq
from mitiq import zne, benchmarks

def execute(circuit, noise_level=0.001):
  noisy_circuit = circuit.with_noise(cirq.depolarize(p=noise_level))
  return (
    cirq.DensityMatrixSimulator()
    .simulate(noisy_circuit)
    .final_density_matrix[0, 0]
    .real
  )

circuit = benchmarks.generate_rb_circuits(n_qubits=1, num_cliffords=50
                                          )[0]

true_value = execute(circuit, noise_level=0.0)
noisy_value = execute(circuit)
zne_value = zne.execute_with_zne(circuit, execute)

print(f"Error (w/o  Mitiq): %0.4f" %abs((true_value - noisy_value) /
```

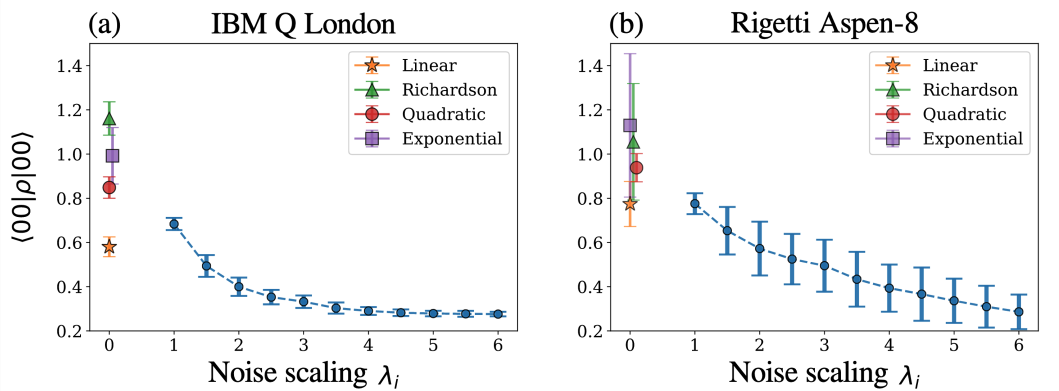
Running quantum programs in practice



Running quantum programs in practice with Mitiq



Does it work?



Quantum 6, 774 (2022).

Unitary Fund

- 501(c)(3) nonprofit dedicated to growing the quantum open-source ecosystem
- Run microgrant program; $4k grants to those developing cool quantum projects in the open
- Develop mitiq
- Run metriq (`metriq.info`): a platform for community driving quantum benchmarks
- Community development

Unitary Fund

Microgrant Program:

- 68 Microgrants awarded
- 23 countries
- 16+ publications
- 30+ libraries, 6k commits
- 2 startups, 1 nonprofit

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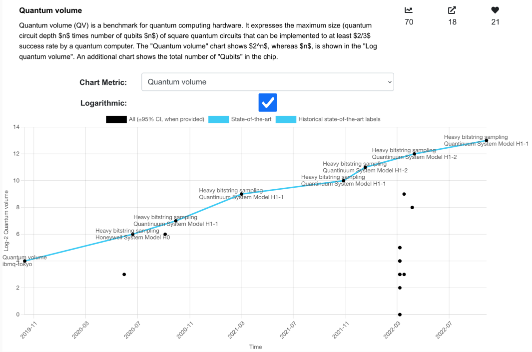

https://metriq.info

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Unitary Fund

- UnitaryHACK
  - 30 participating projects
  - 66 bounties (with cash prizes)
  - Look out for news on UnitaryHACK 2023!
- `http://discord.unitary.fund`
  - Community calls for projects: Mitiq, QIR Alliance, QuTiP, OpenQAOA

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Summary

- QEM is a growing field of research working towards better results for existing quantum computers.
- ZNE and PEC are promising, and easy to use techniques.
- Mitiq can provide out-of-the-box support for running quantum programs with QEM.
- Unitary Fund is helping grow the quantum open-source community and ecosystem.

References

Thank you!