Quantum-Inspired Tensor Networks for Unsupervised and Supervised Cancer Detection in Medical Imaging

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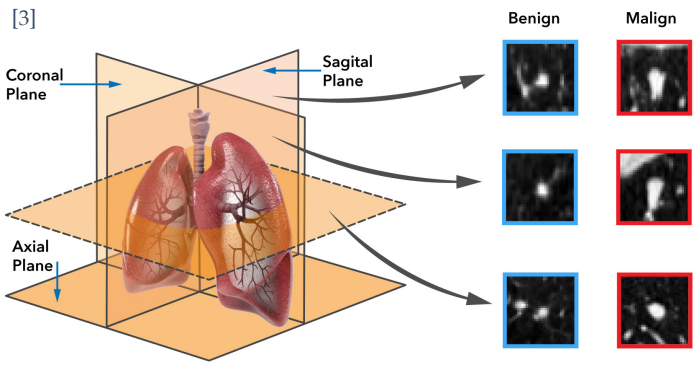
Data: Lung CT scans

[LIDC dataset] [3]



Quantum-Inspired: Motivation and Goals

- Leverage complex relationships ⟶ requires less data
- Matches classical methods even on smaller datasets and lower image resolution
- Robustness to new unseen diseases

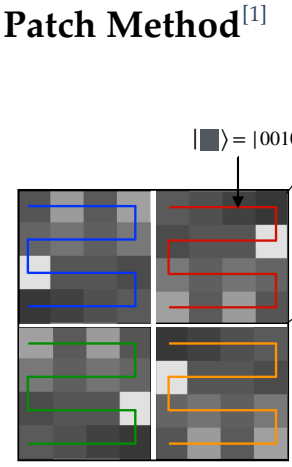
	Unsupervised	*Supervised*
pros	no labels	labels
cons	lower bound of supervised	lack of labeled data

Challenges

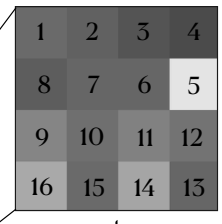
- Embedding large medical images into **Tensor Networks**
- Limited number of labeled medical samples

Data Embedding

I. Patch Method[1]

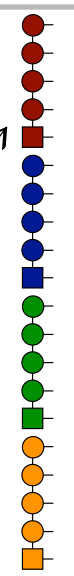


$|\blacksquare\rangle = |0010\rangle$



$$|\psi\rangle = \frac{1}{\sqrt{N}} \sum_{x=0}^{M-1} |x\rangle \left(cos\frac{\pi}{2} p_x |0\rangle + sin\frac{\pi}{2} p_x |1\rangle \right)$$

$\#tensors_{patch} = \log_2(M) - 1$

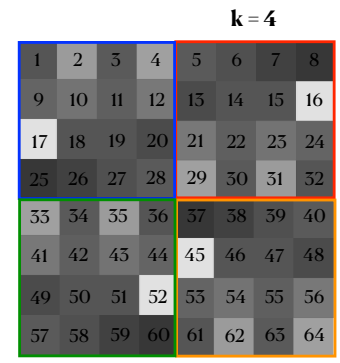


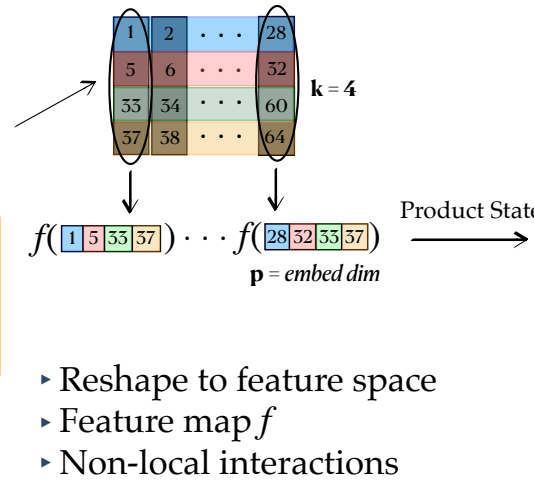
- Pixel intensity + location
- MPS approximation
- Local interactions

$M = \#pixels_{patch}$

MPS

II. Squeeze Method





- Reshape to feature space
- Feature map f
- Non-local interactions

[2] squeeze function + feature map

choose I. or II. + Model Optimization

UNSUPERVISED

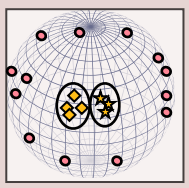
SMPO* model

- unsupervised training on healthy images
- mapping $S : V \rightarrow \nu$

$$L(x) = \left(\log(\|S\Phi(X)\|) - 1\right)^2$$

Unsupervised score

$\|S\Phi(X)\|$ dist. to origin



SUPERVISED

MPS* model

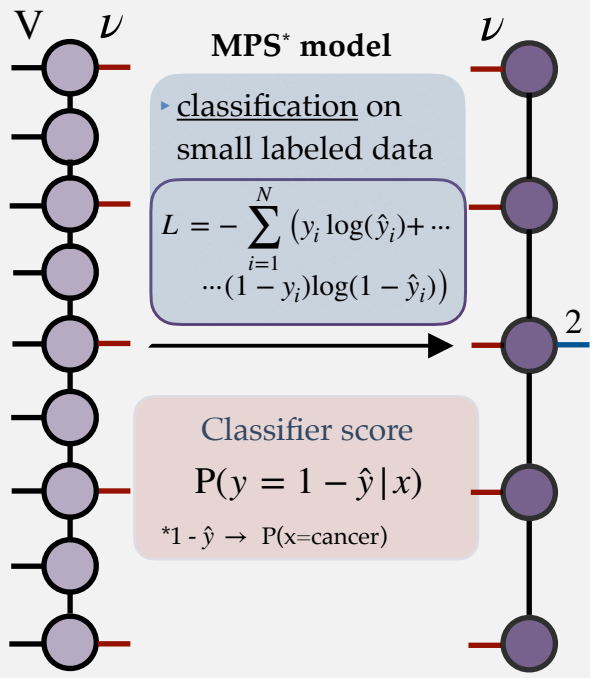
- classification on small labeled data

$$L = -\sum_{i=1}^{N} \left(y_i \log(\hat{y}_i) + \cdots \right.$$
$$\left. \cdots (1 - y_i) \log(1 - \hat{y}_i) \right)$$

Classifier score

$P(y = 1 - \hat{y} \,|\, x)$

*1 - $\hat{y}$ → P(x=cancer)

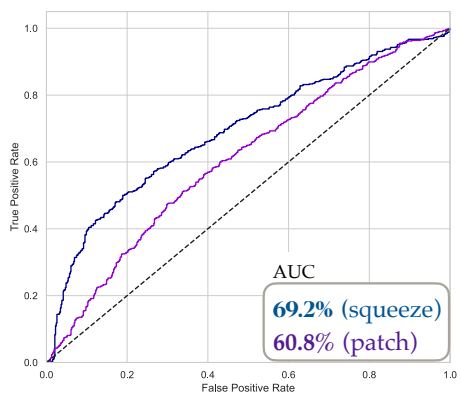


*Spaced Matrix Product Operator

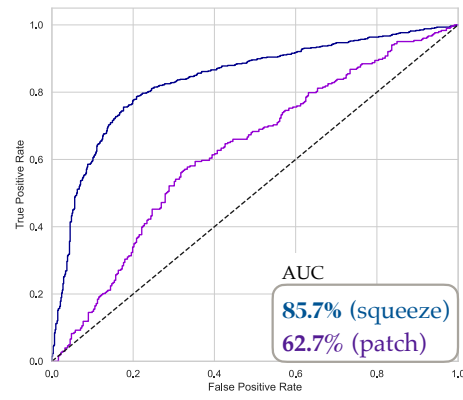
*Matrix Product State

Cancer Detection

Unsupervised



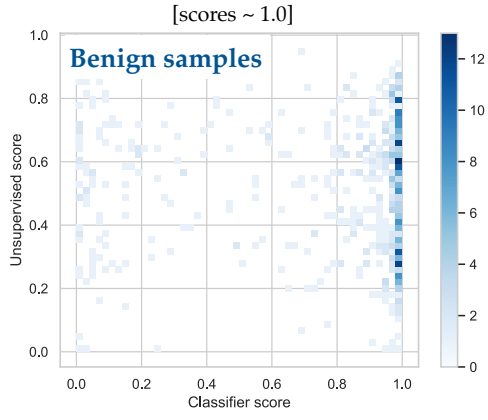
Supervised



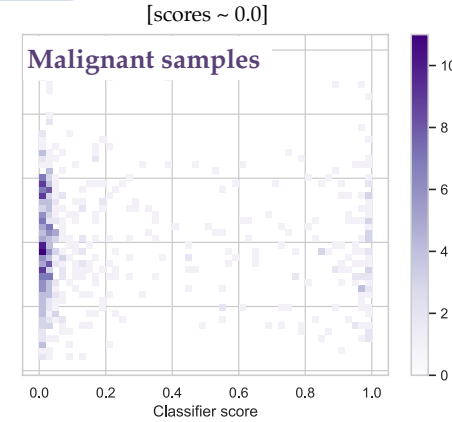
*choose best embedding

Separation

[scores ~ 1.0]



[scores ~ 0.0]



Conclusion and Discussion

- **Data Embedding**
  - Truncation in $|\psi\rangle$ → MPS impacts the results
- **Cancer Detection**
  - Unsupervised: results comparable to classical methods even with lower resolutions (GAN - 66% auc, SVDD-AE - 81% auc)
  - Supervised: Upper bound for unsupervised, trained on small labeled dataset, shows good AUC even on small subsets (85.7%)

[1] Data compression for quantum machine learning [10.1103/PRR.4.043007]

[2] Locally orderless tensor networks for classifying two- and three-dimensional medical images [2009.12280]

[3] Quantum Machine Learning for Biomedical Data Analysis Quantum Generative Models (X. F. Aragonés, Master Thesis)

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