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Certification and error mitigation platform for quantum computers

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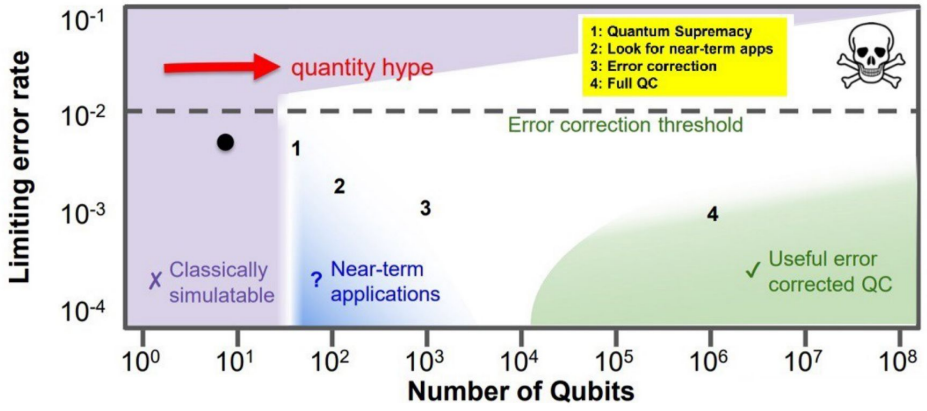
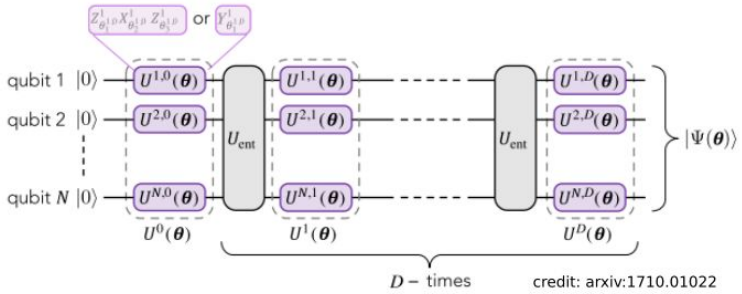
European Funds Smart Growth
Republic of Poland
European Union European Regional Development Fund

Motywacja

Motivation



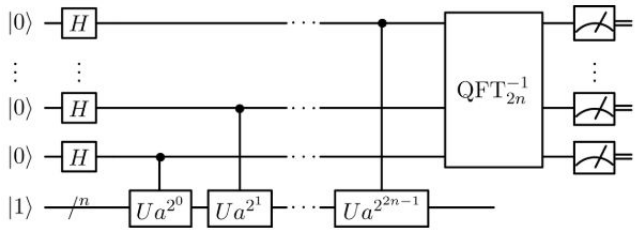
Heuristic algorithms



Applications:

- Optimization
- Quantum chemistry
- Machine learning

Rigorous algorithms

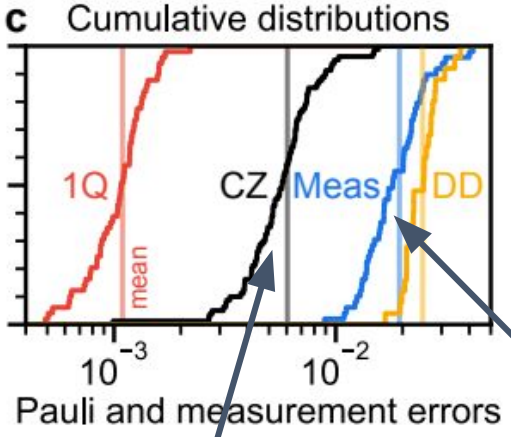


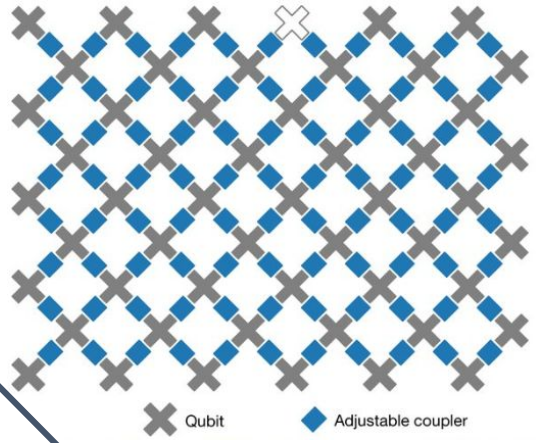
Applications

- Factoring
- Simulation of quantum systems
- Solution of linear systems

Motivation

Google Sycamore





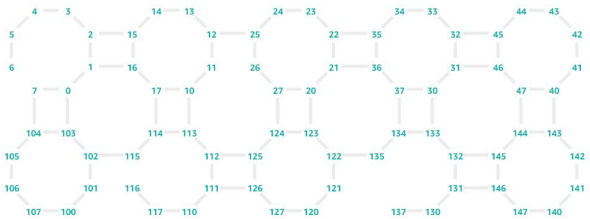
2 qubit gate errors

Readout errors

[Source: Google Quantum AI]

Rigetti Aspen-M-3

Qubit	Fidelity (simultaneous RB)	Readout fidelity
0	99.590 ± 0.014	92.900
1	98.749 ± 0.049	87.100
2	99.711 ± 0.015	94.100



1 qubit gate errors

Readout errors

[Source: AWS Braket]

Classical Model of Readout Noise

IDEAL SIGNAL

$$\vec{P}_{ideal}$$

READOUT NOISE

CORRUPTED SIGNAL

$$\vec{P}_{noisy} = \Lambda \vec{P}_{ideal}$$

[Source: Rigetti Computing]

Classical Model of Readout Noise

[Source: Rigetti Computing]

IDEAL SIGNAL

$$\vec{P}_{ideal}$$

READOUT NOISE

CORRUPTED SIGNAL

$$\vec{P}_{noisy} = \Lambda \vec{P}_{ideal}$$

Issues: exponential complexity of

- Description of noise
- Characterization of errors

Classical Model of Readout Noise

[Source: Rigetti Computing]

IDEAL SIGNAL

$$\vec{P}_{ideal}$$

READOUT NOISE

CORRUPTED SIGNAL

$$\vec{P}_{noisy} = \Lambda \vec{P}_{ideal}$$

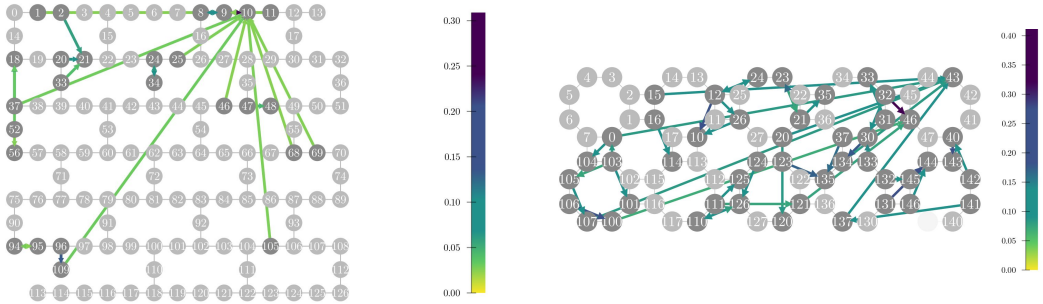
Error mitigation

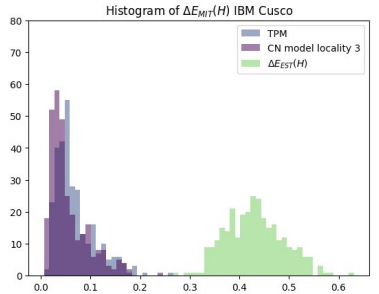
1. Compute Λ^{-1}
2. Estimate $\vec{P}_{ideal} = \Lambda^{-1}\vec{P}$

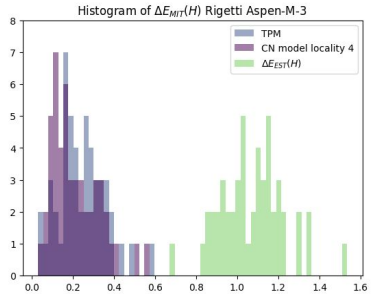
Certification and error mitigation platform for quantum computers

Readout errors characterization module

Readout errors mitigation module

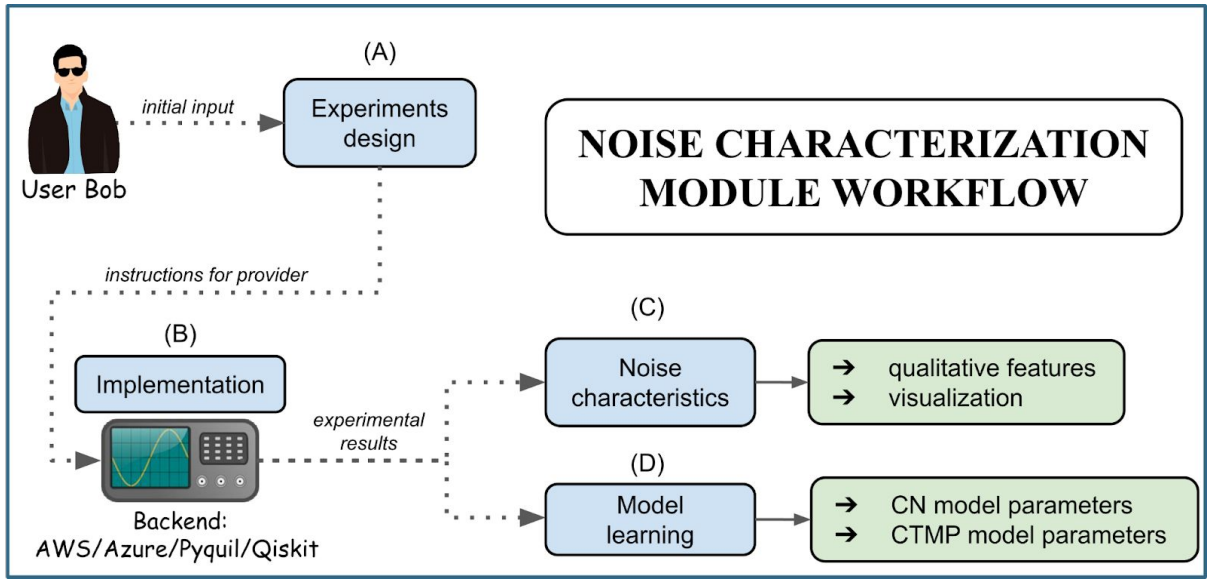




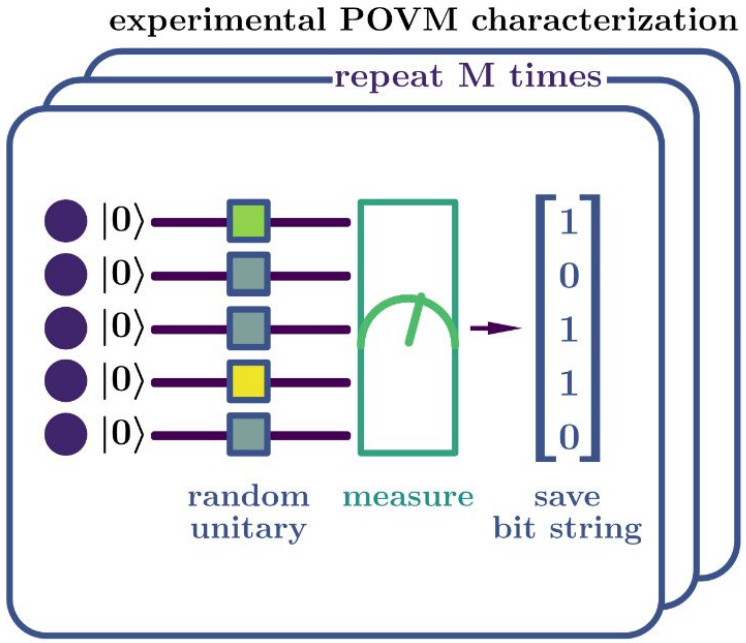


25% improvement in results accuracy for MAX-2-SAT problems on Rigetti and IBM devices

Readout errors characterization module



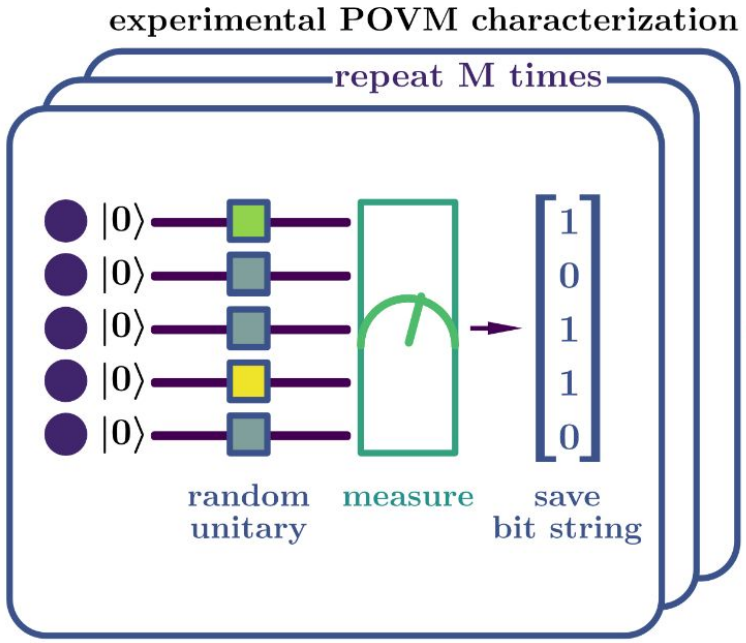
Experiments design



Parallel detector tomography protocol
Required number of circuits

$$M \sim \frac{1}{\epsilon^2} \exp(k) \log(N)$$

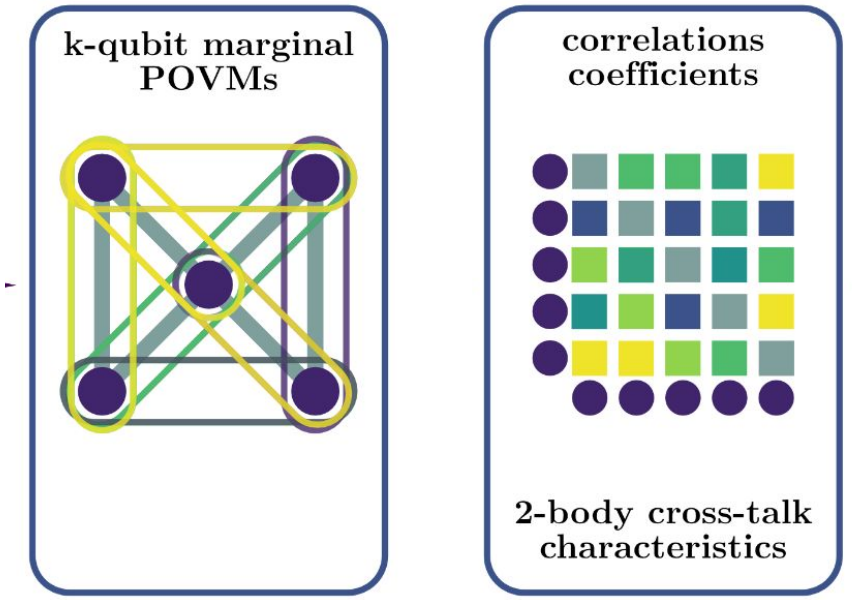
Experiments implementation



Support for implementation:

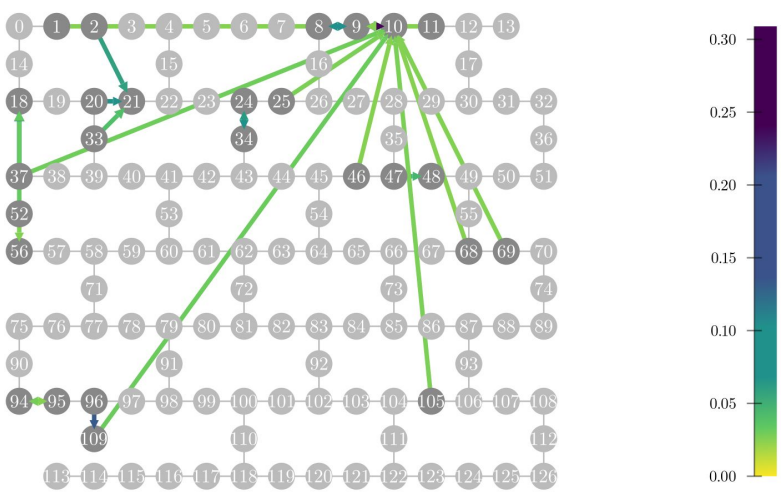
- IBM (via IBM Quantum)
- Rigetti (via AWS)

Noise characteristics

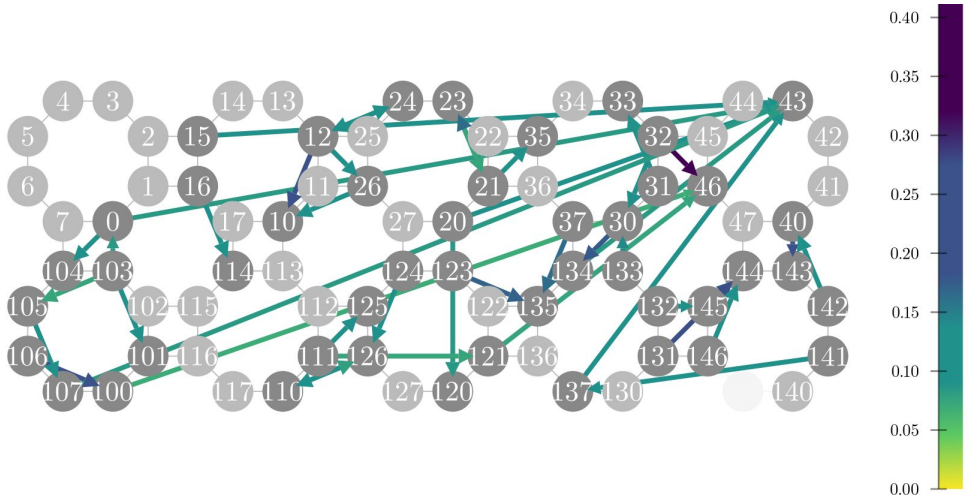


Versatile set of tools for readout noise error characterization

Noise characteristics



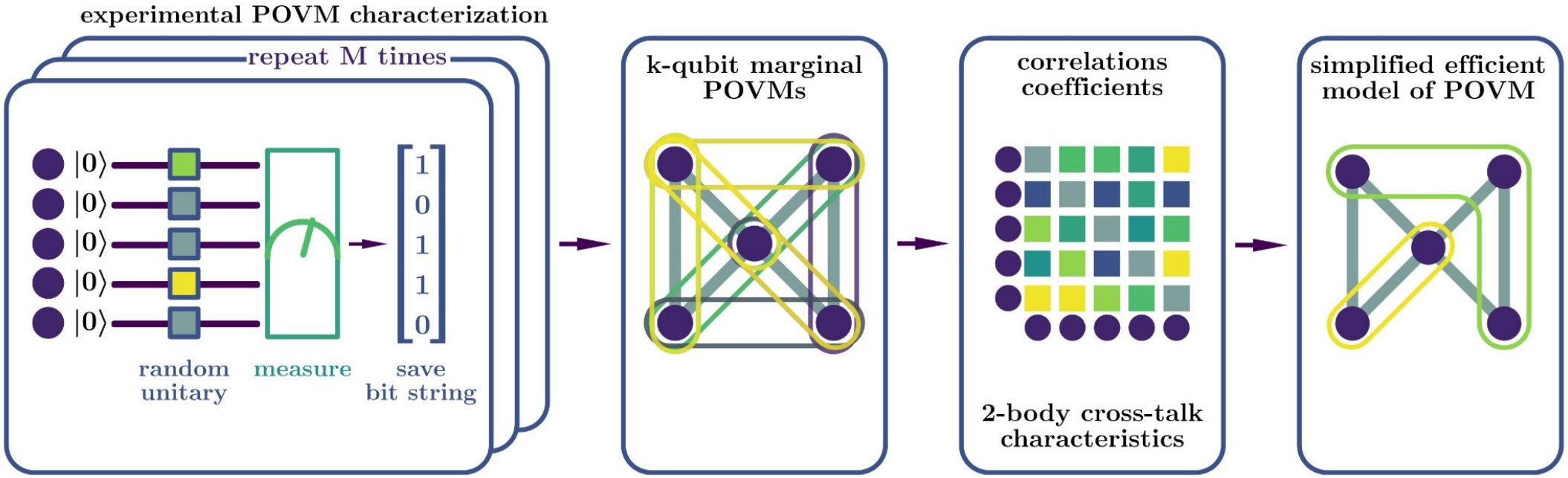
IBM Cusco



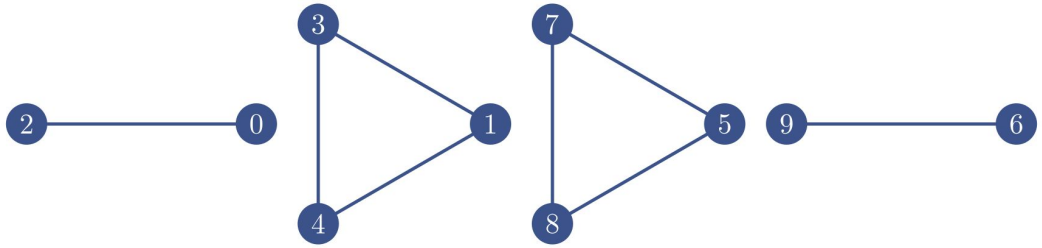
Rigetti ASPEN-M-3

Pairwise correlations in readout noise

Noise model reconstruction



Local noise models

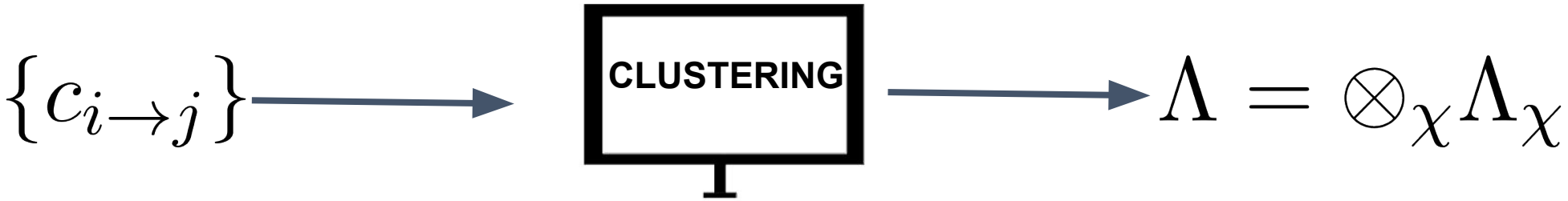


$$C_{\chi 0} \quad C_{\chi 1} \quad C_{\chi 2} \quad C_{\chi 3}$$

$$\Lambda = \otimes_{\chi} \Lambda_{\chi}$$

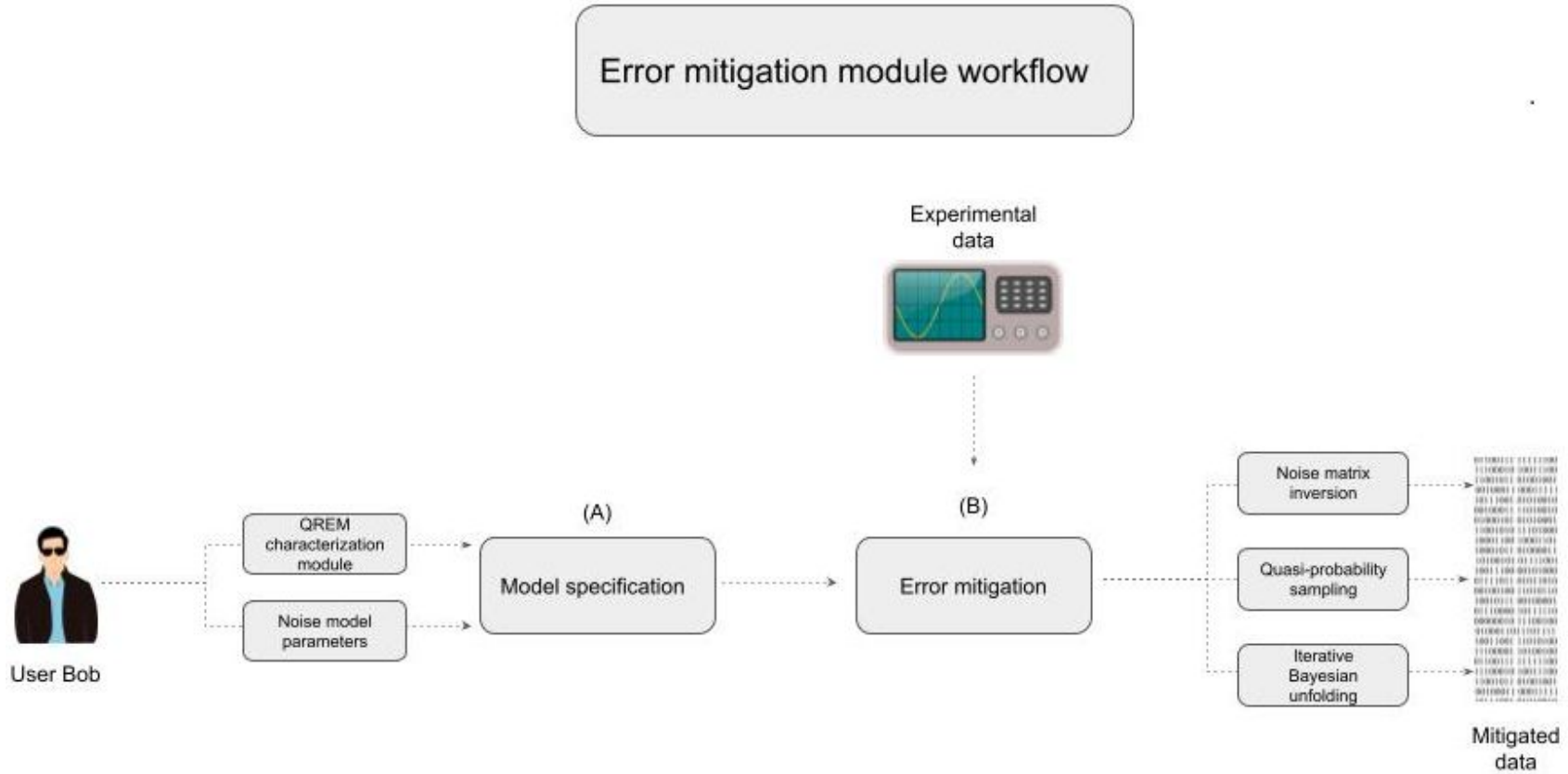
Efficient noise model reconstruction algorithm

Local noise models



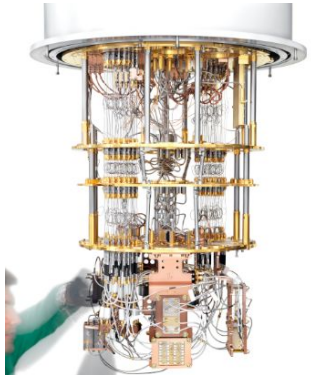
Pairwise correlations are input data for clustering algorithm

Readout noise model mitigation module



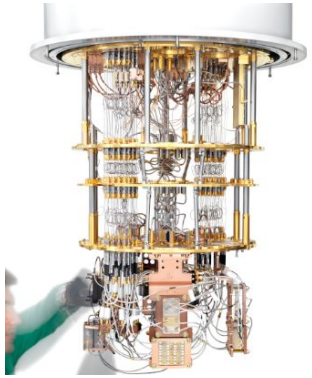
Readout noise model mitigation module

TASK: Energy estimation for random MAX-2-SAT

Specify input data → **Run quantum machine** →  → **Collect data Mitigate errors** → Λ^{-1} → **Output energy estimate**

Readout noise model mitigation module

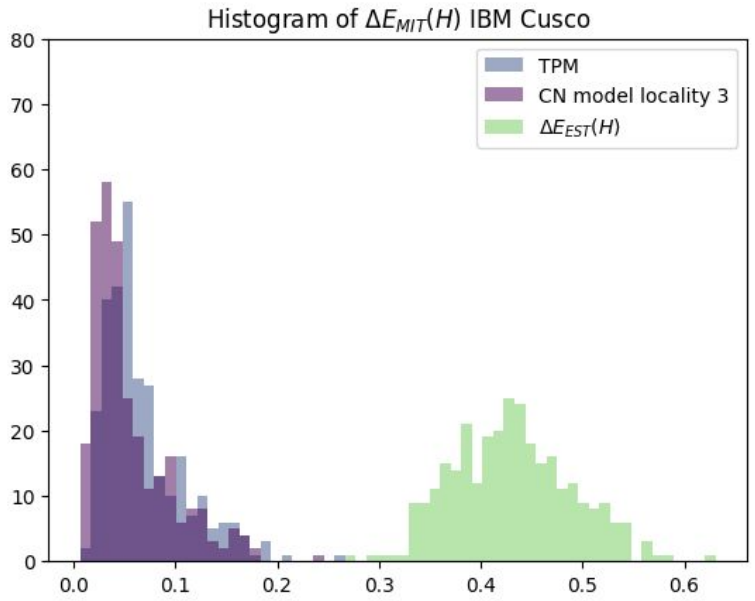
TASK: Energy estimation for random MAX-2-SAT

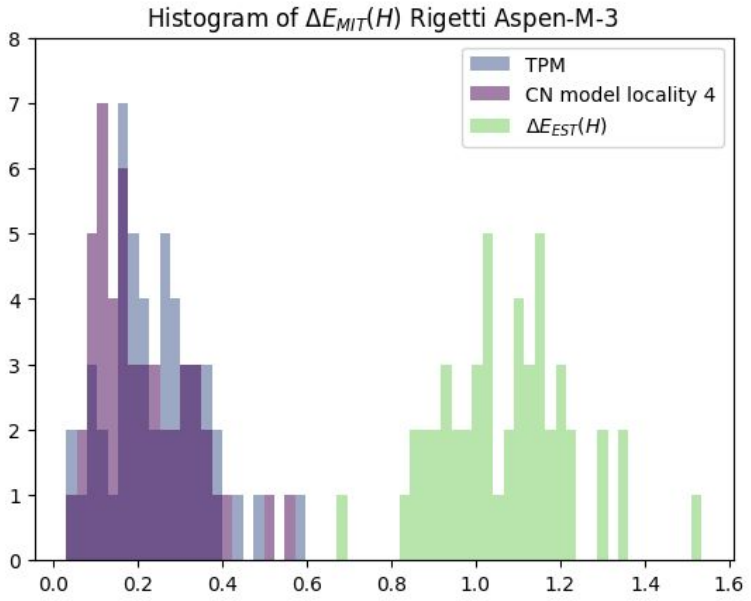
Specify input data → **Run quantum machine** →  → **Collect data Mitigate errors** → Λ^{-1} → **Output energy estimate** → **Quantify Mitigation Error**

Compute energy on a classical computer

Readout noise model mitigation module

TASK:Solution of MAX-2-SAT problem





No mitigation

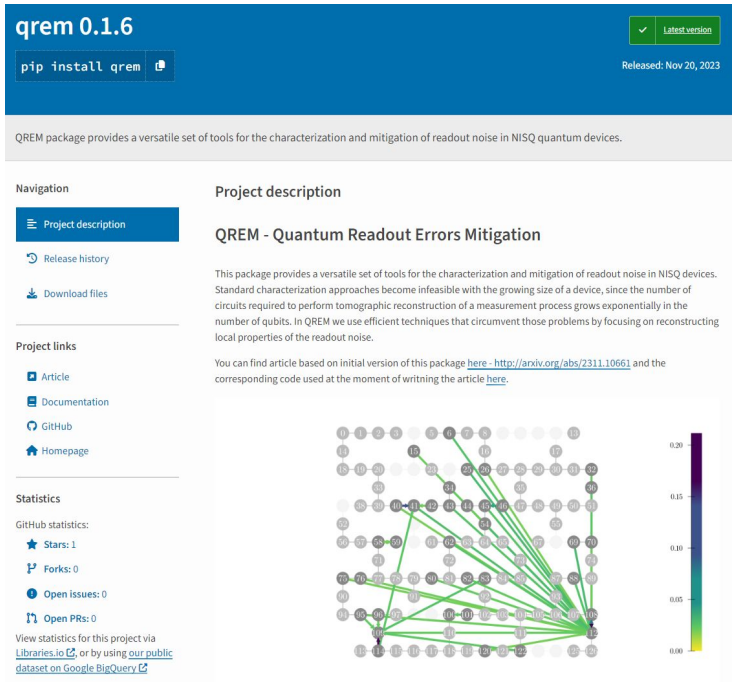
Mitigation (no correlations)

Mitigation (with correlations)

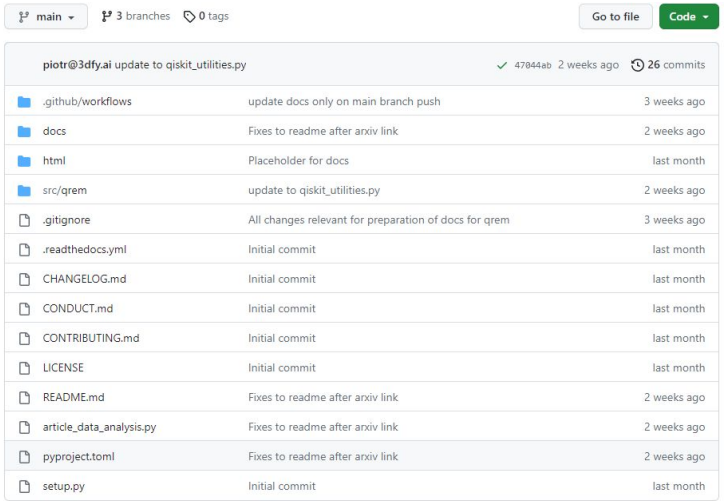
25% improvement in results accuracy for IBM and Rigetti devices

Readout noise model mitigation module

PyPI



GitHub



Theory

Efficient reconstruction, benchmarking and validation of cross-talk models in readout noise in near-term quantum devices

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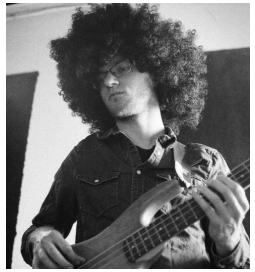
(Dated: November 20, 2023)

Readout errors contribute significantly to the overall noise affecting present-day quantum computers. However, the complete characterization of generic readout noise is infeasible for devices consisting of a large number of qubits. Here we introduce an appropriately tailored quantum detector tomography protocol, the so called Quantum Detector Overlapping Tomography, which enables efficient characterization of $k-$local cross-talk effects in the readout noise as the sample complexity of the protocol scales logarithmically with the total number of qubits. We show that QDOT data provides information about suitably defined reduced POVM operators, correlations and coherences in the readout noise, as well as allows to reconstruct the correlated clusters and neighbours readout noise model. Benchmarks are introduced to verify utility and accuracy of the reconstructed model. We apply our method to investigate cross-talk effects on 79 qubit Rigetti and 127 qubit IBM devices. We discuss their readout noise characteristics, and demonstrate effectiveness of our approach by showing superior performance of correlated clusters and neighbours over models without cross-talk in model-based readout error mitigation applied to energy estimation of MAX-2-SAT Hamiltonians, with the improvement on the order of 20% for both devices.

Development team

J. Majsak



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