Error Mitigation with Mitiq

Part 1: Zero-Noise Extrapolation & Calibration

Jordan Sullivan, Nate Stemen & Misty Wahl

Aug 17, 2024

Unitary Fund

Numerical Methods
in Quantum Information Science

Mitiq

README.md

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Mitiq is a Python toolkit for implementing error mitigation techniques on quantum computers.

Current quantum computers are noisy due to interactions with the environment, imperfect gate applications, state preparation and measurement errors, etc. Error mitigation seeks to reduce these effects at the software level by compiling quantum programs in clever ways.

Want to know more? Check out our documentation and chat with us on Discord.

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Mitiq is a Python toolkit for implementing error

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level by compiling quantum programs in clever

Want to know more? Check out our documenta

Error mitigation techniques

You can check out currently available quantum error mitigation techniques by calling

```
mitiq.qem_methods()
```

Technique	Documentation	Mitiq module	Paper Reference(s)
Zero-noise extrapolation	ZNE	`mitiq.zne`	1611.09301 1612.02058 1805.04492
Probabilistic error cancellation	PEC	`mitiq.pec`	1612.02058 1712.09271 1905.10135
(Variable-noise) Clifford data regression	CDR	`mitiq.cdr`	2005.10189 2011.01157
Digital dynamical decoupling	DDD	`mitiq.ddd`	9803057 1807.08768
Readout-error mitigation	REM	`mitiq.rem`	1907.08518 2006.14044
Quantum Subspace Expansion	QSE	`mitiq.qse`	1903.05786
Robust Shadow Estimation 🚧	RSE	`mitiq.qse`	2011.09636 2002.08953

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```diff
  import cirq
+ import mitiq

  qubit = cirq.LineQubit(1)
  circuit = cirq.Circuit(cirq.X(qubit) for _ in range(100))

- expval = execute(circuit)
+ expval = mitiq.zne.execute_with_zne(circuit, execute)

  print(f"Error: {1 - expval:.3}")
- # Error: 0.244
+ # Error: 0.058
```

Mitiq

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Follow along!

https://github.com/unitaryfund/Mitiq-Workshop-QNumerics-Summer-School

Experience

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3. Who has used error mitigation?
4. Who has used Mitiq?

Tutorial goals

1. Understand context, and general ideas of quantum error mitigation (QEM).
2. Understand main ideas of ZNE, PEC, and DDD along with pros and cons of each technique.
3. Ability to use Mitiq to apply these techniques in a quantum pipeline.

What is Quantum Error Mitigation?

Quantum Error Mitigation (QEM)

The acceptance that available quantum devices are noisy. . . maybe very much so.

But we still want to use them!

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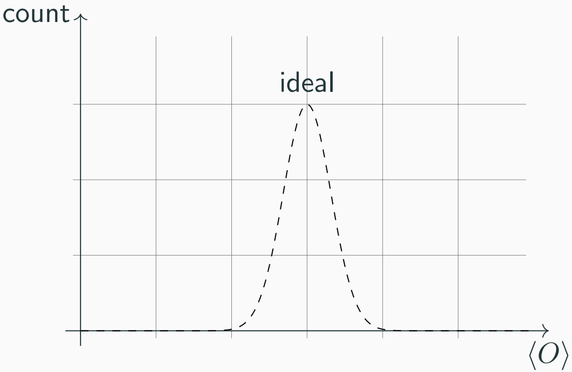

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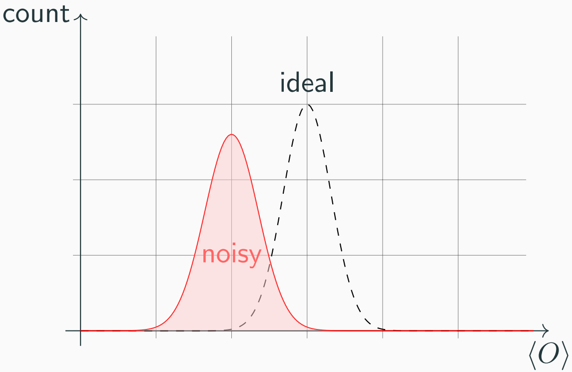

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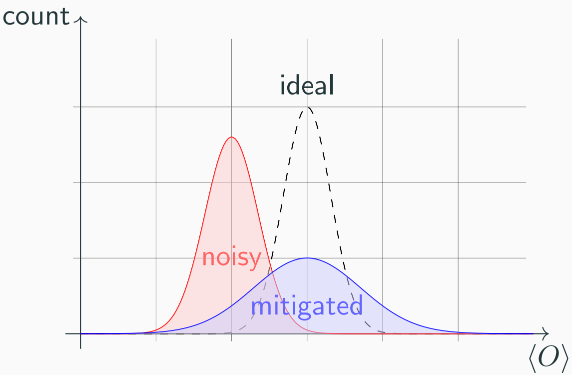
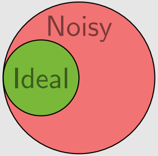


QEM Methods

Zero-Noise Extrapolation

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

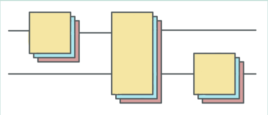
Symmetry-based techniques



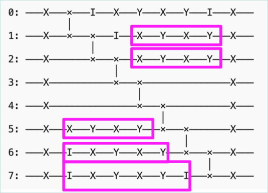
$$M\,|\psi\rangle = |\psi\rangle$$

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

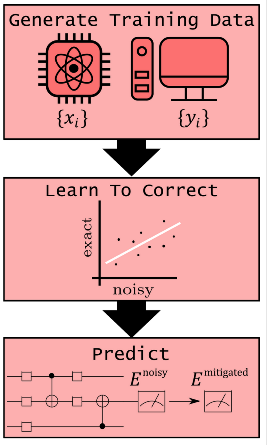
Probabilistic Error Cancellation



Dynamical Decoupling



Learning-based methods



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Error Correction

- Encode logical qubits into many physical qubits
- Intermediate measurements produce syndromes
- Use syndromes to correct errors

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Error Mitigation

- Perform multiple and different noisy computations
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- Infer ideal expectation values

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Needs few noisy qubits

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Key Idea

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

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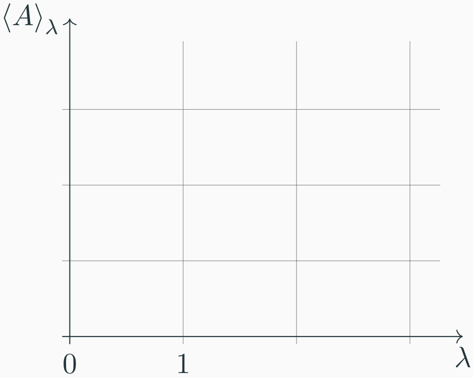

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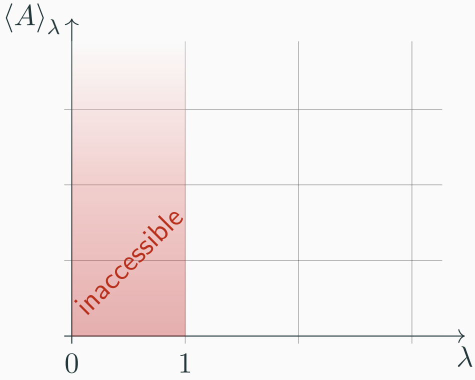

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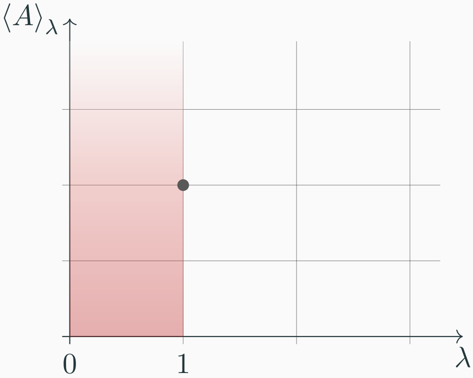

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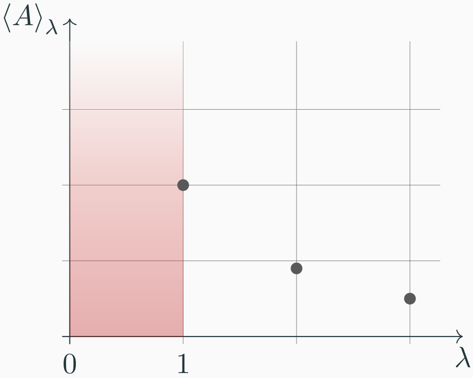

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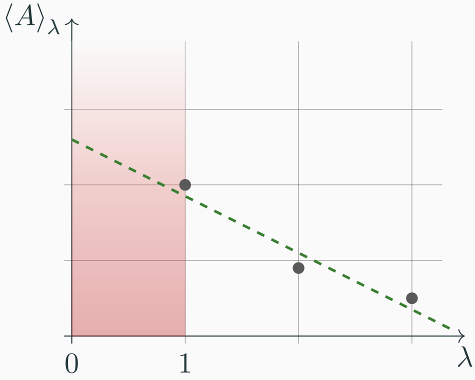

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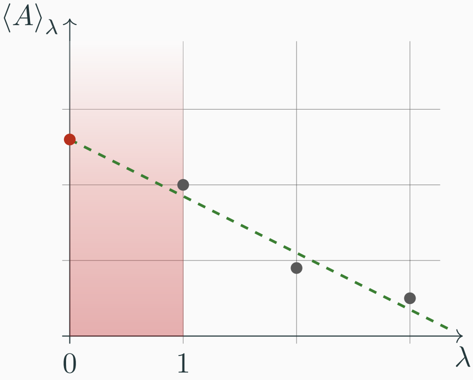

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How do we scale the noise **up**?

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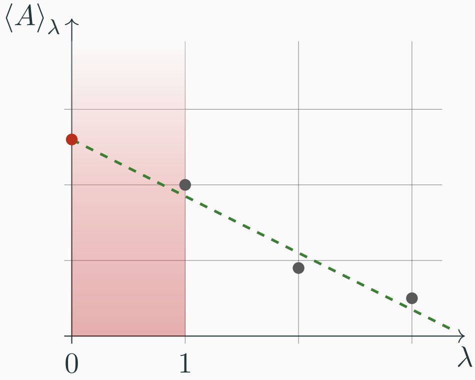

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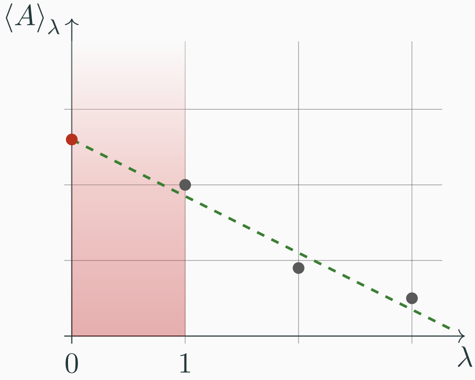

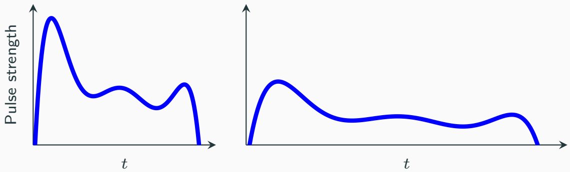

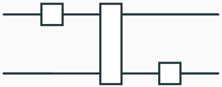

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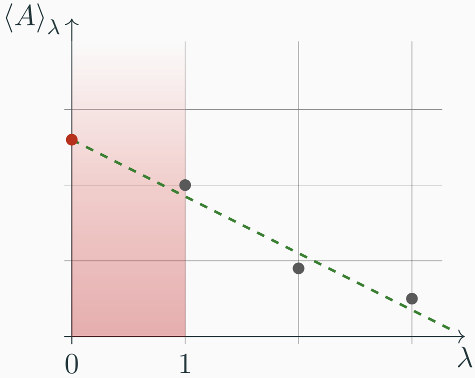

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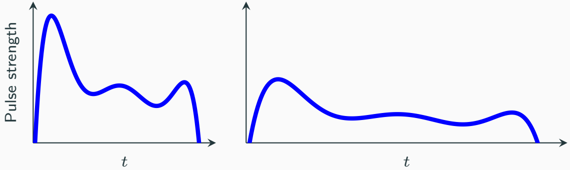
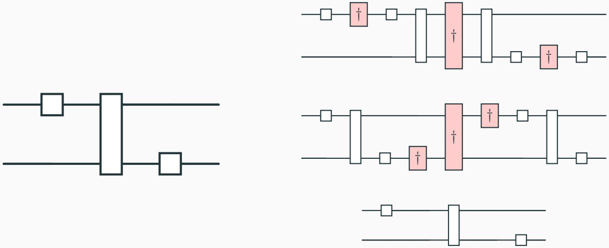
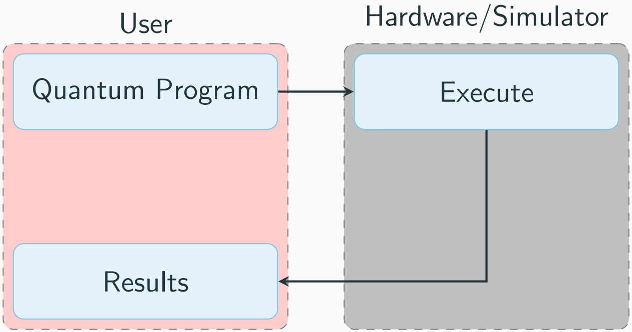
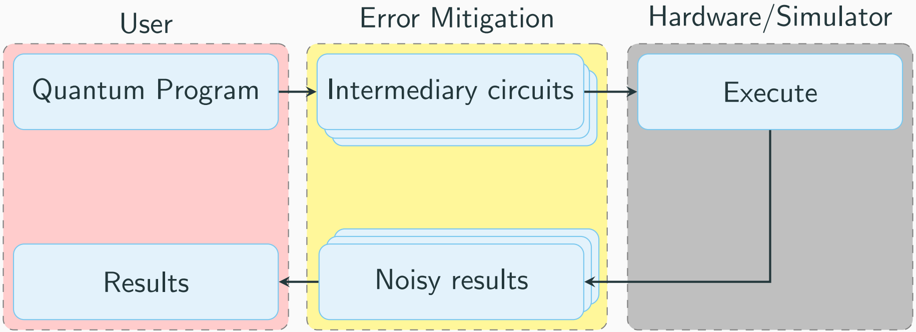




Running quantum programs in practice



Running quantum programs in practice with Mitiq



A peak into the future...

QEC + QEM

Mitigate errors on encoded logical qubits.

When should we use which techniques?

How do we balance classical and quantum resources?

Open questions! For instance...

arXiv > quant-ph > arXiv:2304.14985

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Quantum Physics

[Submitted on 28 Apr 2023 (v1), last revised 25 Jul 2023 (this version, v2)]

Zero noise extrapolation on logical qubits by scaling the error correction code distance

Misty A. Wahl, Andrea Mari, Nathan Shammah, William J. Zeng, Gokul Subramanian Ravi

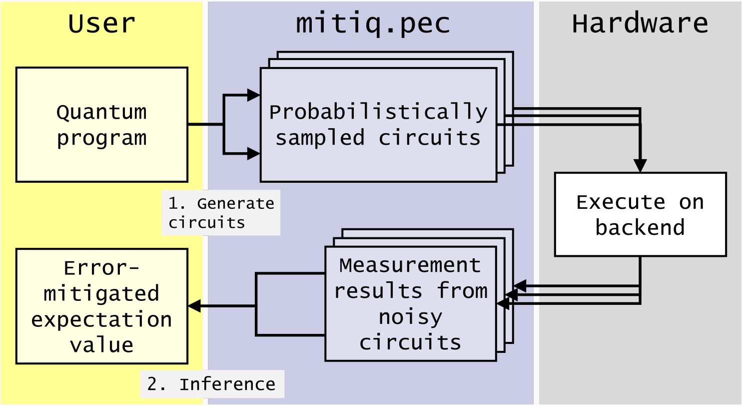
In this work, we migrate the quantum error mitigation technique of Zero-Noise Extrapolation (ZNE) to fault-tolerant quantum computing. We employ ZNE on logically encoded qubits rather than physical qubits. This approach will be useful in a regime where quantum error correction (QEC) is implementable but the number of qubits available for QEC is limited. Apart from illustrating the utility of a traditional ZNE approach (circuit-level unitary folding) for the QEC regime, we propose a novel noise scaling ZNE method specifically tailored to QEC: distance scaled ZNE (DS-ZNE). DS-ZNE scales the distance of the error correction code, and thereby the resulting logical error rate, and utilizes this code distance as the scaling `knob' for ZNE. Logical

Let's try Mitiq!

https://github.com/unitaryfund/
Mitiq-Workshop-QNumerics-Summer-School/mitiq-zne-tutorial.ipynb

Probabilistic Error Cancellation

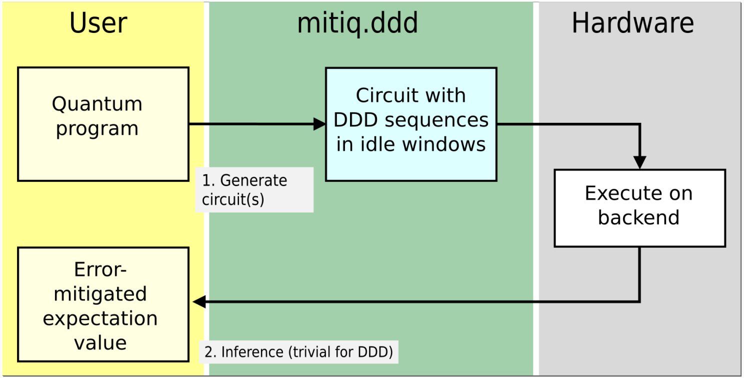
Key Idea: Use noisy operations to build up noiseless ones by selective cancellation and sampling.



Sneak Preview of Part II

Digital Dynamical Decoupling

Key Idea: The devil finds work for idle [qubits].



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