

Bitkom Quantum Summit 2022

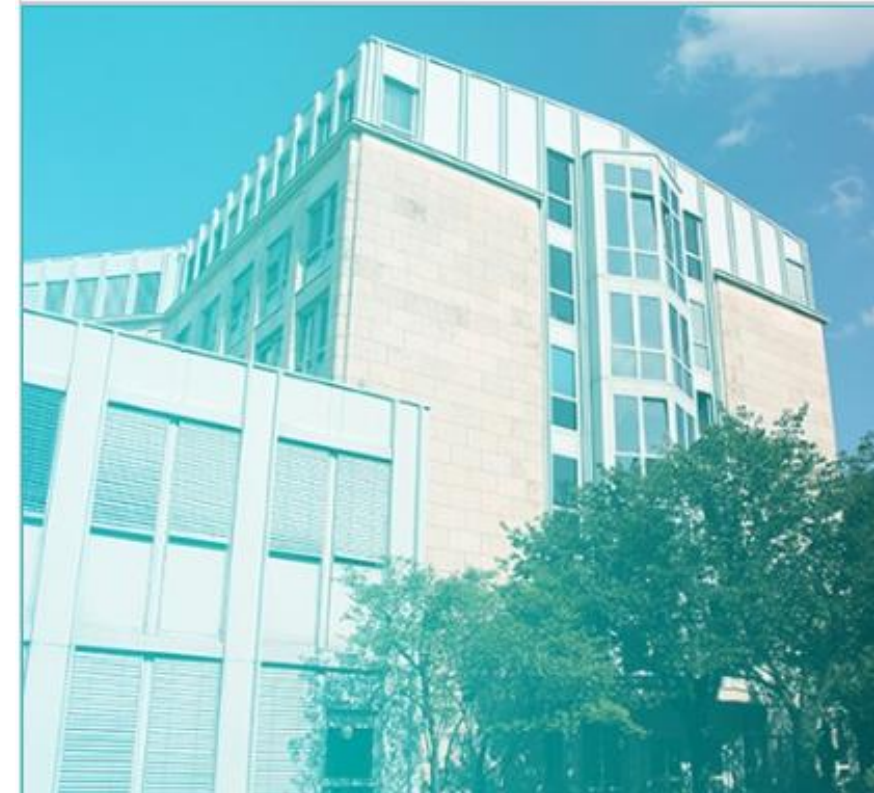
Using hybrid quantum-classical convolutional neural networks to identify cancer

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12.05.2022

Fraunhofer IKS – Competency in SAFE INTELLIGENCE

Fraunhofer Institute for Cognitive Systems IKS

- Founded in 2019
- Application-oriented research for reliable software technologies
- Expertise on cognitive systems, AI and modern software architectures in safety-critical applications
- Combining Safety and Intelligence:
Safe Intelligence

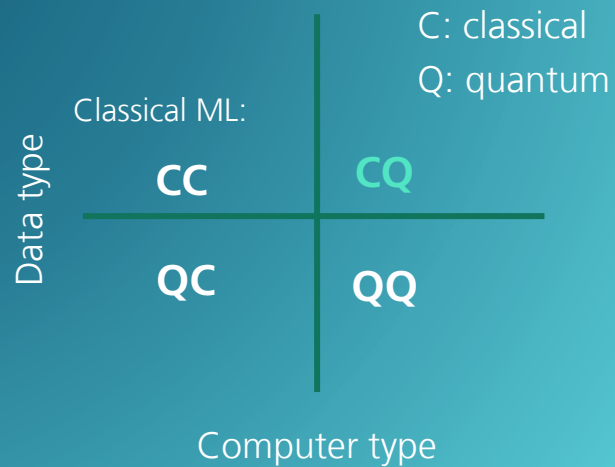


Introduction

Quantum machine learning and QCCNNs



QML may have different meanings



CQ – current practises: either **enhancing classical ML by some quantum subroutine**, or trying to resemble ML architecture by a quantum variant

QML one of the areas assumed to show a practical quantum advantage early

- Studies at Fraunhofer IKS: **Hybrid quantum-classical convolutional neural networks** (QCCNNs)
- Joint project together with the LMU hospital
- Part of Bavarian Competence Center Quantum Security and Data Science (BayQS)
- **Paper:** "Quantum-classical convolutional neural networks in radiological image classification", A. Matic, M. Monnet, J. Lorenz, B. Schachtner, T. Messerer, [arXiv:2204.12390](https://arxiv.org/abs/2204.12390)

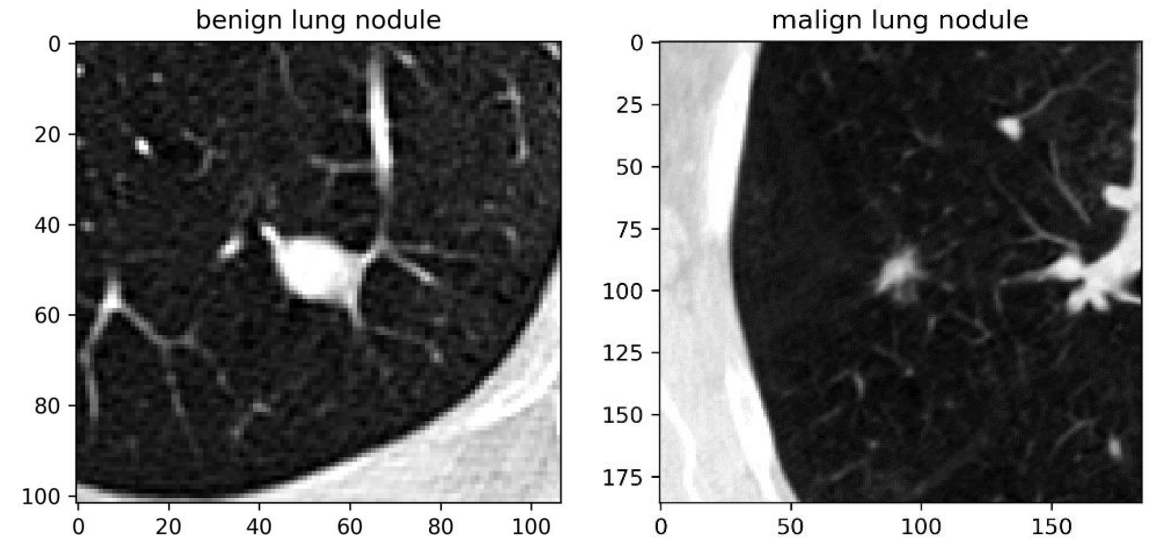
Motivation

Reliable QC-assisted AI for medical classification tasks

- Artificial intelligence increases in importance in medical diagnosis tasks.
- **Image data is expensive, complex and only available in small numbers (10^2 - 10^3).**
- Decision process needs to be comprehensible and reliable.
→ Classical methods need large training datasets.

Motivation for the usage of quantum computers:

QC-assisted methods might result in a faster training, especially for situations with little training data



Classical machine learning

Convolutional neural networks

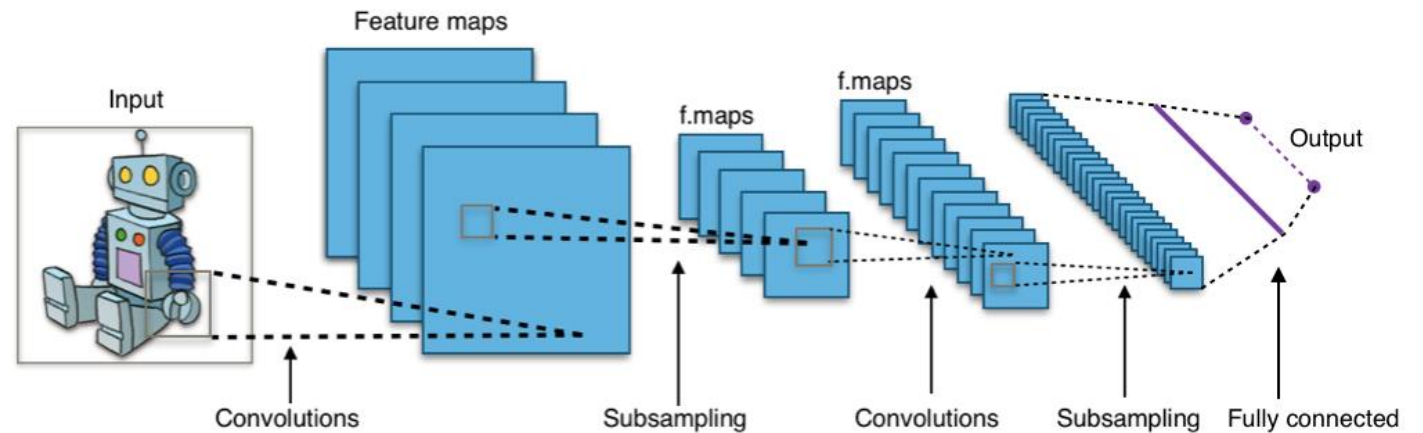
CNNs: Successful algorithms for image classification tasks

Architecture: One or more **convolutional layers**, followed by **fully connected layer(s)**

Image convolved with filters → extraction of **features**, e.g. edges, shapes

Classification in final fully connected layer

Classical CNN:



Source: https://upload.wikimedia.org/wikipedia/commons/6/63/Typical_cnn.png, Aphex34, CC BY-SA 4.0 <<https://creativecommons.org/licenses/by-sa/4.0/>>, via Wikimedia Commons

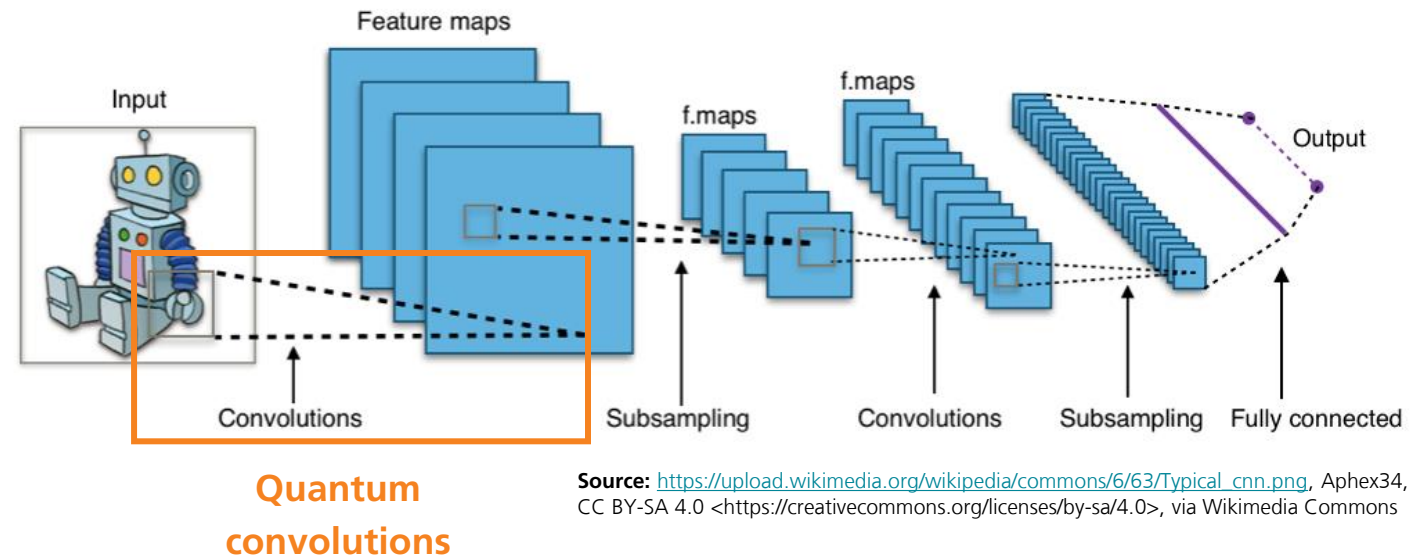
Hybrid quantum-classical convolutional neural networks

Idea: Replace some of the convolutional layers by quantum convolutional layers

QCCNNs promise to be better suited for situations with **little training data** → potentially more precise and faster training convergence

Hybrid ansatz → possible to execute on current or soon-available NISQ quantum computers

Hybrid QCCNN:



Source: https://upload.wikimedia.org/wikipedia/commons/6/63/Typical_cnn.png, Aphex34, CC BY-SA 4.0 <<https://creativecommons.org/licenses/by-sa/4.0/>>, via Wikimedia Commons

QCCNNs on 2D medical data

Datasets

Selected two MedMNIST datasets

1) Breast ultrasound:

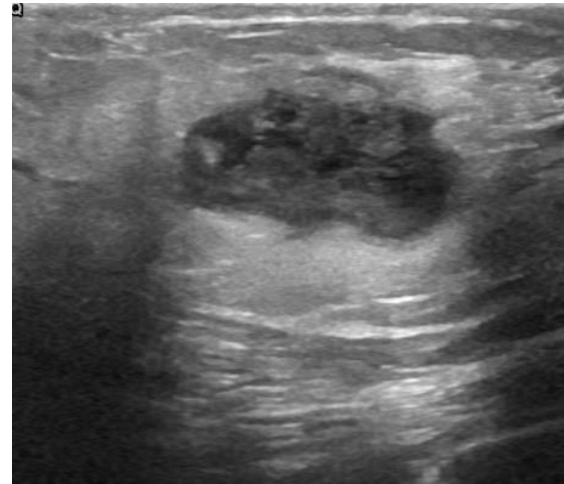
- Binary classification of non-malignant and malignant lesions
- **Small dataset** with ~ 600 images

2) Abdominal CT scans:

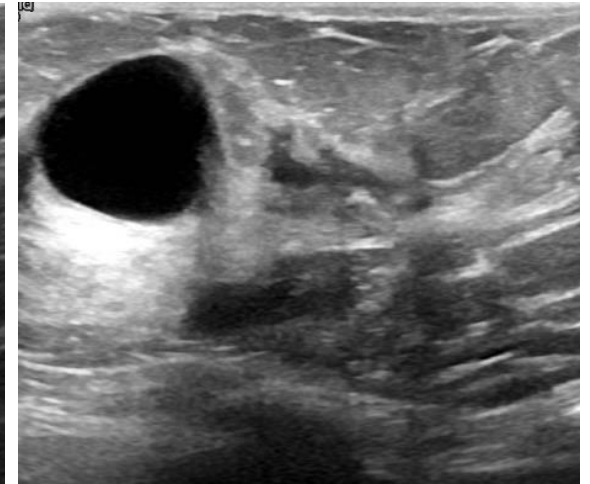
- 2D-projected CT scans
- Multi-class classification of 11 organs

Images downscaled to 28 x 28 pixels

Malign breast lesion



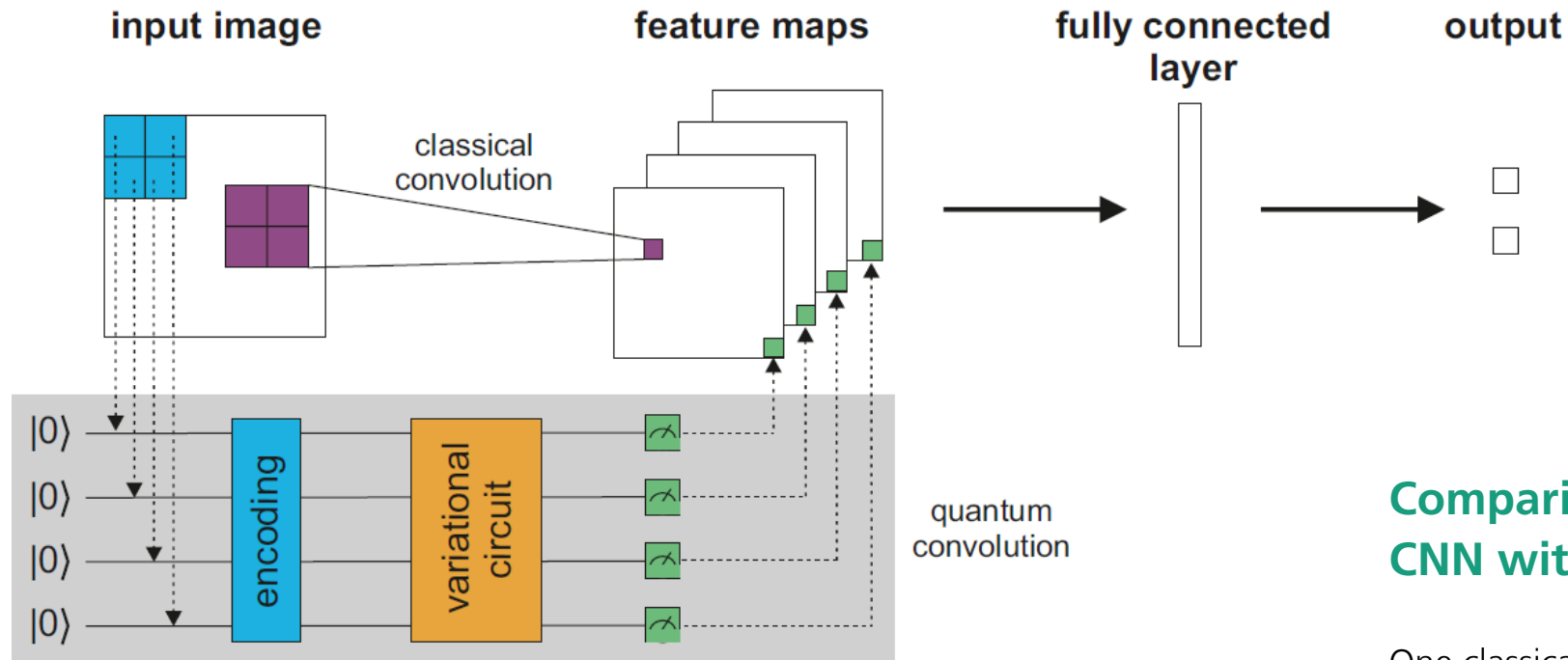
Benign breast lesion



Source: W. Al-Dhabyani, et al, "Dataset of breast ultrasound images". Data Brief, vol 28, pp 104863, 2020

QCCNNs on 2D medical data

Experimental setup



Classical data transformed into quantum states

Sequence of one and two-qubit gates, rotation angles are **trainable parameters**

Comparison of a classical CNN with different QCCNNs

One classical convolutional vs. one quantum convolutional layer

QCCNNs on 2D medical data

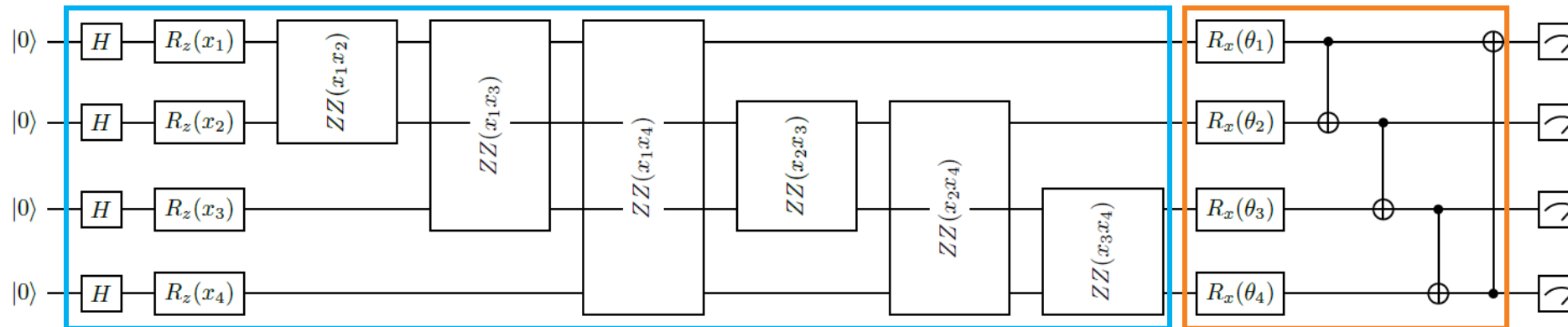
Encoding and circuits designs

Tested encoding techniques:

- **Threshold encoding:** Simple encoding with only two encoded states $|0\rangle$ or $|1\rangle$
- **Higher-order encoding:** More complex encoding based on qubit rotations and entanglement

Tested circuit designs:

- **Basic entangling layer:** Trainable parameters from X-axis rotations
- **Strongly entangling layer:** Trainable parameters from X, Y and Z-axis rotations $\rightarrow$ 3x more parameters



Example circuit:

Higher order encoding

Basic entangling layer

QCCNNs on 2D medical data

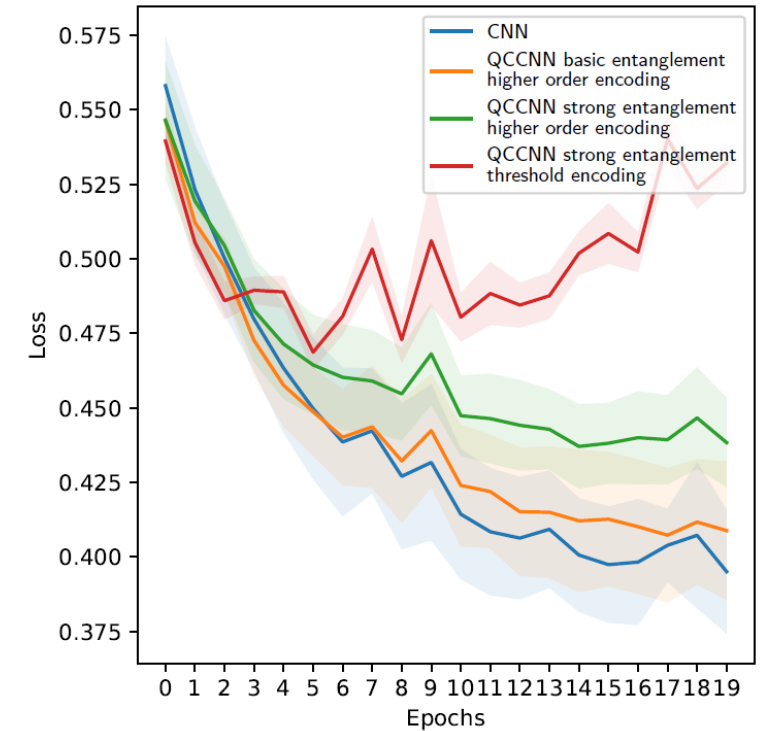
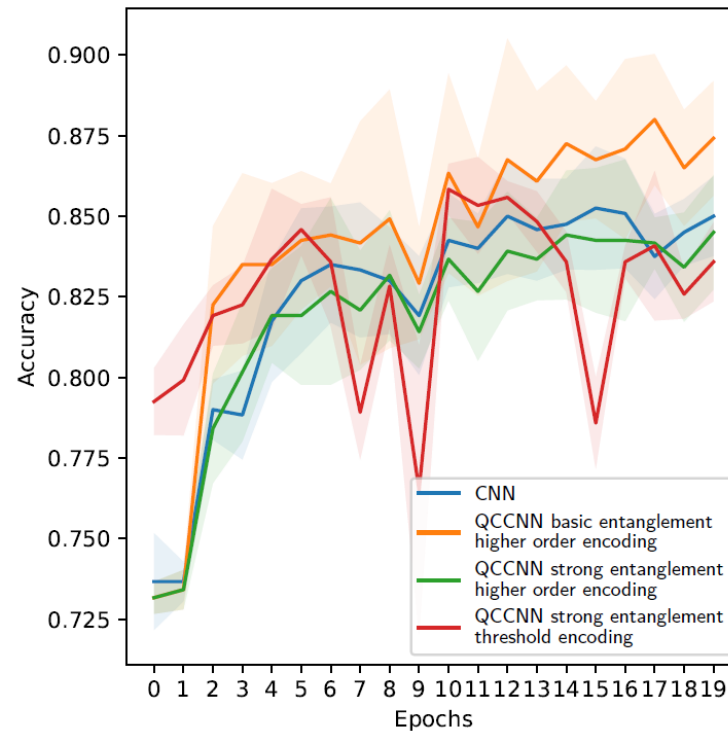
Results

Promising performance of QCCNNs

Circuit design with less trainable parameters yields better performance

Complex encoding more promising than simpler technique

Results for breast ultrasound dataset



QCCNN on 3D medical data

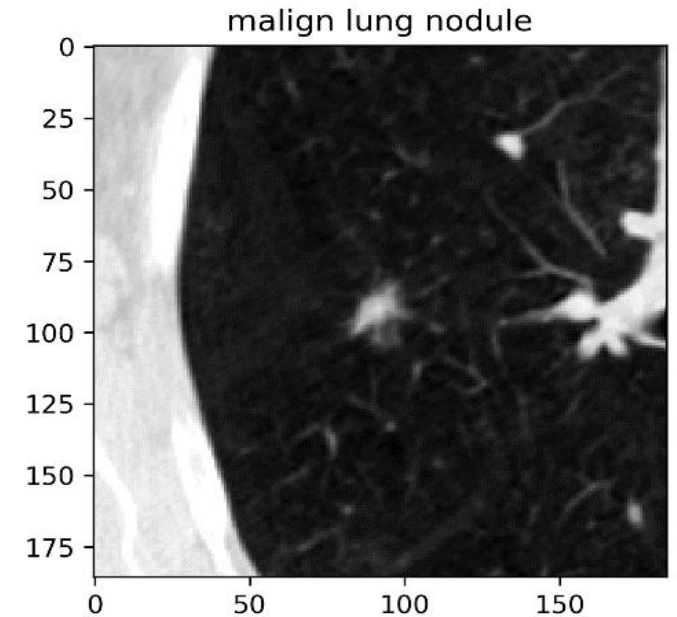
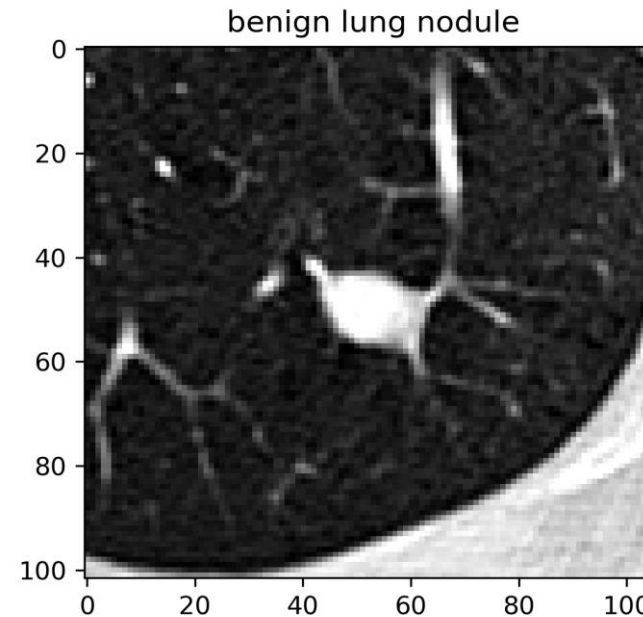
Dataset

3D CT scans of the lung:

Binary classification of malignant and non-malignant nodules

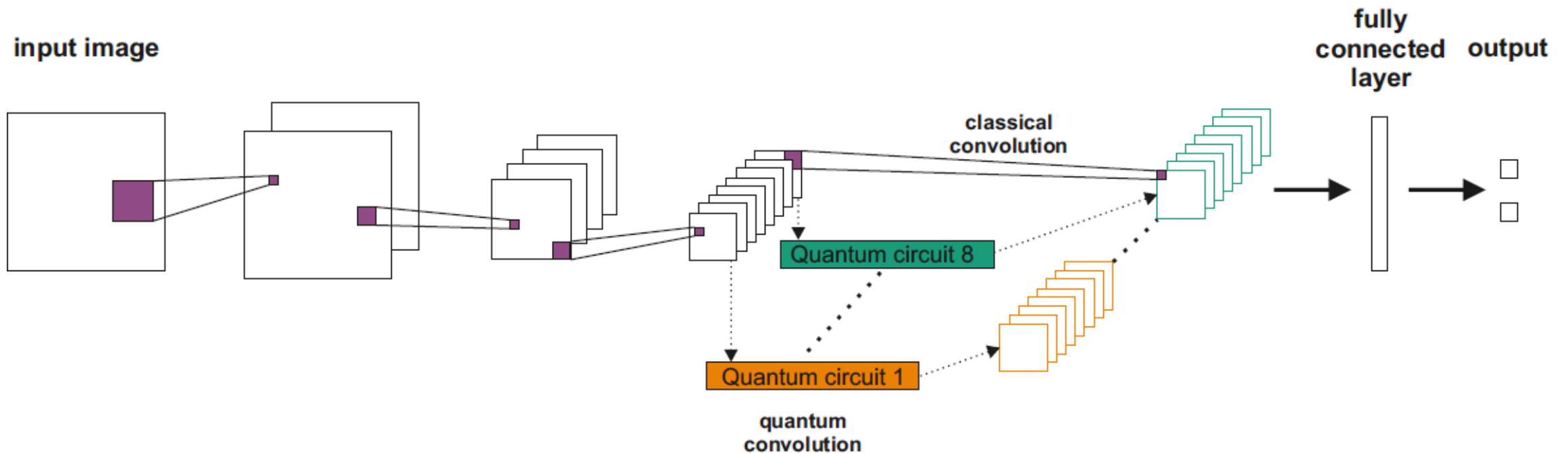
Image size: 128 x 128 x 64

- Long runtimes of quantum computing simulations
- **Data compression required** before quantum convolutional layer



QCCNN on 3D medical data

Experimental setup



Sequence of classical convolutional layers before quantum convolutional layer

→ Data compression

→ Inputs to quantum convolutional layer are not image data, but the outputs of the last classical convolutional layer

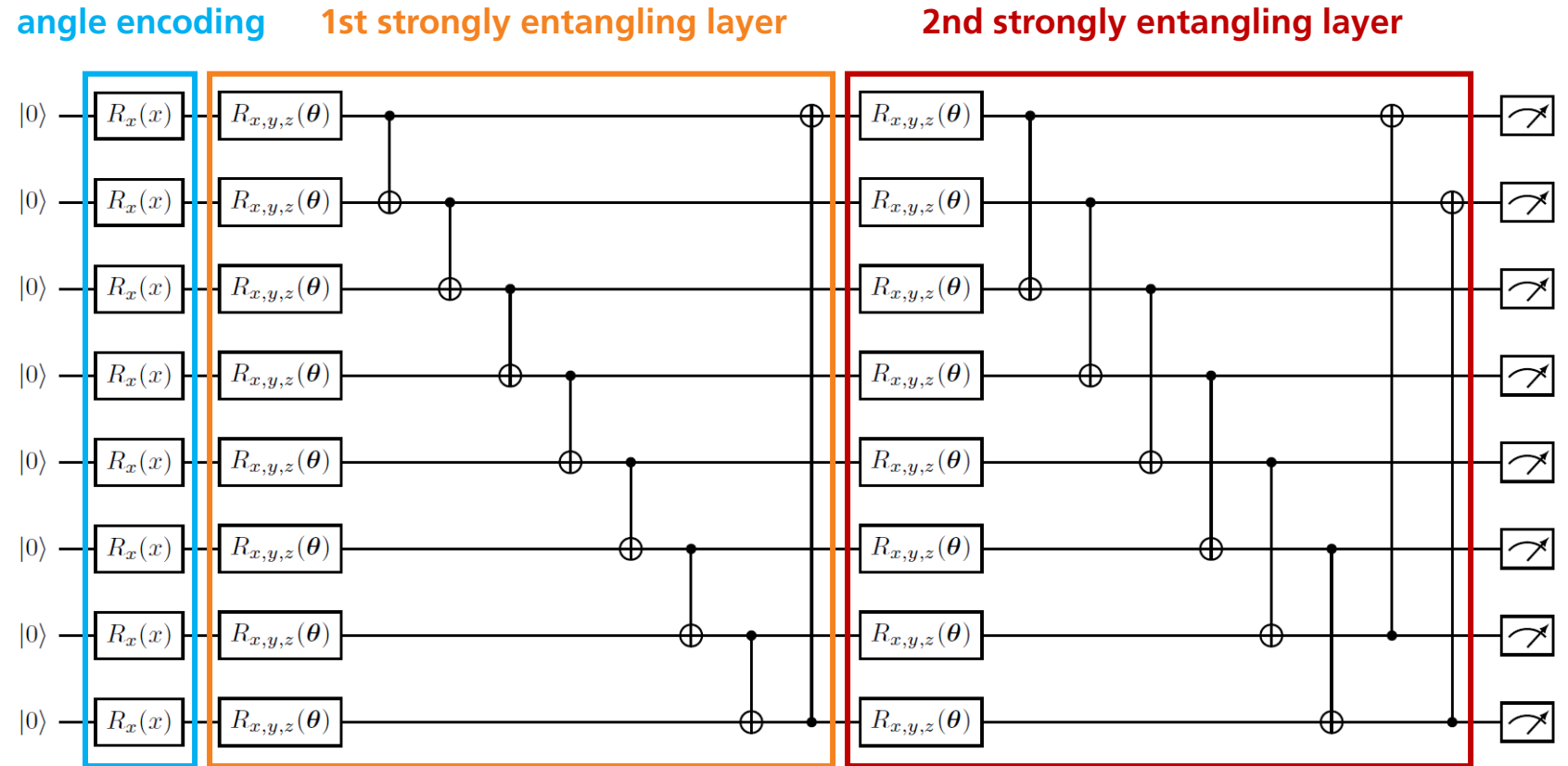
QCCNN on 3D medical data

Encoding and circuits designs

Encoding via angles in rotation gates

Circuit design: Either **one or two strongly entangling layers** afterwards

Example circuit with two strongly entangling layers:



QCCNN on 3D medical data

Results

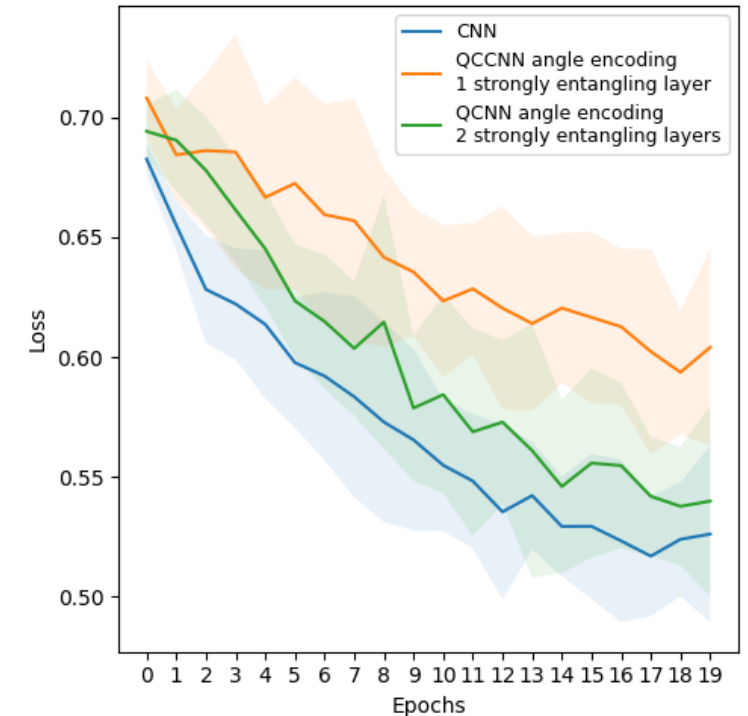
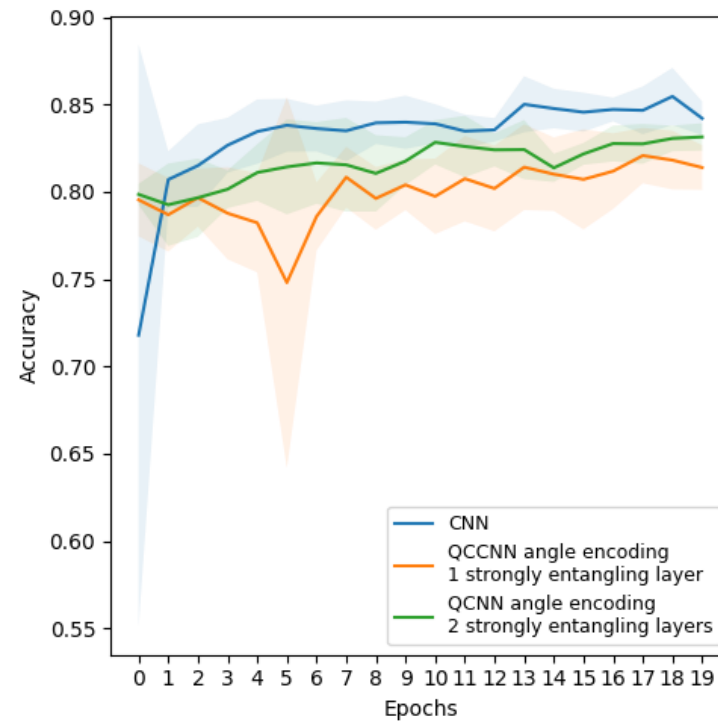
First-time analysis of medical 3D image data with QCCNNs

No superior performance of the QCCNN visible yet

Promising to already reach a **similar performance as classical setup**

Better performance with two than with only one strongly entangling layer

Results for 3D lung CT dataset



Conclusion and outlook

Studies on quantum-classical convolutional neural networks (QCCNNs) for radiological image classification

- Motivation: QCCNNs might result in more precise and faster training convergence → Potential improvement of medical image classification tasks
- Compared performance of different QCCNN designs with classical CNNs
- Studied datasets: 2D and 3D medical images → **First-time example of processing 3D medical data with QCCNNs**
- Promising results: Achieved already **similar performance** with QCCNNs as with classical CNNs

Many possibilities for future studies, including:

- **Encoding:** Which technique is the most suitable one for which dataset?
- **Quantum circuit design:** Can the performance of the QCCNNs be enhanced with a more sophisticated circuit design?

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