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UNIVERSITÀ DEGLI STUDI FIRENZE

Quantum-Enhanced Machine Learning for Classifying Quantum Phases of Matter

Mehran Khosrojerdi
mehran.khosrojerdi@unifi.it

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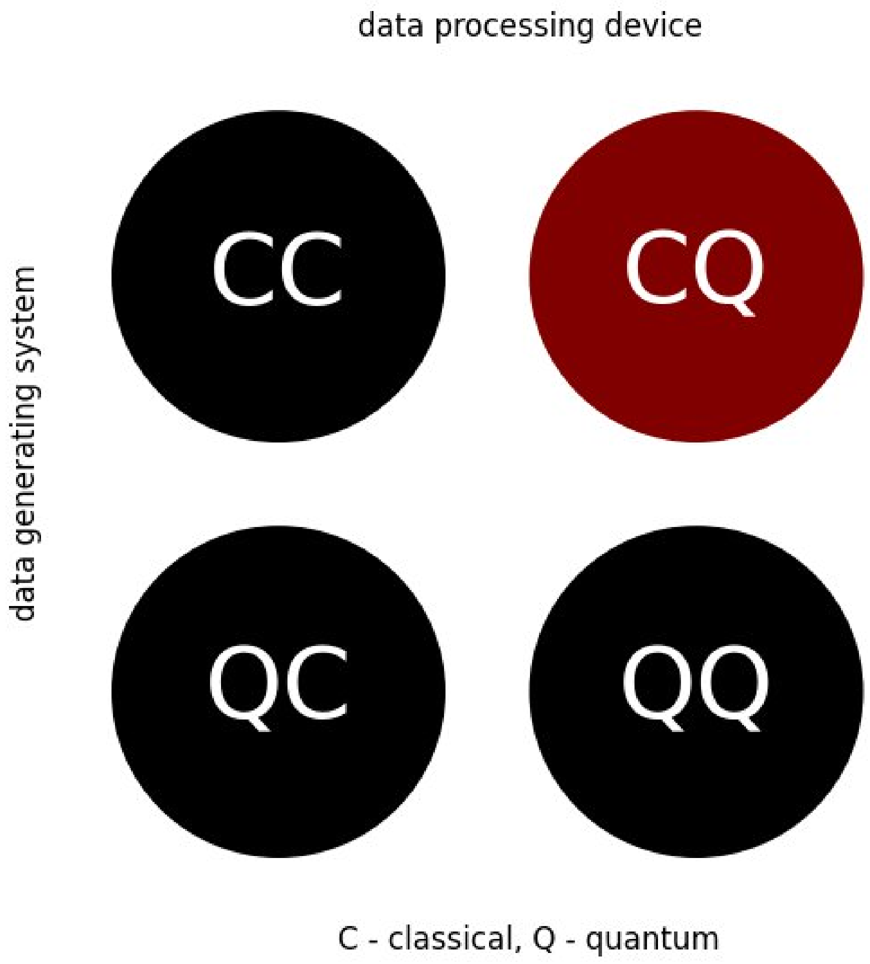
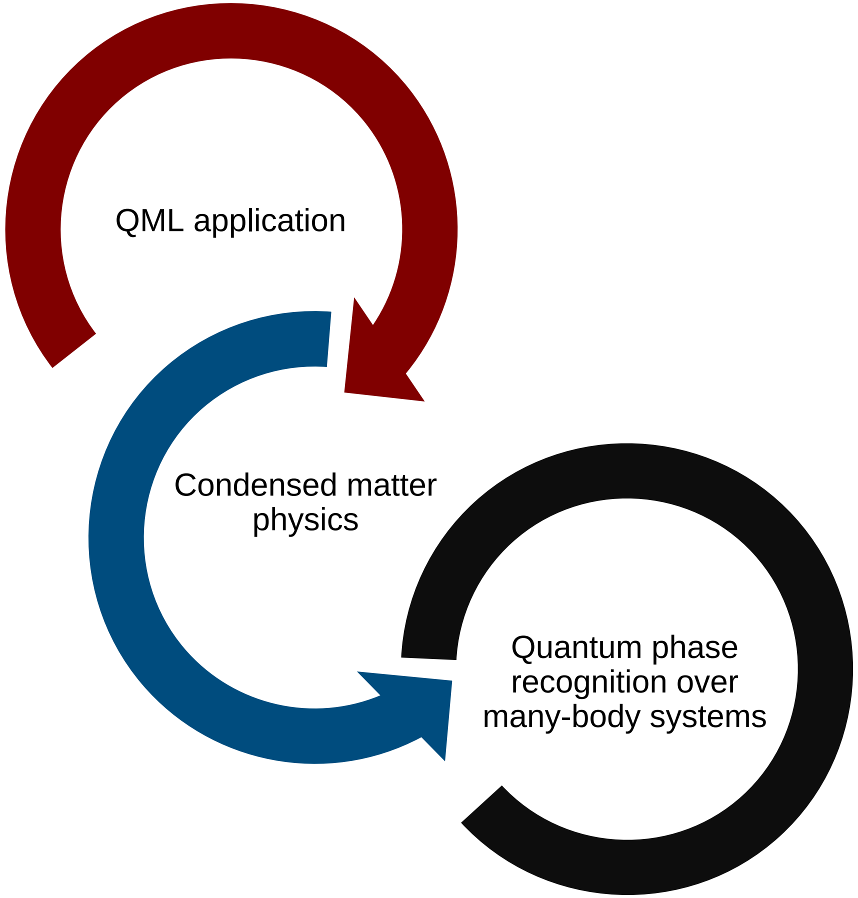
Learning to Classify Quantum Phases of Matter with a Few Measurements

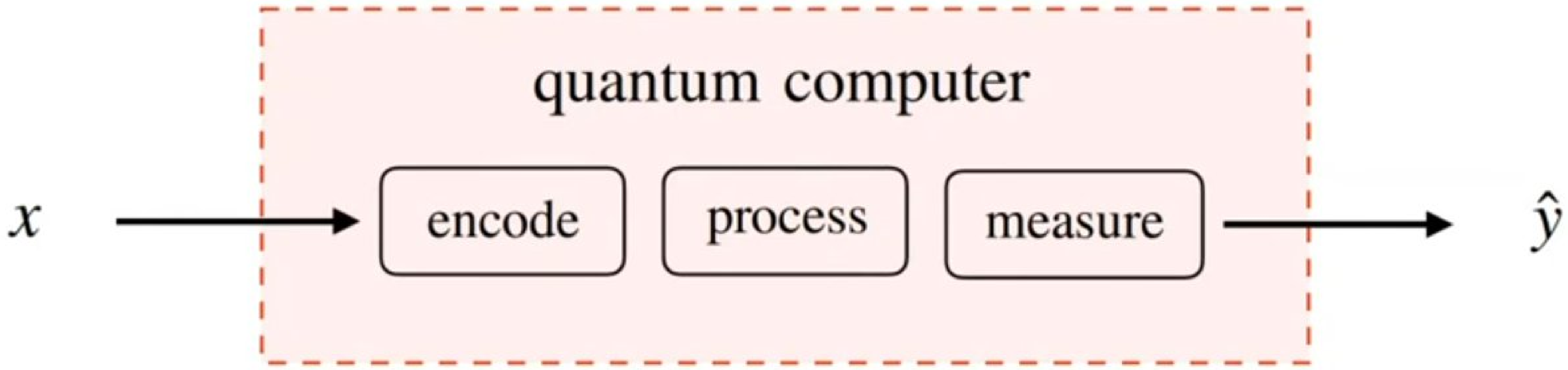
arXiv: 2409.05188

Mehran Khosrojerdi, Jason L. Pereira, Alessandro Cuccoli, Leonardo Banchi

- Quantum Machine Learning
- Quantum Model: Quantum Support vector Machine (QSVM)
- Dataset: Tensor Networks
- Axial Next-Nearest-Neighbour Ising (ANNNI) example
- Haldane chain example


data processing device
data generating system
CC
CQ
QC
QQ
C - classical, Q - quantum


QML application
Condensed matter physics
Quantum phase recognition over many-body systems



The QML Flow
Credit: Maria Schuld

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$$y = \{+1, -1\}, \qquad x \rightarrow \rho(x), \qquad f(x) = \mathrm{Tr}\left[W\rho(x)\right] + b = 0$$

$$W = \sum_{i=1}^{M} y_i \alpha_i \rho(x_i) \qquad\qquad b = \sum_{i=1}^{M} \left(\frac{y_i - \sum_{j=1}^{M} y_j \alpha_j k(x_i, x_j)}{M} \right)$$

$$y_{predicted} = sign\left[f(x)\right] = sign\left[b + \sum_{i=1}^{M} y_i \alpha_i k(x_i, x)\right]$$

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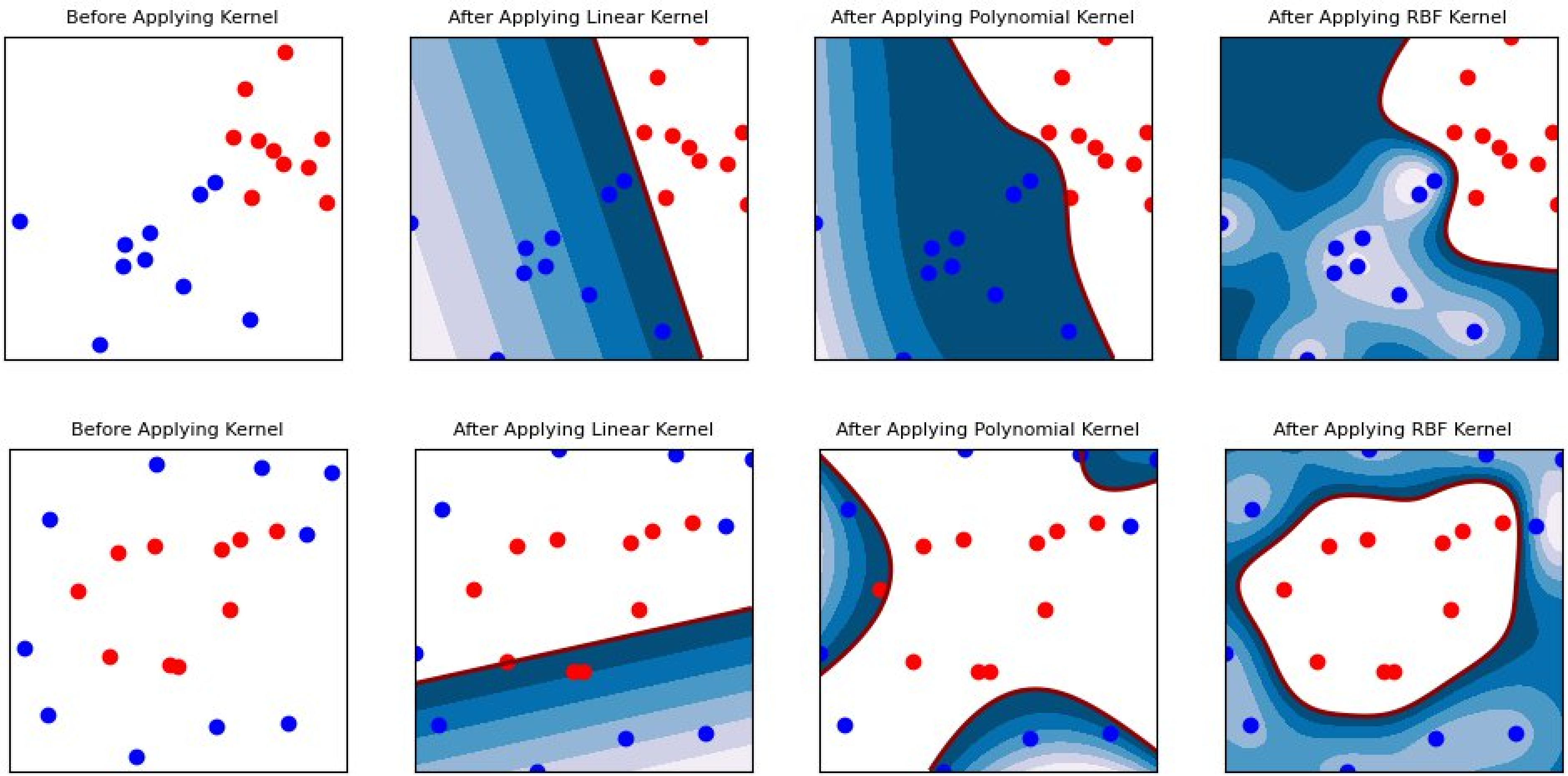

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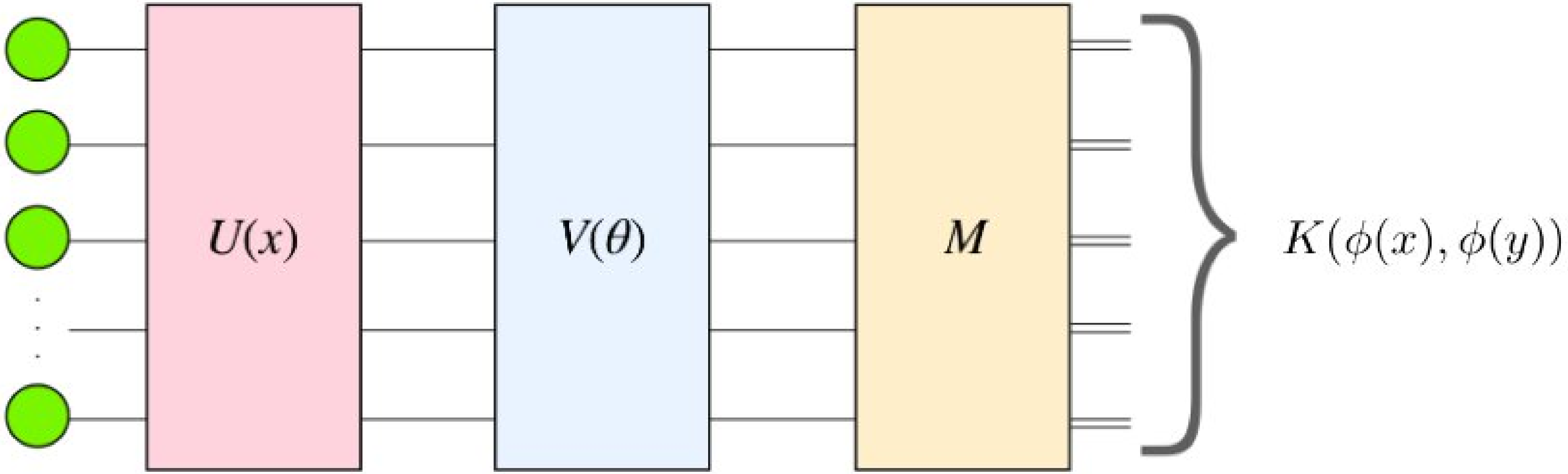
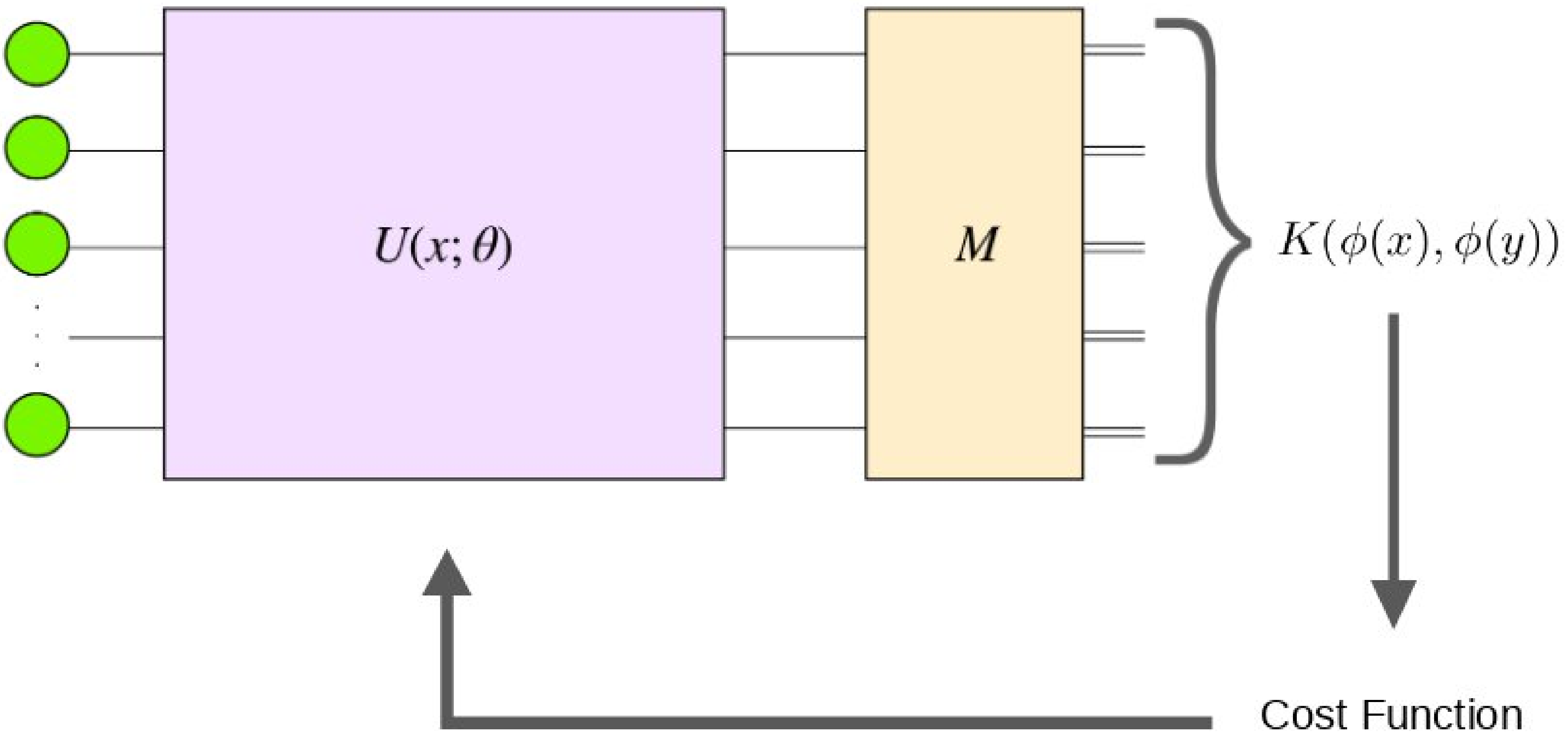


$$k(\varphi(x_n), \varphi(x_m)) = Tr\left[\rho(x_n)\rho(x_m)\right] = |\langle\varphi(x_n)|\varphi(x_m)\rangle|^2$$



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- Lloyd, Seth, et al. "Quantum embeddings for machine learning." *arXiv preprint arXiv:2001.03622* (2020).

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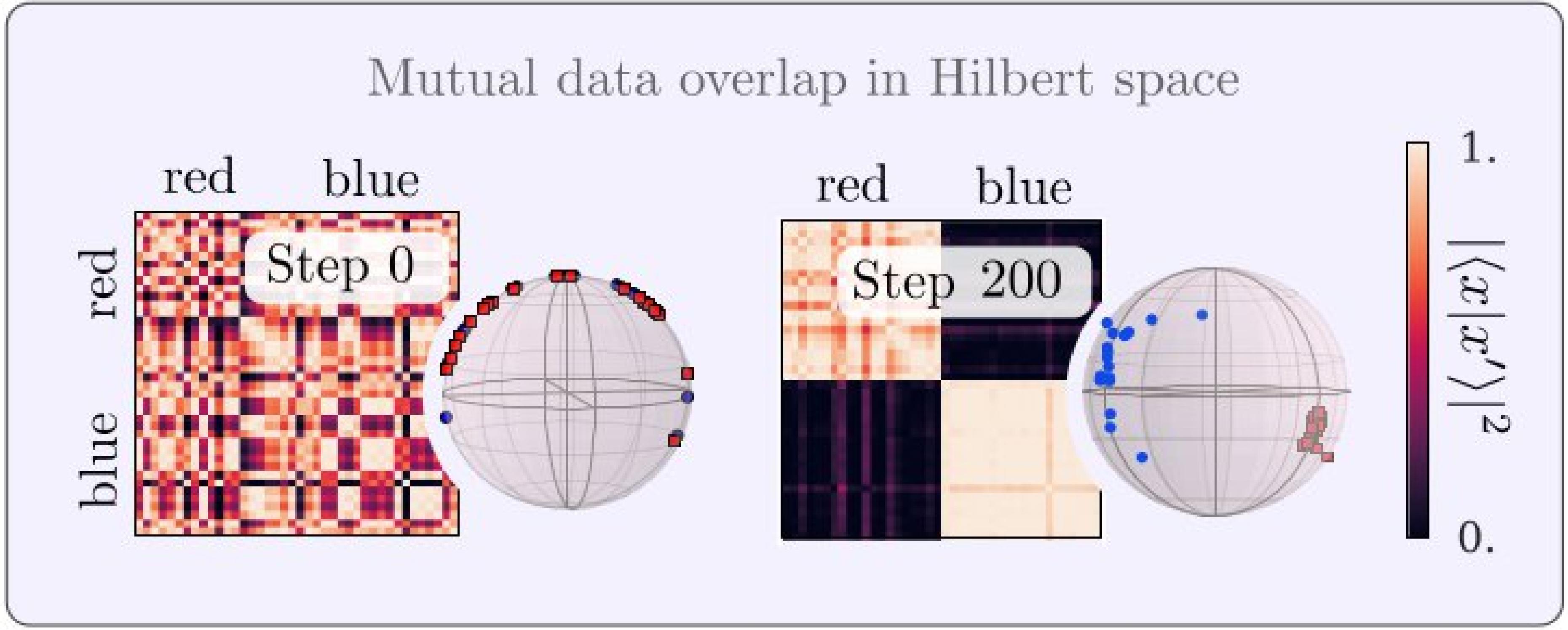

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$$H(p_1, p_2, \dots, p_n) = MPO(p_1, p_2, \dots, p_n)$$

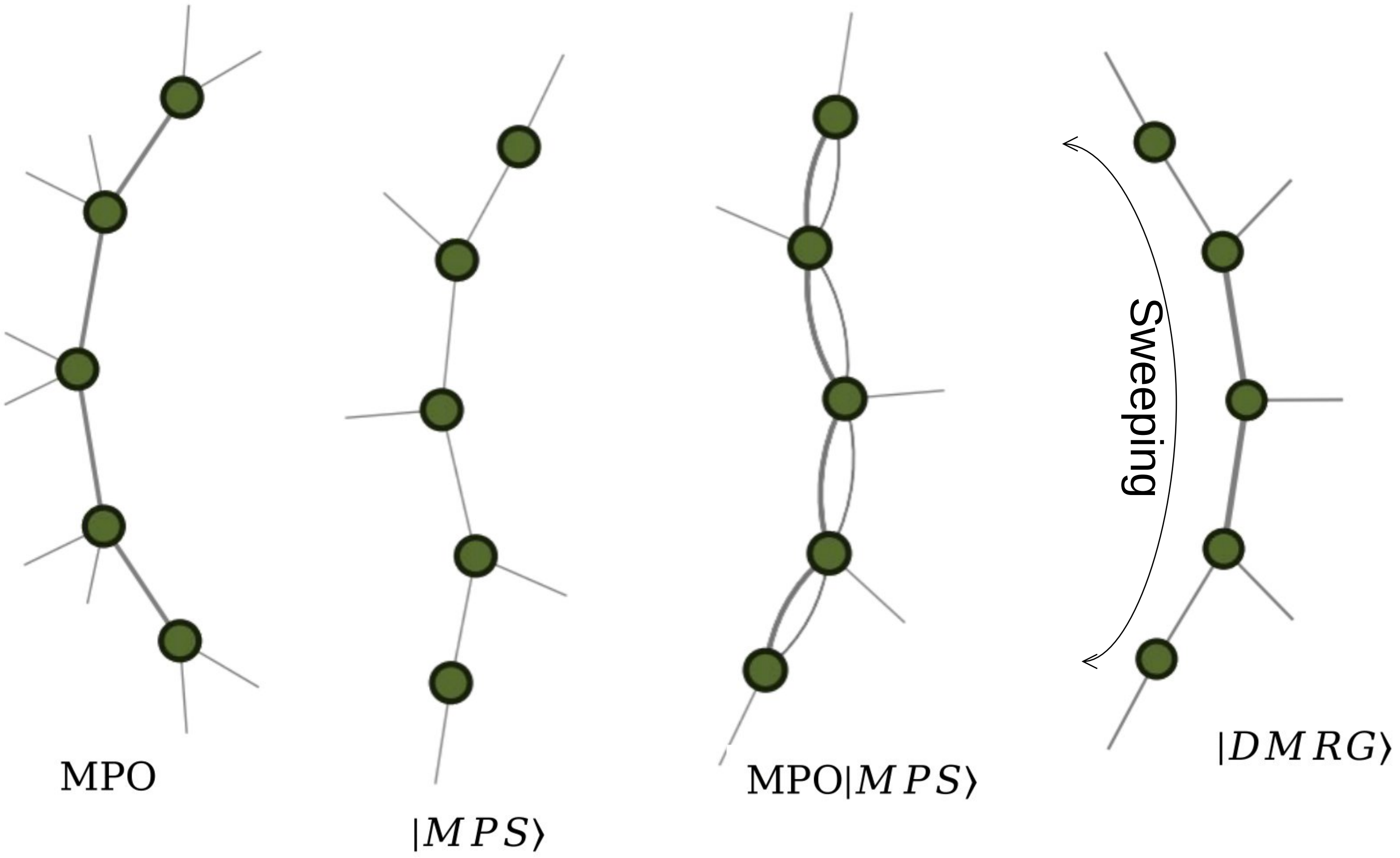
$$|\psi\rangle = |MPS\rangle$$

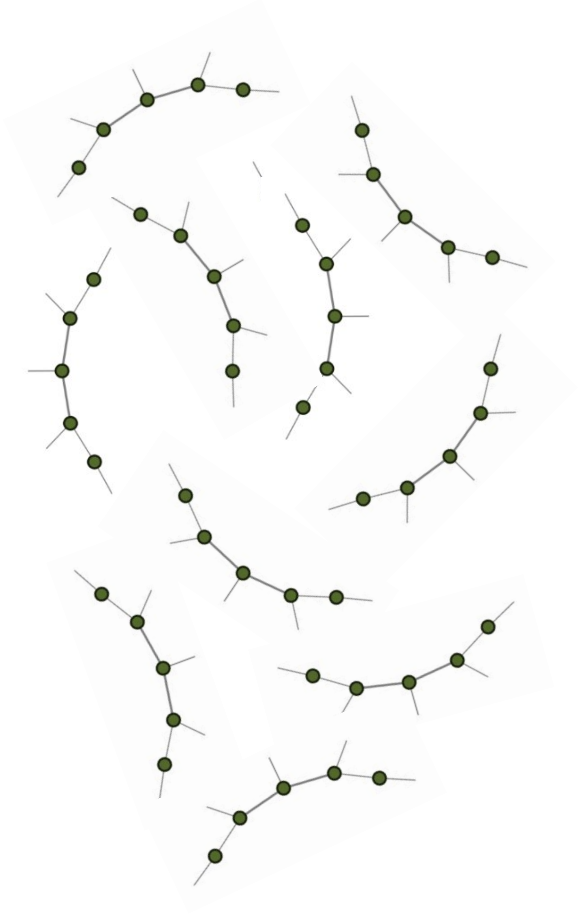
DMRG model

$MPO\ |MPS\rangle_{\text{rand}}$

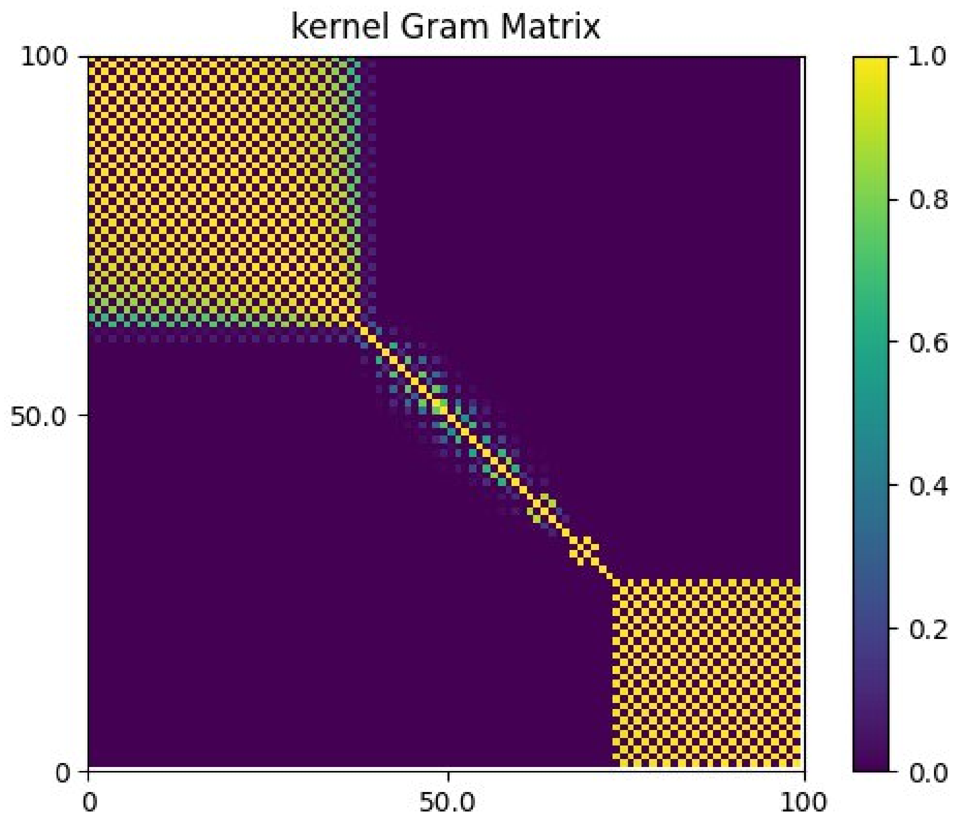
→

Optimized DMRG states





$$k(x_n, x_m) = \left|\langle \psi(x_n) | \psi(x_m) \rangle\right|^2$$



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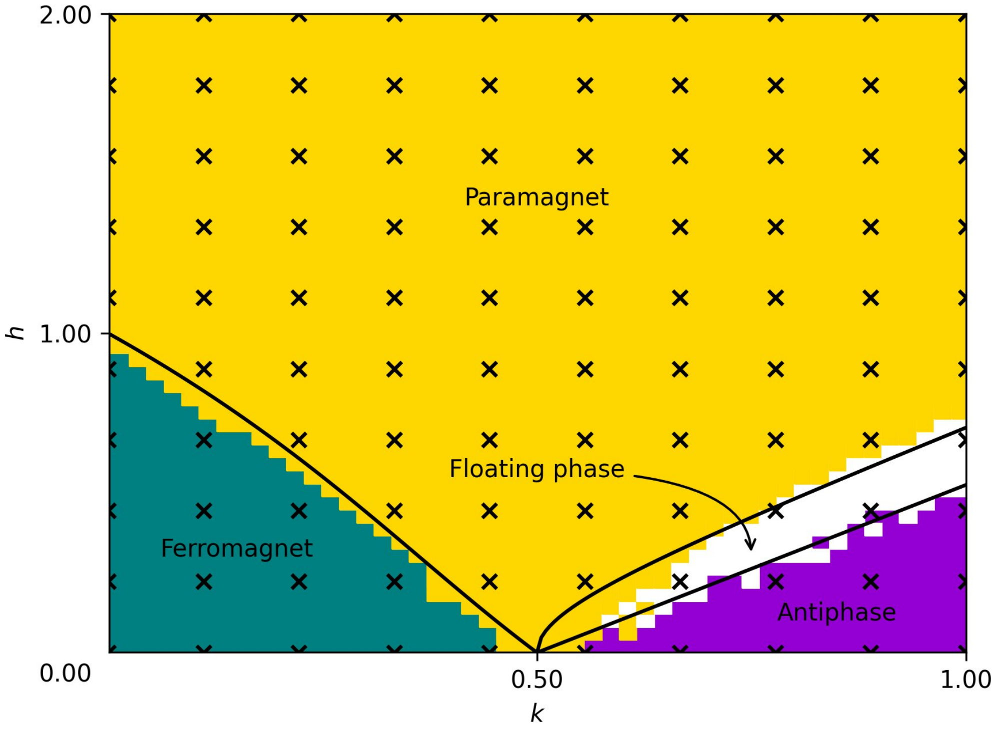

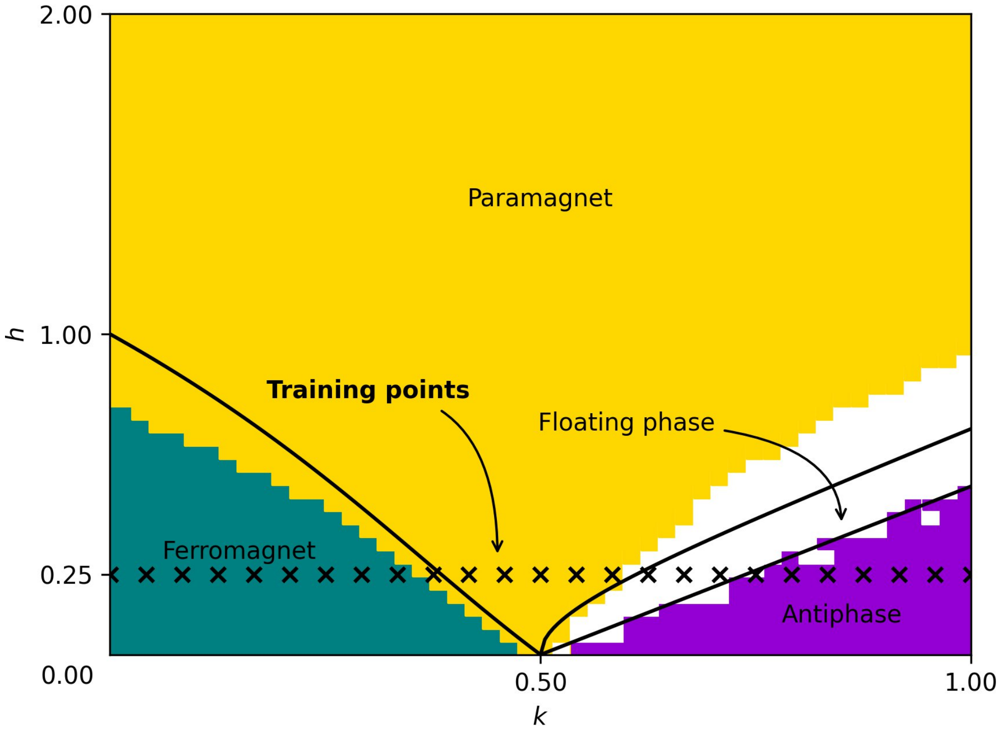

$$H_{ANNNI} = -\sum_{j=1}^{N-1} \sigma_j^x \sigma_{j+1}^x + k \sum_{j=1}^{N-2} \sigma_j^x \sigma_{j+2}^x - h \sum_{j=1}^{N} \sigma_j^z$$

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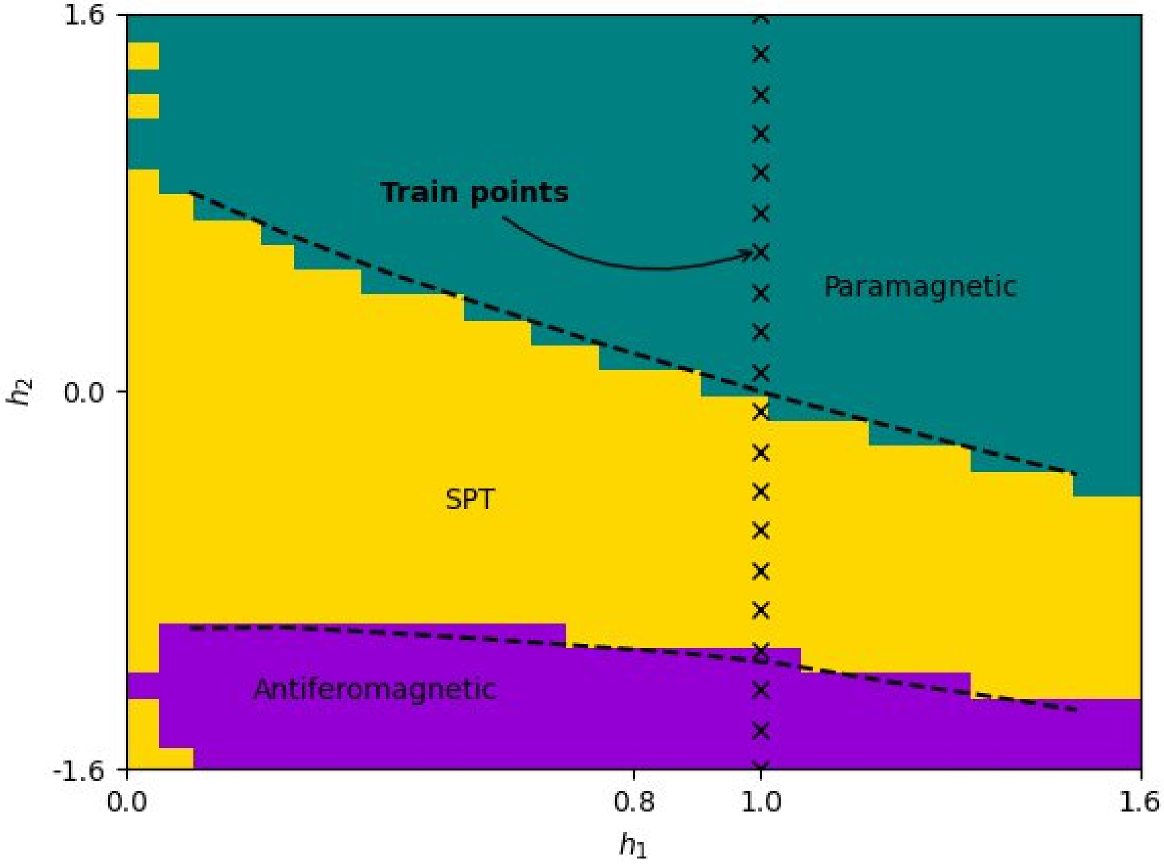

$$H_{Haldan} = -\sum_{j=1}^{N-2} \sigma_j^z \sigma_{j+1}^x \sigma_{j+2}^z - h_2 \sum_{j=1}^{N-1} \sigma_j^x \sigma_{j+1}^x - h_1 \sum_{j=1}^{N} \sigma_j^x$$

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Conclusion:

- Tensor networks successfully work in classification problems
- This classifier can successfully interpolate and extrapolate phase diagram, accurately predicting quantum phases for new parameter sets.

Future:

- Implement this approach using unsupervised learning to tackle the clustering problem.
- Replace tensor networks with Quantum Variational Eigensolvers (QVE) and perform a comparative analysis.

Acknowledgements:

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Thank you for your time and attention!
Curious to hear your thoughts.