Qiskit QCBMs
Checkpoint 2 report

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Abstract

We describe our progress in *Qiskit QCBMs*, a project where we develop a set of tools for the implementation of Quantum Circuit Born Machines within the Qiskit 2.x and Qiskit Patterns framework. This project is part of Qiskit Advocate Mentorship Program QAMP 2025.

1 The project in a Nutshell

Quantum Circuit Born Machines (QCBMs) are generative models in which the probability distribution of a dataset is represented in terms of a quantum state via Born's rule. QCBMs are known for their expressive power and have been widely recognized as a useful component in hybrid algorithms with a potential for quantum advantage.

Our aim is to take advantage of various tools in the Qiskit ecosystem in order to optimize QCBMs for their use in near term devises. Qiskit QCBMs is being developed as a qiskit add-on which will be accompanied by a set of notebooks both showcasing the tools through examples and serving as an introduction to the theory.

2 Workflow, progress and status of the project

Our team, consisting of two mentees together with one mentor, has held weekly meetings since the beginning of the program in October 2025.

At this point we have:

- Build a github repository where the code developed so far is hosted. The repo also contains a substantial amount of information on QCBMs and documents the evolution of the project:
`https://github.com/jorgeplazas/Qiskit-QCBMs`
- Reviewed the state of the art both in the literature and in avaliable projects which use QCBMs.
- Implemented a set of core and auxiliary functions.
- Ran various experiments and tests using simulators.
- Made first versions of the jupyter notebooks accompanying the project.
- Structured some of the tools within a documented module.

A word on Qiskit

The circuit part of a QCBM consist of two kinds of layers:

- Rotation layers.
- Entanglement layers.

This structure can be realized as an instance of the `efficient su2`[1] circuit in qiskit. Because of the above many of the choices made in the project reflect those underlying this type of circuit as the core component.

The training loop of the model consist of a series of passes where samples from states prepared by the circuit are taken. Because of this the `Sampler`[2] primitive plays a central role in the project.

Astrolabe

Three works have been specially relevant in guiding the route taken by the project:

1. The seminal work of Liu and Wang [3] where QCBMs are studied in depth.
2. The work ok Hamilton et. al. [2] which building upon the above work uses QCBMs to benchmark quantum computers.
3. The work of Ghazi Vakili et. al. [1] where new inhibitors for KRAS are discovered using a hybrid algorithm with a QCBM as its main quantum component.

From the first two we have taken our base-test examples for distributions to be learned by the models: Gaussian distributions and the distribution underlying the Bars and Stripes dataset. To these we have added the distribution of a sum-of-dice simulator.

The last reference was one of our initial motivations and contains a pipeline that we aim to improve.

3 Challenges

We are currently working towards a pipeline for testing our tools in real quantum hardware. Optimizing this for the resources that are available to us is for now the biggest challenge facing the project.

4 The path forward

Our work in the coming months will focus on four core aspects:

1. Run experiments and tests in quantum hardware.

[1] `https://quantum.cloud.ibm.com/docs/en/api/qiskit/qiskit.circuit.library.EfficientSU2`

[2] `https://quantum.cloud.ibm.com/docs/en/api/qiskit-ibm-runtime/sampler-v2`

2. Showcase the tools by implementing a model similar to the one used in [1].

3. Structure the tools developed as a quiskit add-on.

4. Write all the relevant documentation.

References

[1] Mohammad Ghazi Vakili, Christoph Gorgulla, Jamie Snider, AkshatKumar Nigam, Dmitry Bezrukov, Daniel Varoli, Alex Aliper, Daniil Polykovsky, Krishna M. Padmanabha Das, Huel Cox III, Anna Lyakisheva, Ardalan Hosseini Mansob, Zhong Yao, Lela Bitar, Danielle Tahoulas, Dora Čerina, Eugene Radchenko, Xiao Ding, Jinxin Liu, Fanye Meng, Feng Ren, Yudong Cao, Igor Stagljar, Alán Aspuru-Guzik, and Alex Zhavoronkov. Quantum-computing-enhanced algorithm unveils potential kras inhibitors. *Nature Biotechnology*, 43(12):1954–1959, Dec 2025.

[2] Kathleen E. Hamilton, Eugene F. Dumitrescu, and Raphael C. Pooser. Generative model benchmarks for superconducting qubits. *Phys. Rev. A*, 99:062323, Jun 2019.

[3] Jin-Guo Liu and Lei Wang. Differentiable learning of quantum circuit born machines. *Phys. Rev. A*, 98:062324, Dec 2018.