



EuroHPC PL

National Supercomputing Infrastructure for EuroHPC

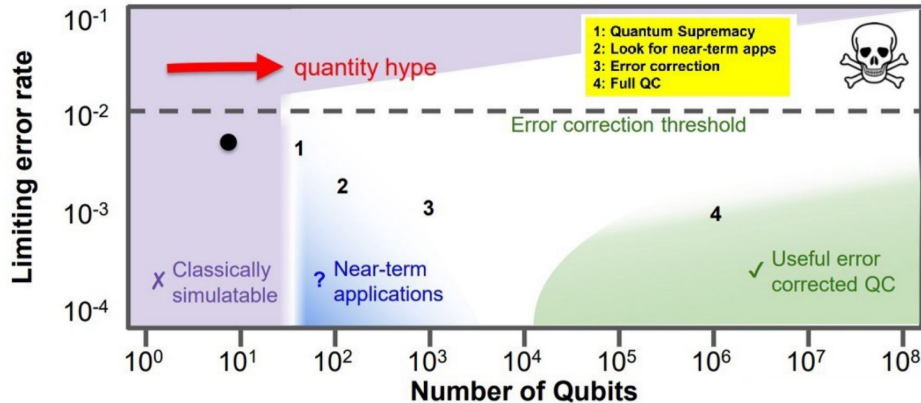
Certification and error mitigation platform for quantum computers

J. Tuziemski, F. Maciejewski, O. Słowik, J. Majsak, M. Kotowski, P. Podziemski, K Kowalczyk - Murynka, M. Oszmaniec CFT PAS

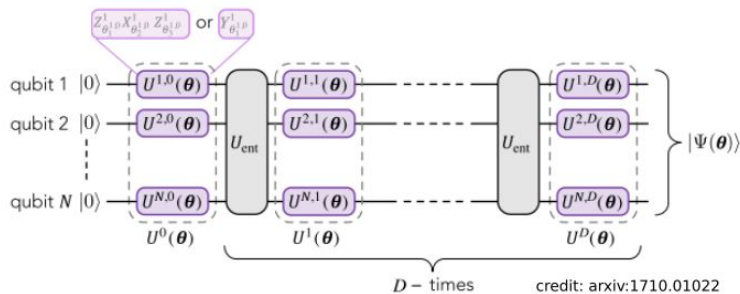




Motivation



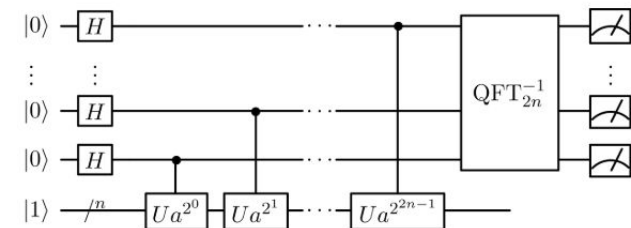
Heuristic algorithms



Applications:

- Optimization
- Quantum chemistry
- Machine learning

Rigorous algorithms



credit: Wikipedia

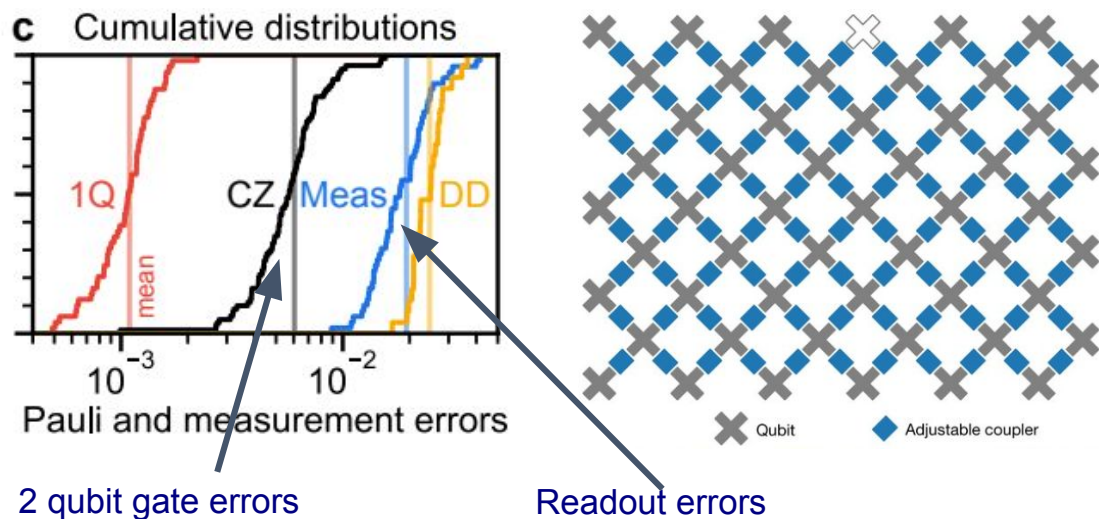
Applications

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



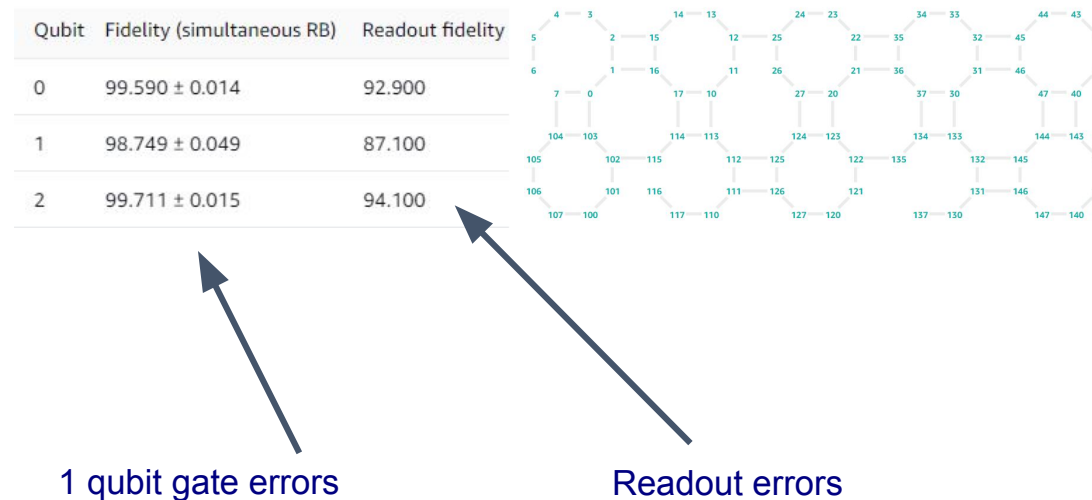
Motivation

Google Sycamore



[Source: Google Quantum AI]

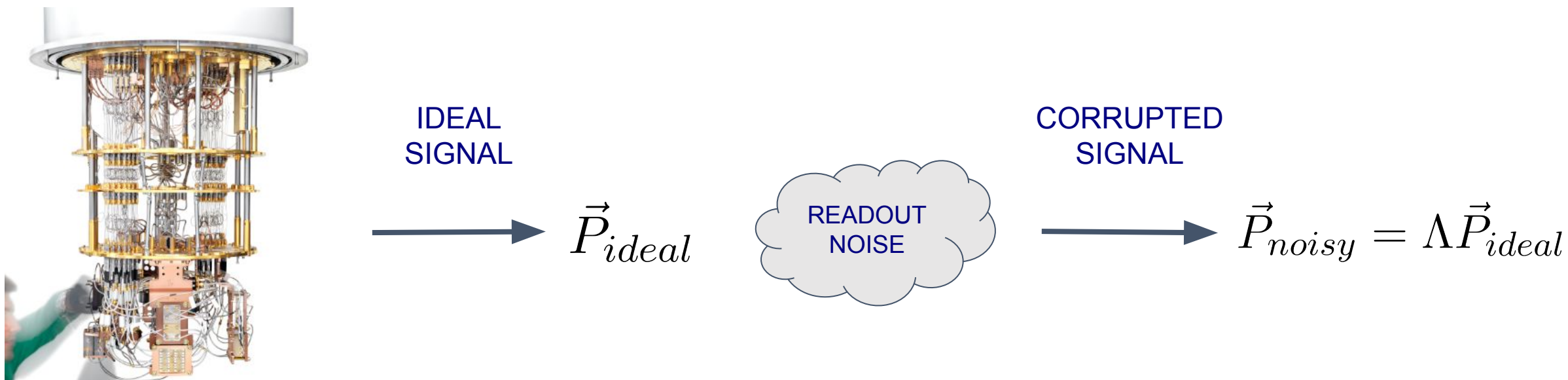
Rigetti Aspen-M-3



[Source: AWS Braket]



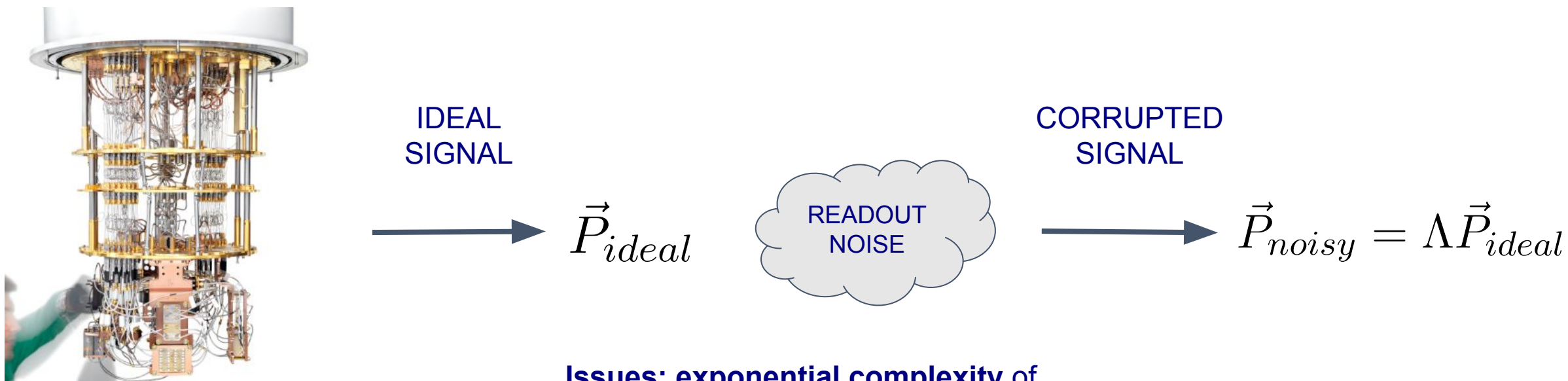
Classical Model of Readout Noise



[Source: Rigetti Computing]



Classical Model of Readout Noise



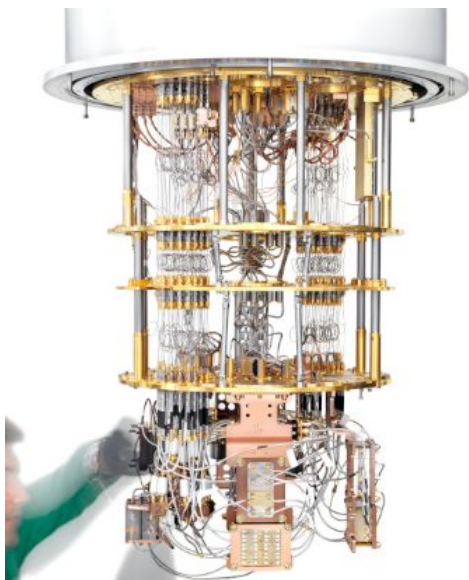
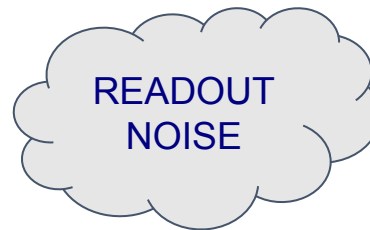
Issues: exponential complexity of

- Description of noise
- Characterization of errors

[Source: Rigetti Computing]



Classical Model of Readout Noise

IDEAL
SIGNAL
 \vec{P}_{ideal}
CORRUPTED
SIGNAL
 $\vec{P}_{noisy} = \Lambda \vec{P}_{ideal}$

Error mitigation

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

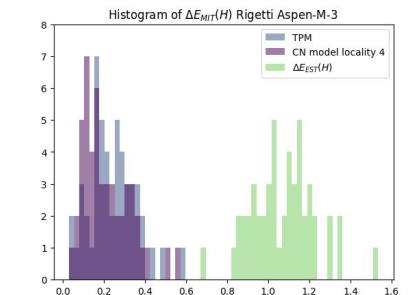
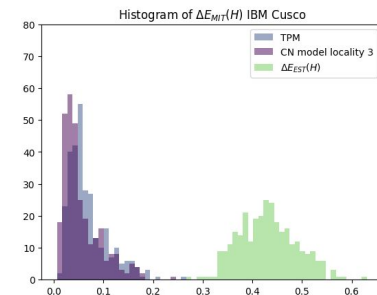
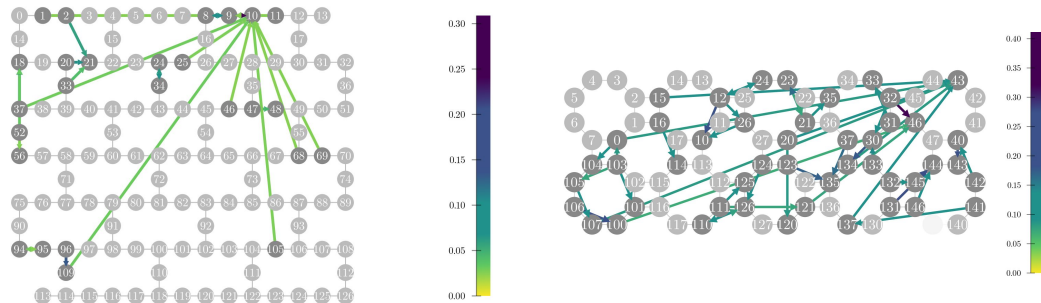
[Source: Rigetti Computing]



Certification and error mitigation platform for quantum computers

Readout errors characterization module

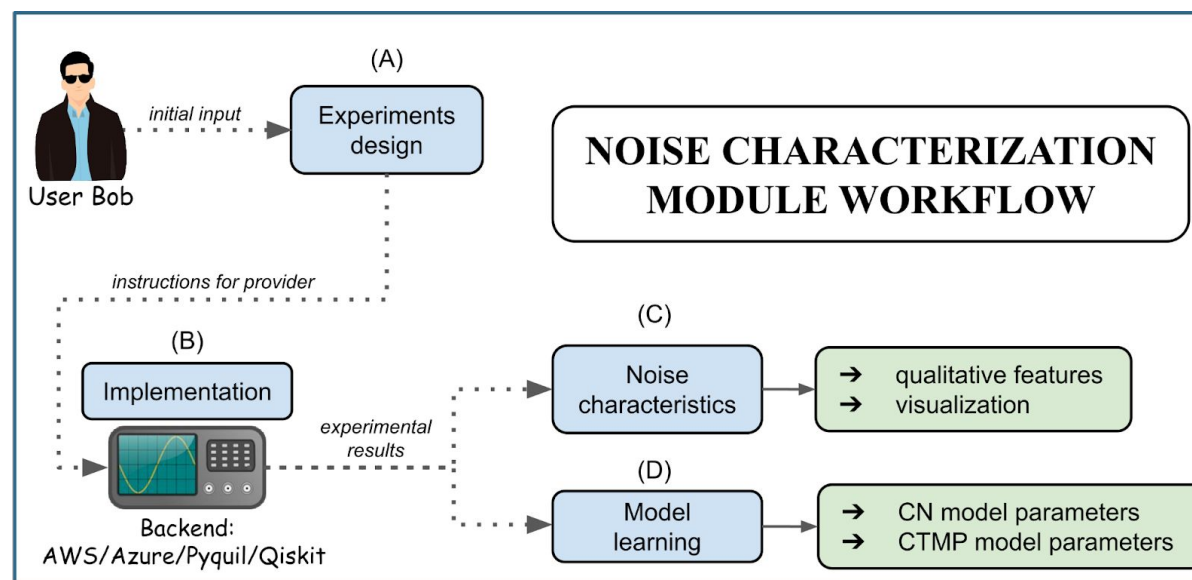
Readout errors mitigation module



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

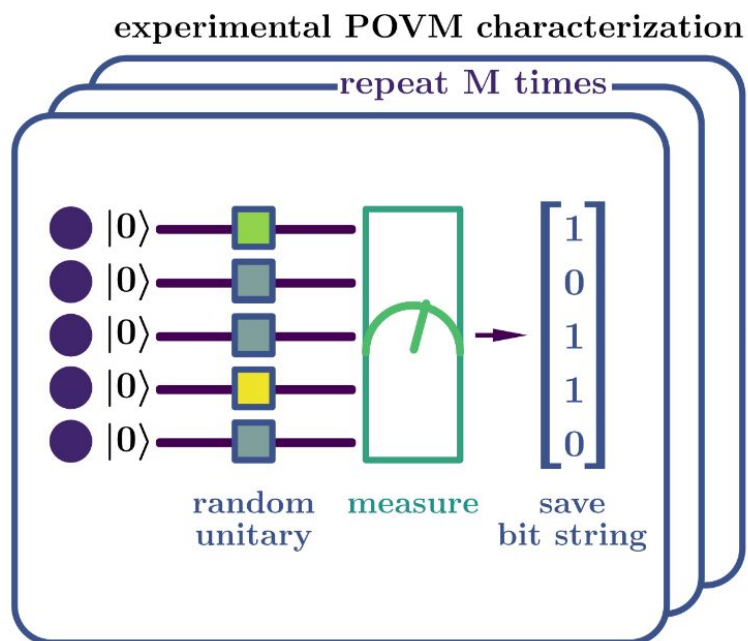


Readout errors characterization module





Experiments design

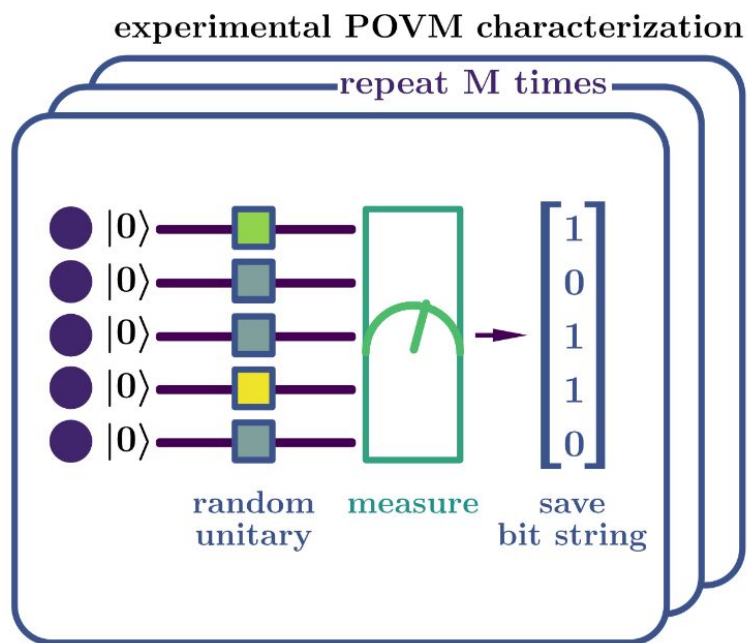


Parallel detector tomography protocol
Required number of circuits

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



Experiments implementation

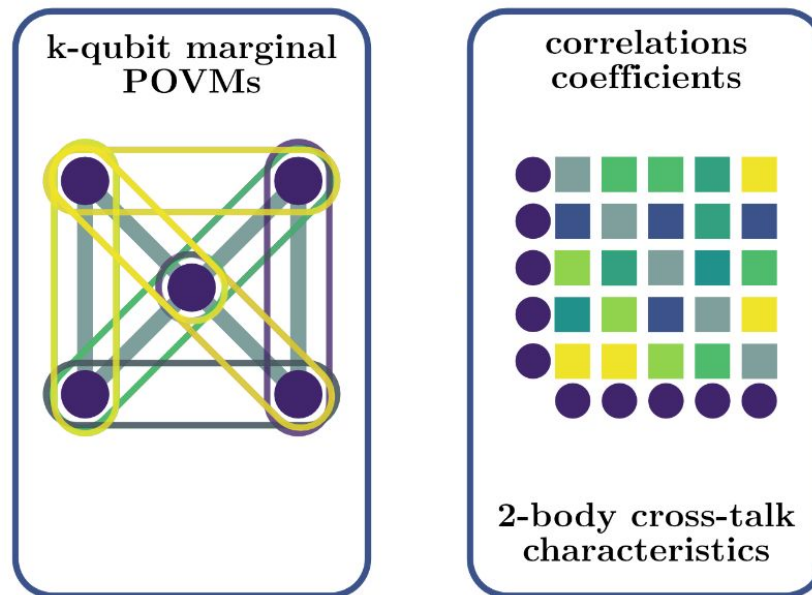


Support for implementation:

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



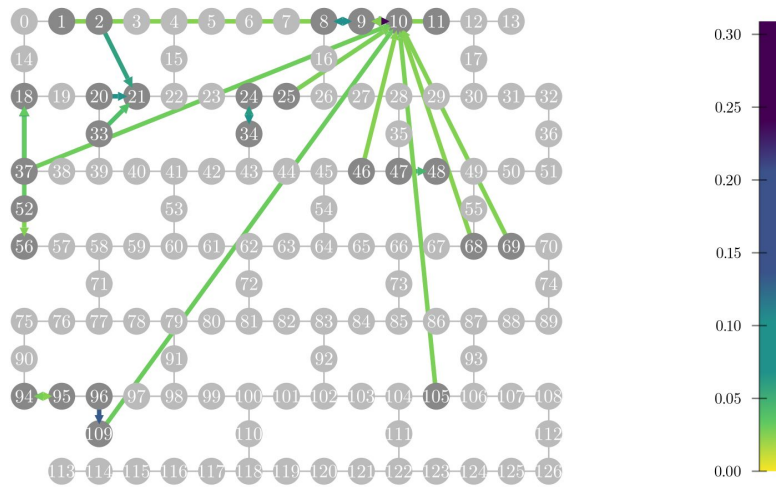
Noise characteristics



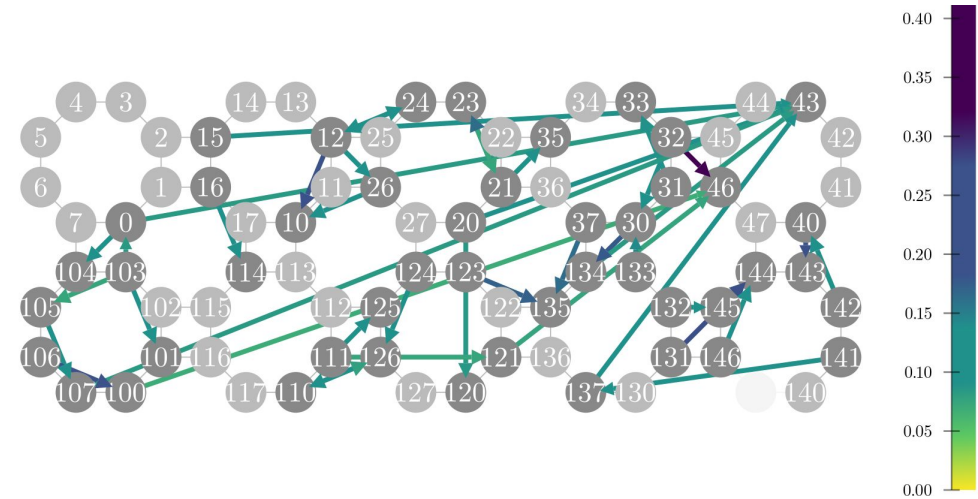
Versatile set of tools for readout noise error characterization



Noise characteristics



IBM Cusco

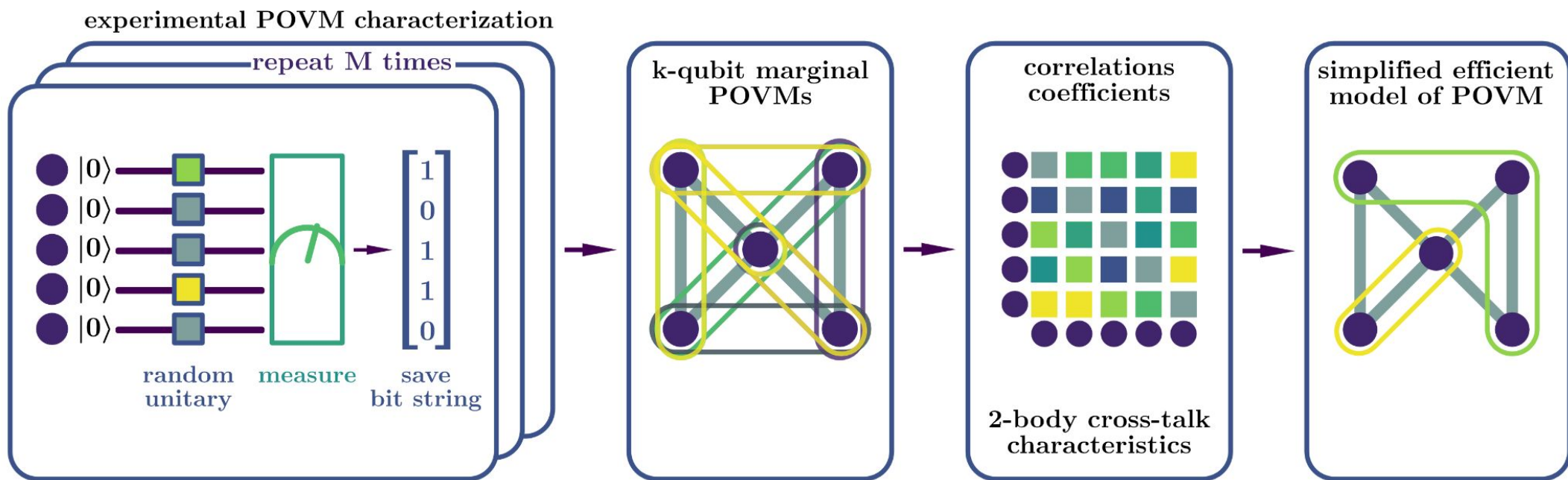


Rigetti ASPEN-M-3

Pairwise correlations in readout noise

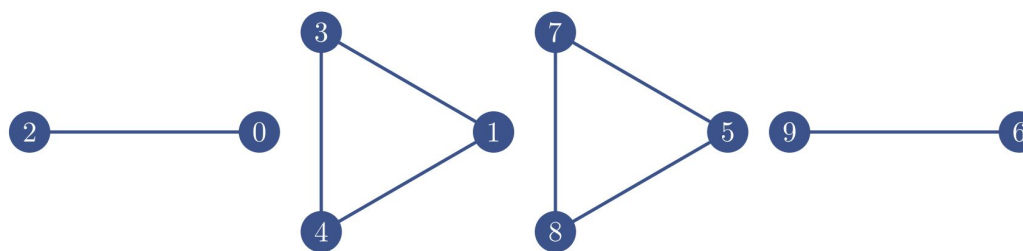


Noise model reconstruction





Local noise models



C_{χ_0}

C_{χ_1}

C_{χ_2}

C_{χ_3}

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

Efficient noise model reconstruction
algorithm



Local noise models

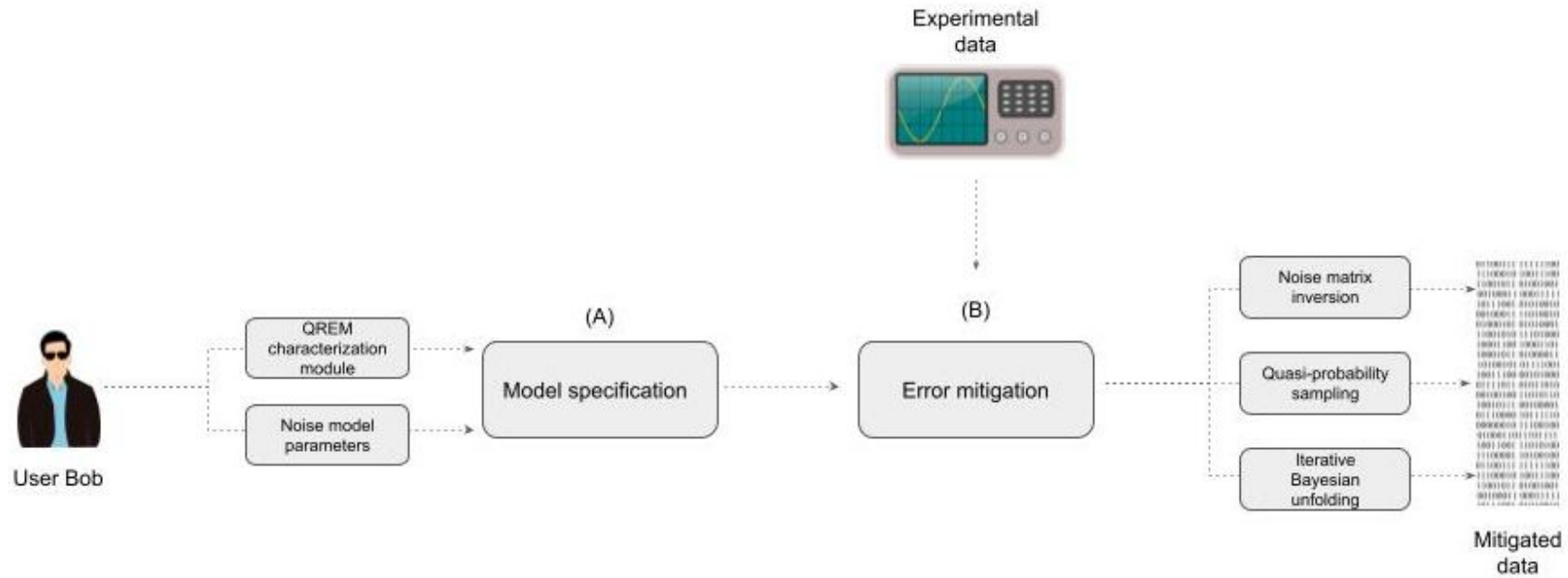


Pairwise correlations are input data for clustering algorithm



Readout noise model mitigation module

Error mitigation module workflow





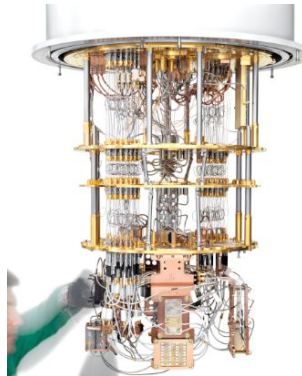
Readout noise model mitigation module

TASK: Energy estimation for random MAX-2-SAT

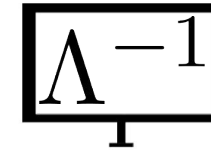
Specify
input data



Run quantum
machine



Collect data
Mitigate errors

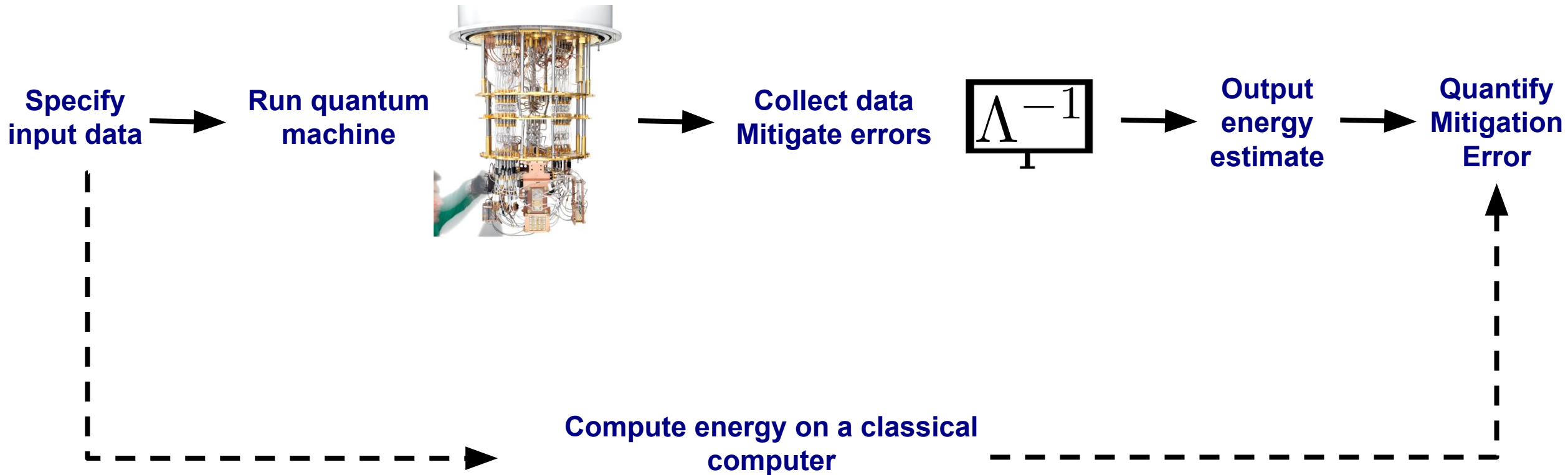


Output
energy
estimate



Readout noise model mitigation module

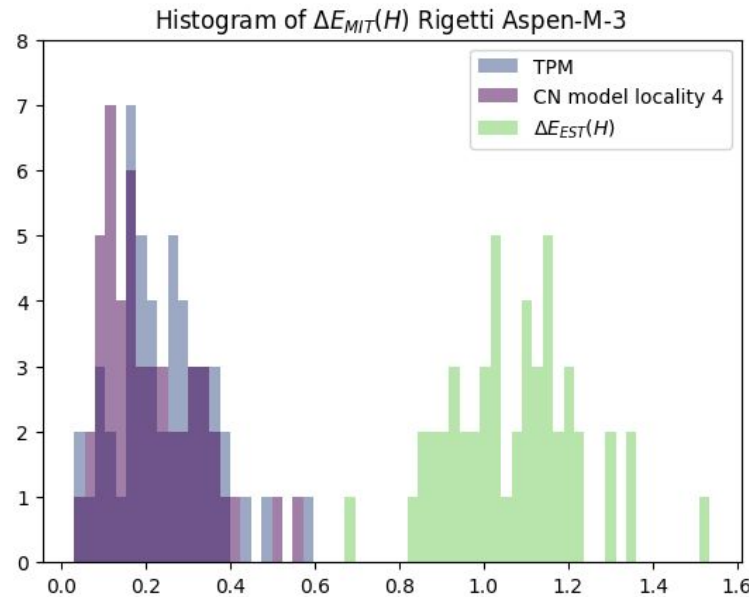
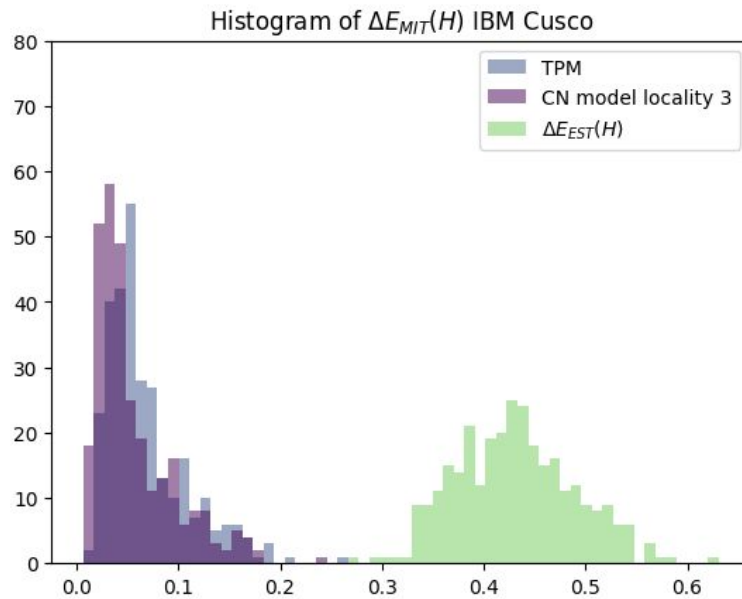
TASK: Energy estimation for random MAX-2-SAT





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

qrem 0.1.6 ✓ Latest version

`pip install qrem` Released: Nov 20, 2023

QREM package provides a versatile set of tools for the characterization and mitigation of readout noise in NISQ quantum devices.

Navigation

- Project description
- Release history
- Download files

Project links

- Article
- Documentation
- GitHub
- Homepage

Statistics

GitHub statistics:

- Stars: 1
- Forks: 0
- Open issues: 0
- Open PRs: 0

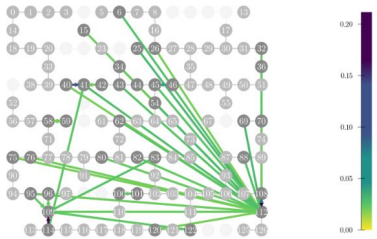
View statistics for this project via [Libraries.io](#), or by using [our public dataset on Google BigQuery](#)

Project description

QREM - Quantum Readout Errors Mitigation

This package provides a versatile set of tools for the characterization and mitigation of readout noise in NISQ devices. Standard characterization approaches become infeasible with the growing size of a device, since the number of circuits required to perform tomographic reconstruction of a measurement process grows exponentially in the number of qubits. In QREM we use efficient techniques that circumvent those problems by focusing on reconstructing local properties of the readout noise.

You can find article based on initial version of this package [here - http://arxiv.org/abs/2311.10661](http://arxiv.org/abs/2311.10661) and the corresponding code used at the moment of writing the article [here](#).



GitHub

main 3 branches 0 tags Go to file Code

piotr@3dfyai update to qiskit_utilities.py ✓ 47844ab 2 weeks ago 26 commits

.github/workflows	update docs only on main branch push	3 weeks ago
docs	Fixes to readme after arxiv link	2 weeks ago
html	Placeholder for docs	last month
src/qrem	update to qiskit_utilities.py	2 weeks ago
.gitignore	All changes relevant for preparation of docs for qrem	3 weeks ago
.readthedocs.yml	Initial commit	last month
CHANGELOG.md	Initial commit	last month
CONDUCT.md	Initial commit	last month
CONTRIBUTING.md	Initial commit	last month
LICENSE	Initial commit	last month
README.md	Fixes to readme after arxiv link	2 weeks ago
article_data_analysis.py	Fixes to readme after arxiv link	2 weeks ago
pyproject.toml	Fixes to readme after arxiv link	2 weeks ago
setup.py	Initial commit	last month

Theory

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

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²Research Institute for Advanced Computer Science (RIACS), USRA, Moffett Field, CA, USA
³Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE
⁴Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland
⁵NASK National Research Institute, Kolska 12, 01-045 Warsaw, Poland*
 (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



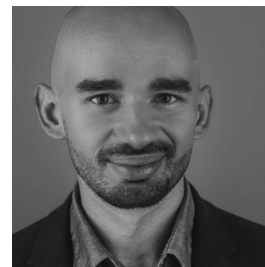
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M. Kotowski



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P. Podziemski



J. Tuziemski



M. Oszmaniec

Former members



F. Maciejewski



O. Słowik