Error Mitigation with Mitiq

Quantum Research & Industry Skills Exchange 2024

Nate Stemen
nate@unitary.fund

March 13, 2024

Unitary Fund

Mitiq

README.md

build passing | docs passing | codecov 98% | pypi package 0.29.0 | arXiv 2009.04417 | Downloads 106k | GitHub

Supported By Unitary Fund | Discord 212 online.

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.

Mitiq

README.md

build passing | docs passing | codecov 98%

Supported By Unitary Fund | Discord 212 online.

Mitiq is a Python toolkit for implementing

Current quantum computers are noisy due
state preparation and measurement errors
level by compiling quantum programs in c

Want to know more? Check out our docun

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

Mitiq

```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
```

README.md

build passing | docs passing | codecov 98% | Supported By Unitary Fund | Discord 212 online.

Mitiq is a Python toolkit for implementing

Current quantum computers are noisy due
state preparation and measurement errors
level by compiling quantum programs in c

Want to know more? Check out our docum

Technique			
Zero-noise extrapolation			
Probabilistic error cancellation	PEC	`mitiq.pec`	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

Mitiq

README.md

mitiq

build passing | docs passing | codecov 98% | Supported By Unitary Fund | Discord 212 online.

Mitiq is a Python toolkit for implementing

Current quantum computers are noisy due
state preparation and measurement errors
level by compiling quantum programs in c

Want to know more? Check out our docum

Technique			
Zero-noise extrapolation			
Probabilistic error cancellation	PEC	`mitiq.pec`	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

```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

README.md

build passing | docs passing | codecov 98%
Supported By Unitary Fund | Discord 212 online.

Mitiq is a Python toolkit for implementing

Current quantum computers are noisy due
state preparation and measurement errors
level by compiling quantum programs in c

Want to know more? Check out our docum

```
  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
```

Technique			
Zero-noise extrapolation			
Probabilistic error cancellation	PEC	`mitiq.pec`	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

Experience

1. Who has written a quantum program before?

Experience

1. Who has written a quantum program before?
2. Who has run a quantum program on hardware before?

Experience

1. Who has written a quantum program before?
2. Who has run a quantum program on hardware before?
3. Who has used error mitigation?

Experience

1. Who has written a quantum program before?
2. Who has run a quantum program on hardware before?
3. Who has used error mitigation?
4. Who has used Mitiq?

Tutorial goals

1. Understand context, and general goal of quantum error mitigation.
2. Understand the main ideas behind Zero-Noise Extrapolation (ZNE) and Digital Dynamical Decoupling (DDD).
3. Ability to use Mitiq to apply these techniques in a quantum pipeline.

What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors

What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors
- Crosstalk

What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors
- Crosstalk
- Calibration errors

What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors
- Crosstalk
- Calibration errors
- . . .

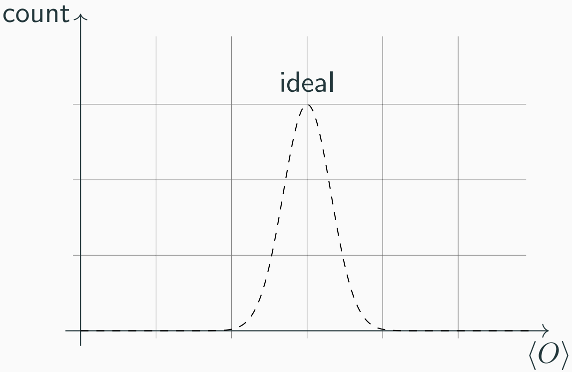
What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors
- Crosstalk
- Calibration errors
- . . .



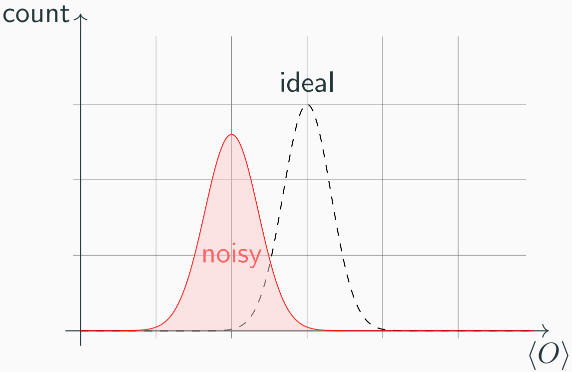
What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors
- Crosstalk
- Calibration errors
- . . .



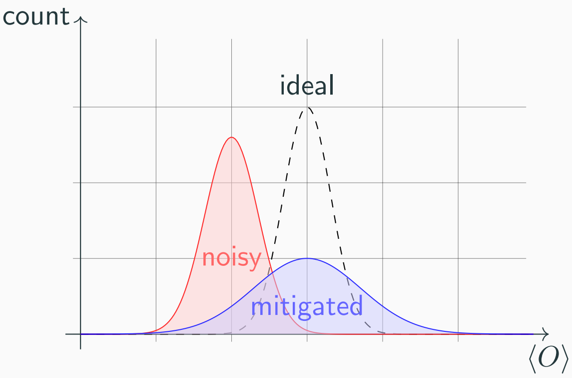
What is Quantum Error Mitigation?

Quantum Error Mitigation

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

But we still want to use them!

- (In)coherent noise
- SPAM errors
- Crosstalk
- Calibration errors
- ...

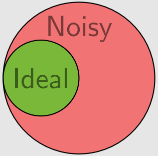


QEM Methods

Zero-Noise Extrapolation

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

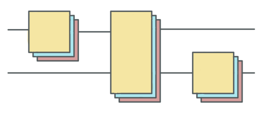
Symmetry-based techniques



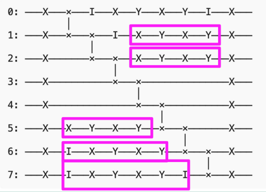
$$M\left|\psi\right\rangle = \left|\psi\right\rangle$$

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

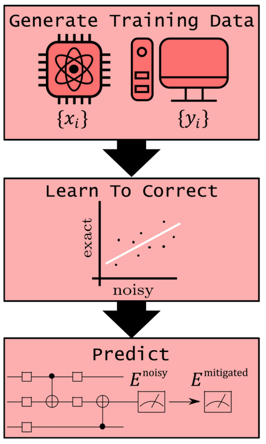
Probabilistic Error Cancellation



Dynamical Decoupling



Learning-based methods



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.

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.

Error Correction

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

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.

Error Correction

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

Error Mitigation

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

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.

Error Correction

- Encode logical qubits in… y physical qubits…
- Int… …ements produce sy…
- Use syndromes to correct errors

Scalable, but unfeasible

Error Mitigation

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

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.

Error Correction

- Encode logical qubits int... y physical qubits
- Int... ements produce sy...
- Use syndromes to correct errors

Scalable, but unfeasible

Error Mitigation

- Perform multiple and diff... noisy computations
- Coll...
- Inf... expectation values

Unscalable*, but feasible

Zero-Noise Extrapolation (ZNE)

Key Idea

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

Zero-Noise Extrapolation (ZNE)

Key Idea

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

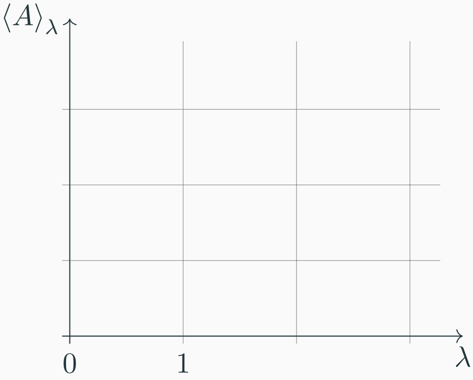
$$\partial_t \rho = -i[H, \rho] + \lambda \mathcal{L}(\rho)$$

Zero-Noise Extrapolation (ZNE)

Key Idea

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

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

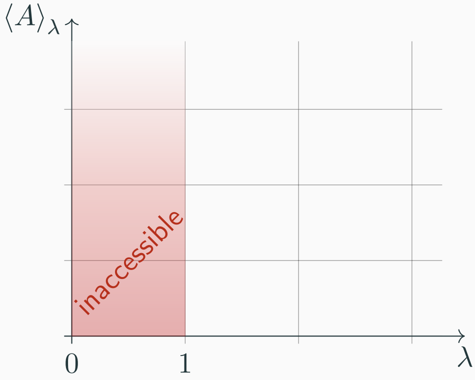


Zero-Noise Extrapolation (ZNE)

Key Idea

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

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

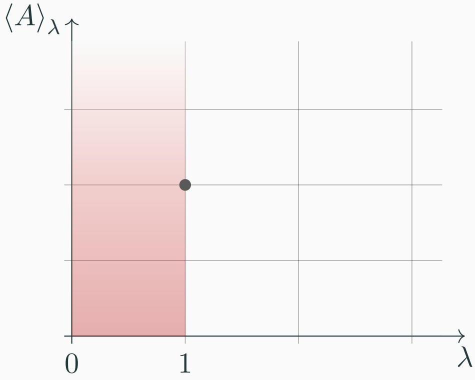


Zero-Noise Extrapolation (ZNE)

Key Idea

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

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

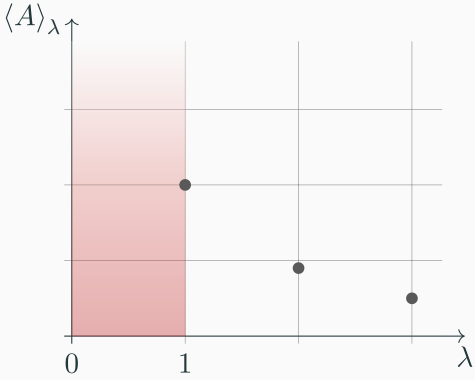


Zero-Noise Extrapolation (ZNE)

Key Idea

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

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

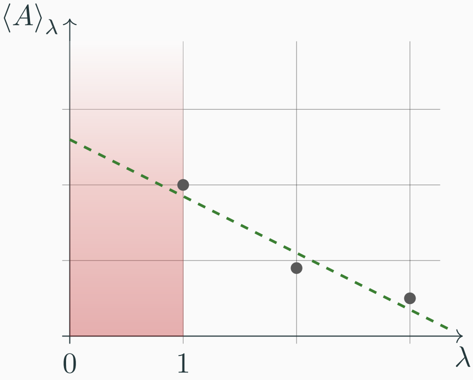


Zero-Noise Extrapolation (ZNE)

Key Idea

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

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

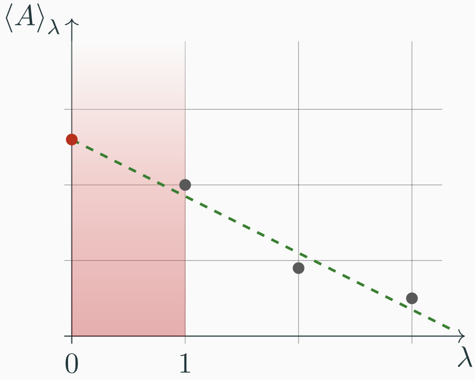


Zero-Noise Extrapolation (ZNE)

Key Idea

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

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



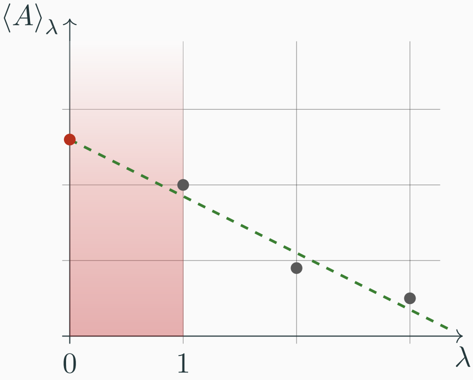
Zero-Noise Extrapolation (ZNE)

Key Idea

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

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

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

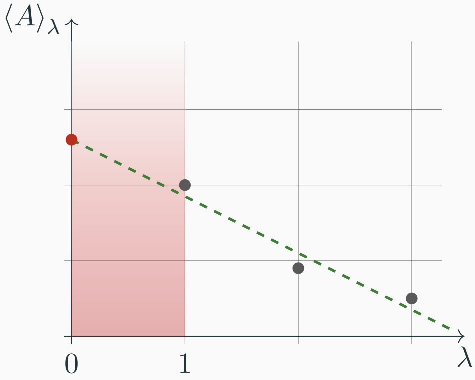


Zero-Noise Extrapolation (ZNE)

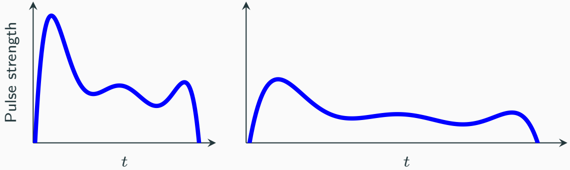
Key Idea

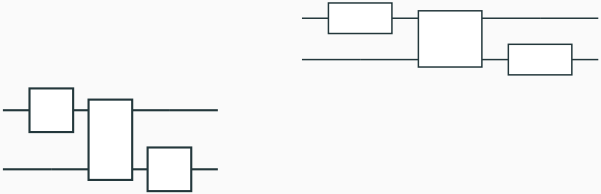
Scale noise up, extrapolate back to zero-noise value.

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



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



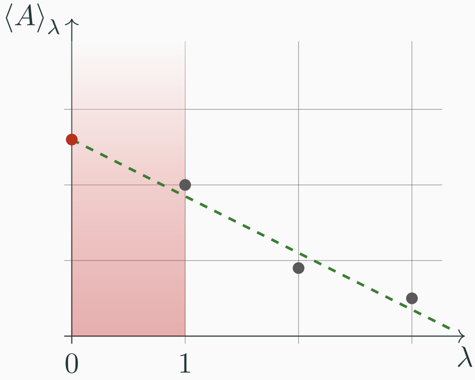


Zero-Noise Extrapolation (ZNE)

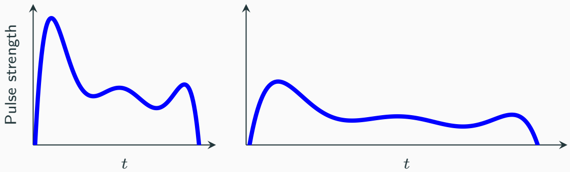
Key Idea

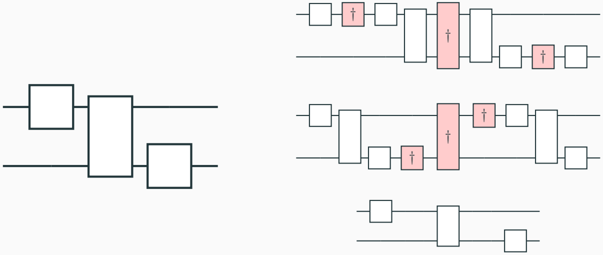
Scale noise up, extrapolate back to zero-noise value.

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

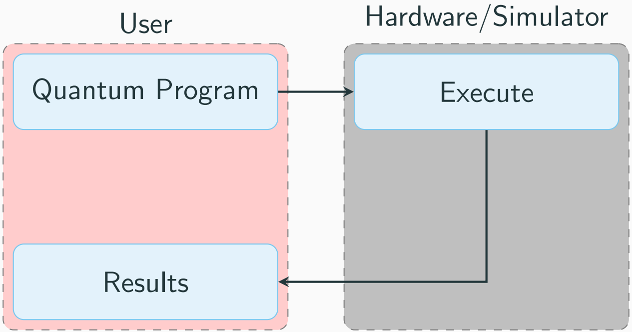


How do we scale the noise **up**?

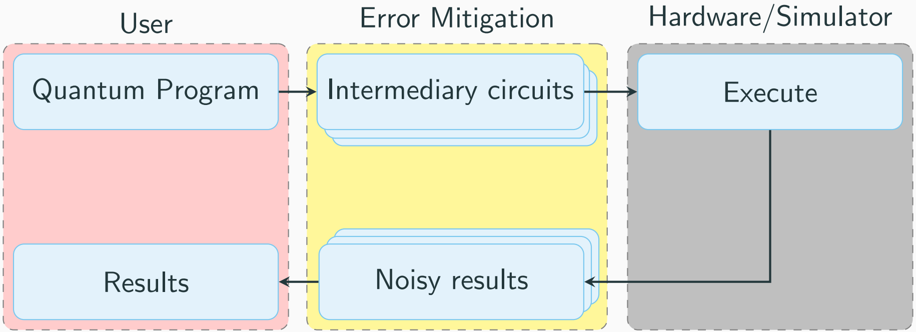




Running quantum programs in practice



Running quantum programs in practice with Mitiq



Let’s try Mitiq!

https://github.com/unitaryfund/mitiq-tutorial/