Laboratorio di computazione quantistica
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Quantum Research - CERN

CERN IT INNOVATION

ANNNI model noisy dynamics

Time Evolution

$$\mathcal{H} = -J_1 \sum_{i=1}^{N} \sigma_x^i \sigma_x^{i+1} - \kappa\, \sigma_x^i \sigma_x^{i+2} - h\, \sigma_z^i$$

$$\kappa \equiv J_1/J_2$$

$$h \equiv \mu/J_1$$

TO DO:

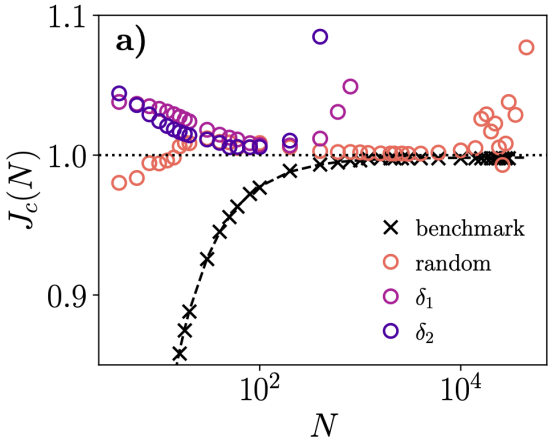
- Encode the full hamiltonian of the Axial Next Nearest Neighbor Ising model for N>2
- Compute the time evolution for total magnetization or another observable
- Compare noiseless and noisy result
- Apply error mitigation

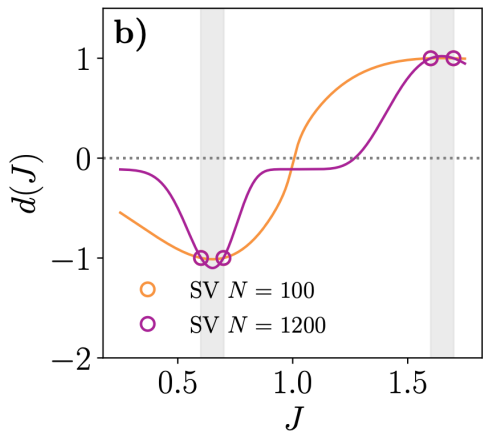
- Reference:
- https://arxiv.org/pdf/2208.08748.pdf
- https://github.com/orielkiss/qiskit-research/blob/DSV_tutorial/qiskit_research/DSV/tutorial_DSV.ipynb

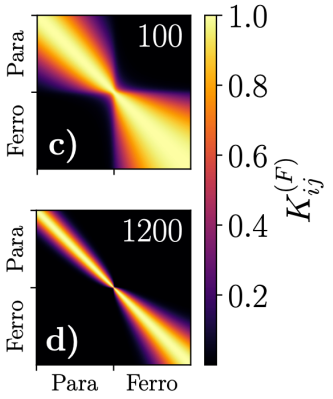
Support Vector Machine to learn Quantum Phase Transitions

QML

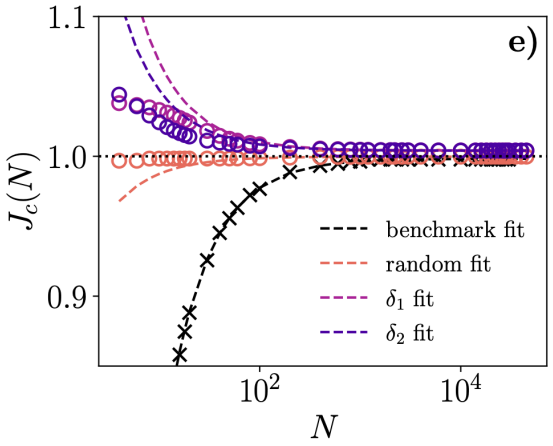
$K^{(F)}$

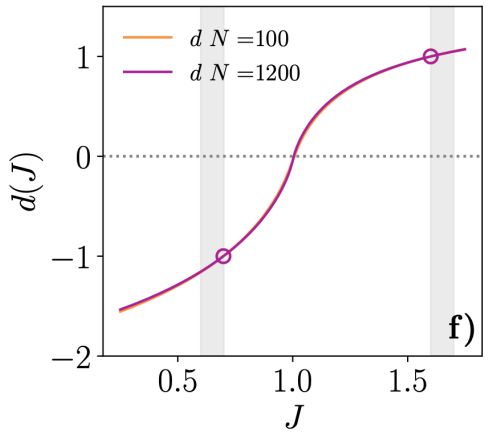


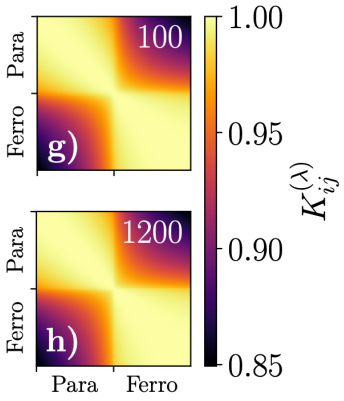




$K^{(\lambda)}$







- Reference:
- https://arxiv.org/pdf/2109.02686.pdf

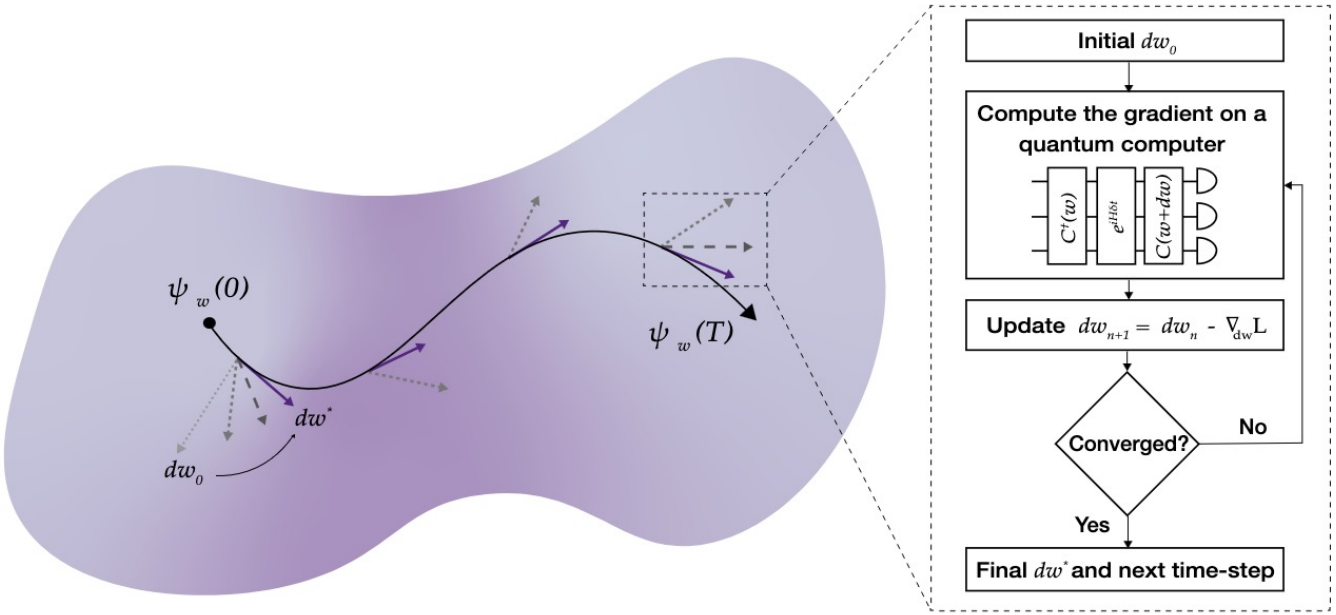
TO DO:

- Classification of different phases for the diagram of transverse field Ising chain:
- Compare classic and quantum SVM
- 1: reproduce the result from the paper for the 'standard' fidelity
- 2: try to discuss and implement the 'fidelity per site' classifier
- Consideration can be done on the scaling with N, with the critical region and eventually noisy simulation.

Projected-Variational Quantum Dynamics

Time Evolution

hybrid algorithm to simulate the real-time evolution of quantum systems using parameterized quantum circuits.



- Reference:
- https://quantum-journal.org/papers/q-2021-07-28-512/pdf/
- https://arxiv.org/pdf/2307.03229.pdf
- https://qiskit.org/ecosystem/algorithms/tutorials/10_pvqd.html

TO DO (different directions):

- starting from EQ2 of https://journals.aps.org/prd/pdf/10.1103/PhysRevD.108.123010

$$\hat{H}_{\nu\nu} \rightarrow \hat{H}^{\mathrm{ax}}_{\nu\nu} = \frac{\mu}{2N} \sum_{i<j} (1 - v_{z,i} v_{z,j}) \hat{\vec{\sigma}}_i \cdot \hat{\vec{\sigma}}_j .$$

Perform the trotterized time evolution of the Hamiltonian, split one trotter step when the Hamiltonian is large with P-VQD

- train on noise model and hardware and using error mitigation

Classification of fraud data

QML

TO DO:

- Implement a quantum algorithm for Fraud detection (classifier). Compare and/or discuss kernel based vs variational quantum algorithm. Benchmark the algorithm with (possibly) the best classic one

- Reference:
- Dataset: https://www.kaggle.com/datasets/nelgiriyewithana/credit-card-fraud-detection-dataset-2023
- https://arxiv.org/pdf/2109.02686.pdf

Example Applications

Quantum **Support Vector Machines** for **classification**

Quantum **Tree Tensor Networks** for pattern recognition

Quantum **Generative Adversarial Networks simulation**

Quantum **Boltzman Machines** and reinforcement learning

Hybrid **quantum-classical data embedding**

Thanks!

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