Learning Properties from Quantum Systems

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overview

- Introduction
- Classical shadows
- Fermionic computing
- Shallow Fermionic shadow

overview

- Introduction
  - Learning properties from quantum systems
  - Quantum state tomography (QST)
  - Drawbacks of QST
- Classical shadows
- Fermionic shadows
- Shallow Fermionic shadow

Hook

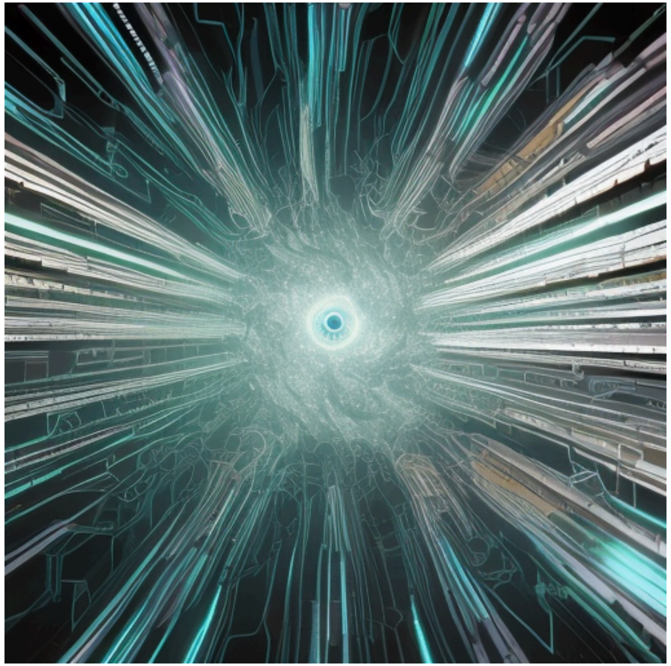

Figure 1: AI generation: Learning Properties from Quantum Systems

Problem: After we manipulating the quantum systems, how can we know certain properties of the system? Say $\mathrm{tr}(O\rho)$.

Quantum State Tomography

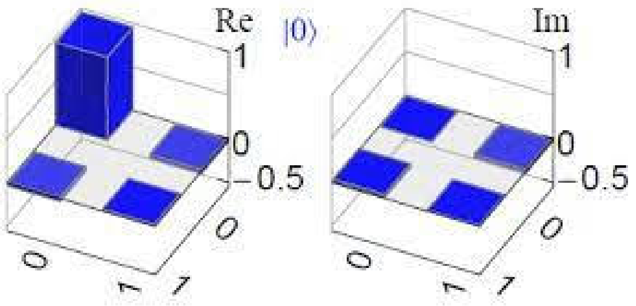

Figure 2: illustrating QST
(a figure from bing)

A solution in stone age:
Quantum state tomography[1]

Expanding state in Pauli basis
Extracting information by insane measurement.

$$\rho = \frac{1}{2^n} \sum c_i P_i, \quad c_i = \mathrm{tr}(\rho P_i), \quad P_i \in \mathcal{P}_n$$

Drawbacks of QST

- A theorem promise that **the number of measurements is exponential** to the number of qubits if we want to get the full information of the quantum state.

- A way out
  - learn "main information" rather than "full information"
  - Example: If we only care $\mathrm{tr}(\rho Z)$, we only need to measure Z basis.

$$\mathrm{tr}\left(\frac{I+Z}{2}\right) = \mathrm{tr}\left(\frac{I+Z+X}{2}\right)$$

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  - Shadow protocol
  - Shallow shadows
- Fermionic shadows
- Shallow Fermionic shadow

Classical Shadows Protocol

Classical shadows [2]: Using random shadows (or projections, sections) to predict the expectation value.

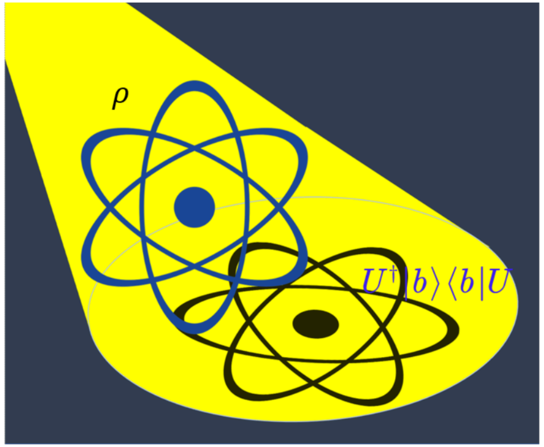
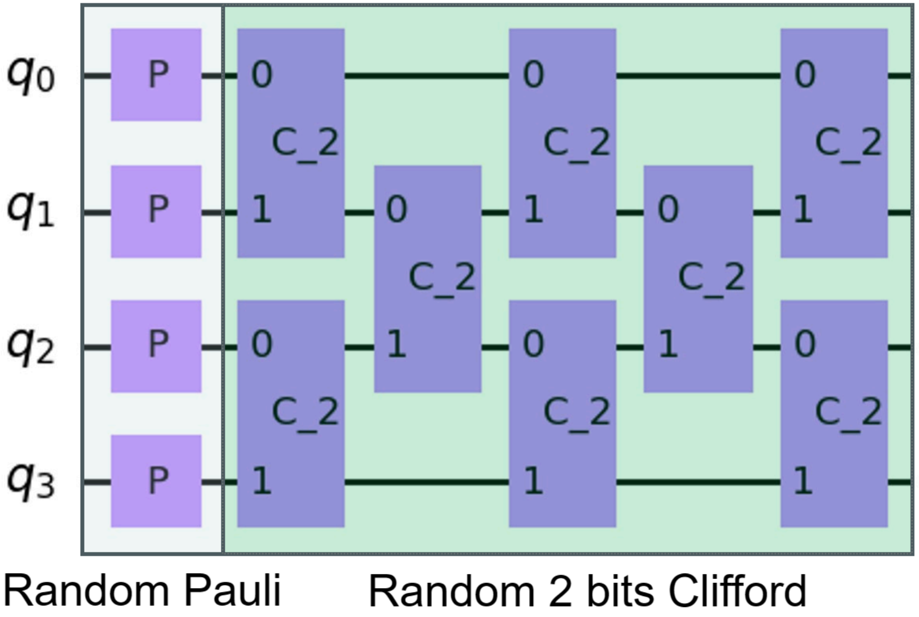


Figure 3: (pennylane.ai)

- Randomly choose a Clifford gate U.
- Aplllly U to ρ, get $U\rho U^\dagger$
- Measure $U\rho U^\dagger$ in computational basis, get $|b\rangle$
- Undo the U, get $U^\dagger|b\rangle\langle b|U$ (shadows $\hat{\rho}$)
- using shadows to calculate the expectation value of O.

Drawbacks of Classical Shadows

The depth of the shadow protocol is $\mathcal{O}(n^2)$



Bibliography

[1] M. A. Nielsen and I. L. Chuang, “Quantum computation and quantum information,” Phys. Today, vol. 54, no. 2, p. 60–61, 2001.

[2] H.-Y. Huang, R. Kueng, and J. Preskill, “Predicting many properties of a quantum system from very few measurements,” Nature Physics, vol. 16, no. 10, pp. 1050–1057, 2020.