Quantum Computing in Medical Imaging: A Glimpse into the Future

Präsentation von Clara Morrissey

ROADMAP

1. The History of QC
2. Basic concepts of QC
3. Challenges of medical Imaging
4. Hybrid Quantum-CNN
5. Conclusion

THE HISTORY OF QUANTUM COMPUTING

1900

Max Planck - quantum hypothesis

1927

Werner Heisenberg - uncertainty principle

1930s

John von Neumann - mathematical framework for QC

1935

Einstein-Podosky-Rosen paradox

1965

John Bell - Bell inequalities

1980

PhysComp Conference

https://quantumpedia.uk/a-brief-history-of-quantum-computing-e0bbd05893d0

THE CONFERENCE

https://research.ibm.com/blog/qc40-physics-computation

FOUNDATIONS OF QUANTUM COMPUTING

- **SUPERPOSITION**
- **INTERFERENCE**
- **ENTANGLEMENT**

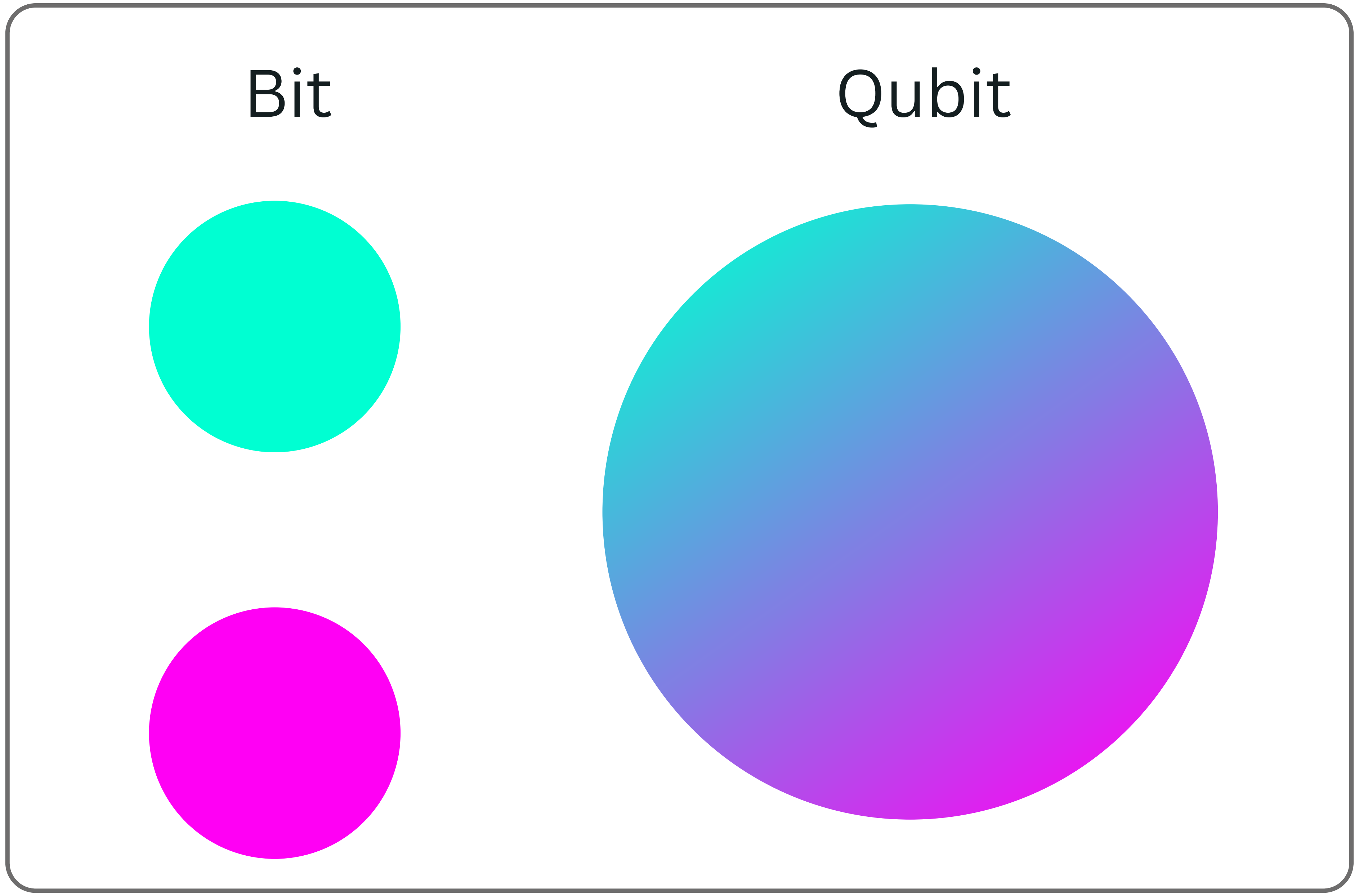
FOUNDATIONS OF QUANTUM COMPUTING

SUPERPOSITION

- multiple states at the same time
- refers to spinning electron's position
- probability distribution
- collapses on measurement (shot)

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$with|\alpha|^2 + |\beta|^2 = 1$$

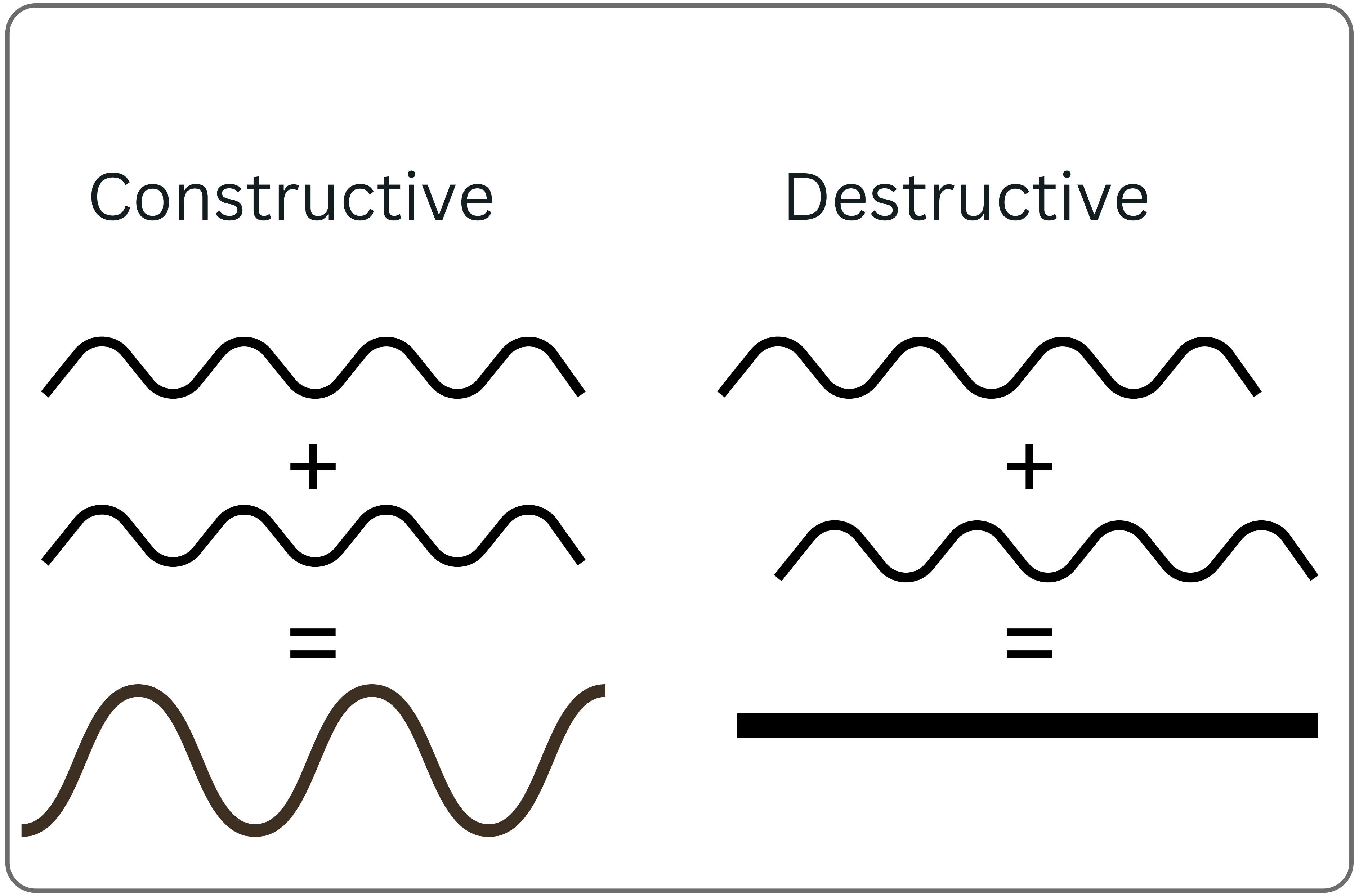


Grafik in Anlehnung an: Giani, Annarita & Eldredge, Zachary. (2021). Quantum Computing Opportunities in Renewable Energy. SN Computer Science. 2. 10.1007/s42979-021-00786-3.

FOUNDATIONS OF QUANTUM COMPUTING

INTERFERENCE

- particles have wavelike properties
- in-phase waves: constructive
- out-of-phase waves: destructive



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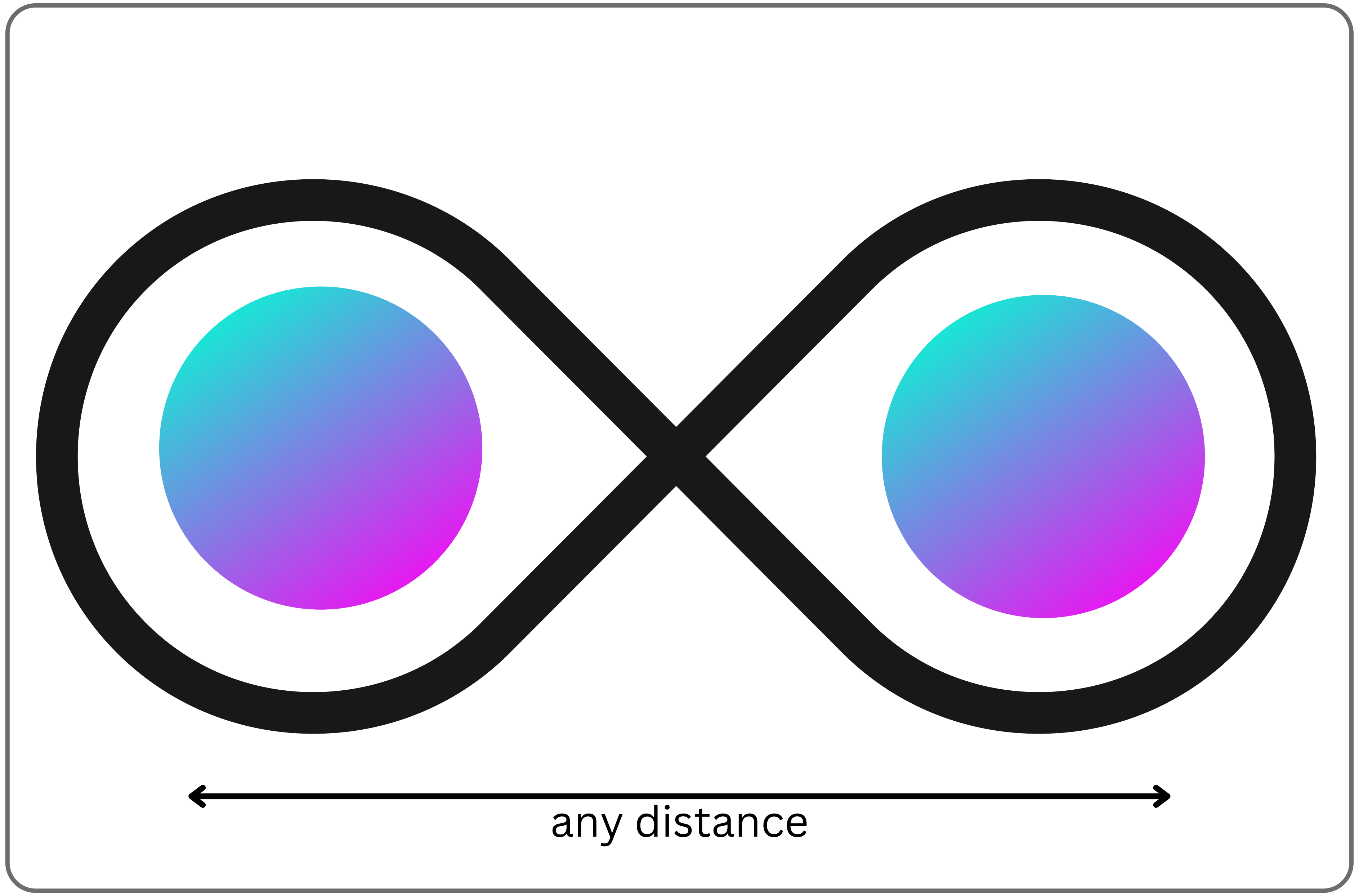
FOUNDATIONS OF QUANTUM COMPUTING

ENTANGLEMENT

- independent from distance
- if one qubit is measured, both collapse into the same state



Grafik in Anlehnung an:Institute of Science and Technology Austria. https://ist.ac.at/en/news/wiring-up-quantum-circuits-with-light/

FOUNDATIONS OF QUANTUM COMPUTING

QUANTUM GATES

- changes state of qubit

$$R(\theta) = \begin{bmatrix} \cos\left(\frac{\theta}{2}\right) & -\sin\left(\frac{\theta}{2}\right) \\ \sin\left(\frac{\theta}{2}\right) & \cos\left(\frac{\theta}{2}\right) \end{bmatrix}$$

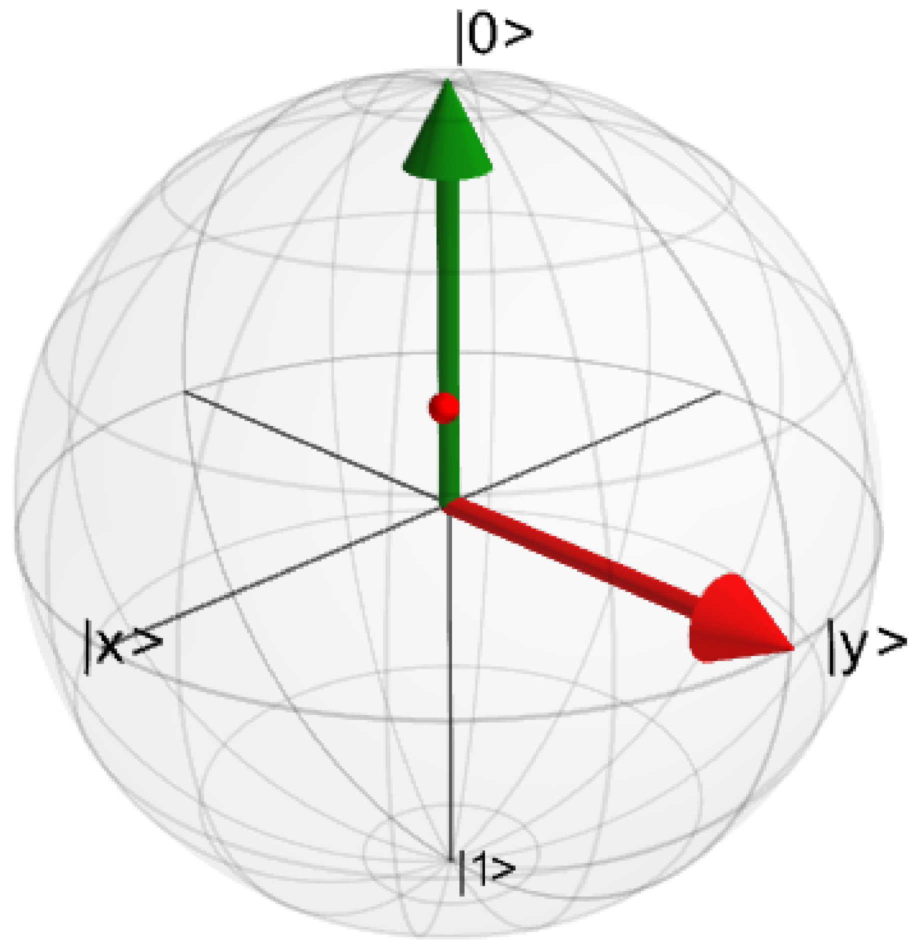


Image: Courtesy of :https://qutip.org/docs/4.1/guide/guide-bloch.html

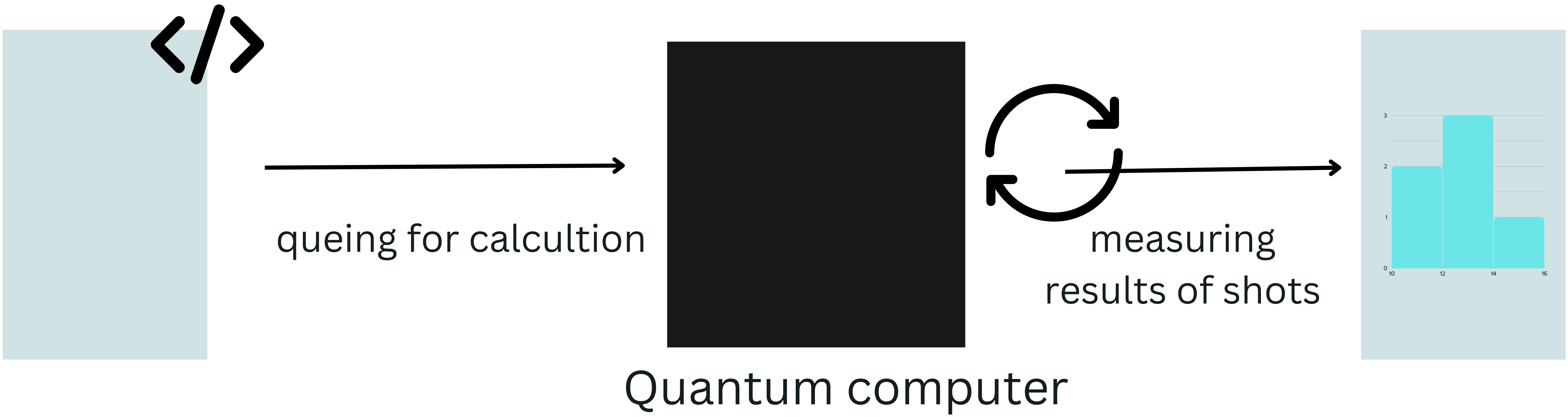
QUANTUM COMPUTER

Image: Courtesy of IBM. Downloaded here: https://newsroom.ibm.com/media-quantum-innovation?l=100&keywords=quantum

	CLASSICAL COMPUTING	QUANTUM COMPUTING
COMPUTING UNITS	Transistors, which can take in 0's ans 1's	Qubits which can represent 0's and 1's simultaneously
COMPUTING CAPACITY	capability increased linearly	capability increased exponentially
ERROR RATES & ENVIRONMENT	low error rates, operate at room temperature	high error rates, need to be kept ultracold
SUITABILITY	suitable for routine processing	suitable for complex processing

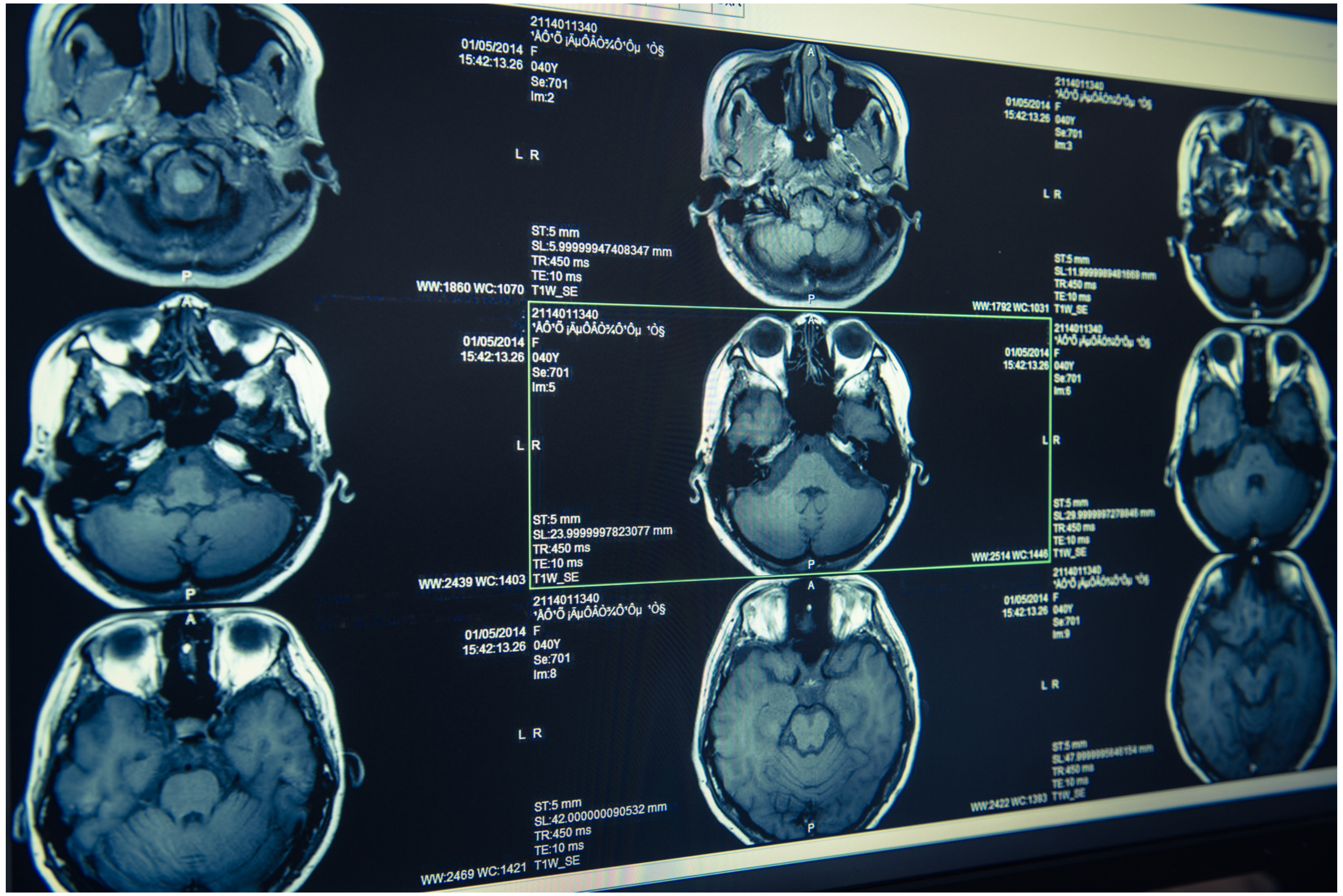
Graphics inspired by: https://www.mdpi.com/1999-5903/15/3/94

COMMUNICATION TO QUANTUM COMPUTERS



MEDICAL IMAGING

- includes many different types of imaging
- helps in diagnosis, prevention and treatment
- visualization of internal structures



MEDICAL IMAGING - CHALLENGES

Storing and processing of images

recognizing patterns in the images

SOLUTIONS IN QC FOR STORAGE PROBLEM

Storing a 16 bit image with 1024 x 1024 pixel

classical computer system: $1024 \times 1024 \times 16 = 16,777,216\, bits\ or\ 2.09\, MB$

quantum computing:

FRQI: $1024 \times 1024 (= 2^{10} \times 2^{10}) = 2^{20} + 1 \rightarrow 21\, qubits$

NEQR: $1024 \times 1024 (= 2^{10} \times 2^{10}) = 2^{20} + 4 \rightarrow 24\, qubits$

SOLUTIONS IN QC FOR ANALYZING IMAGES

HYBRID QUANTUM-CONVOLUTIONAL NEURAL NETWORK

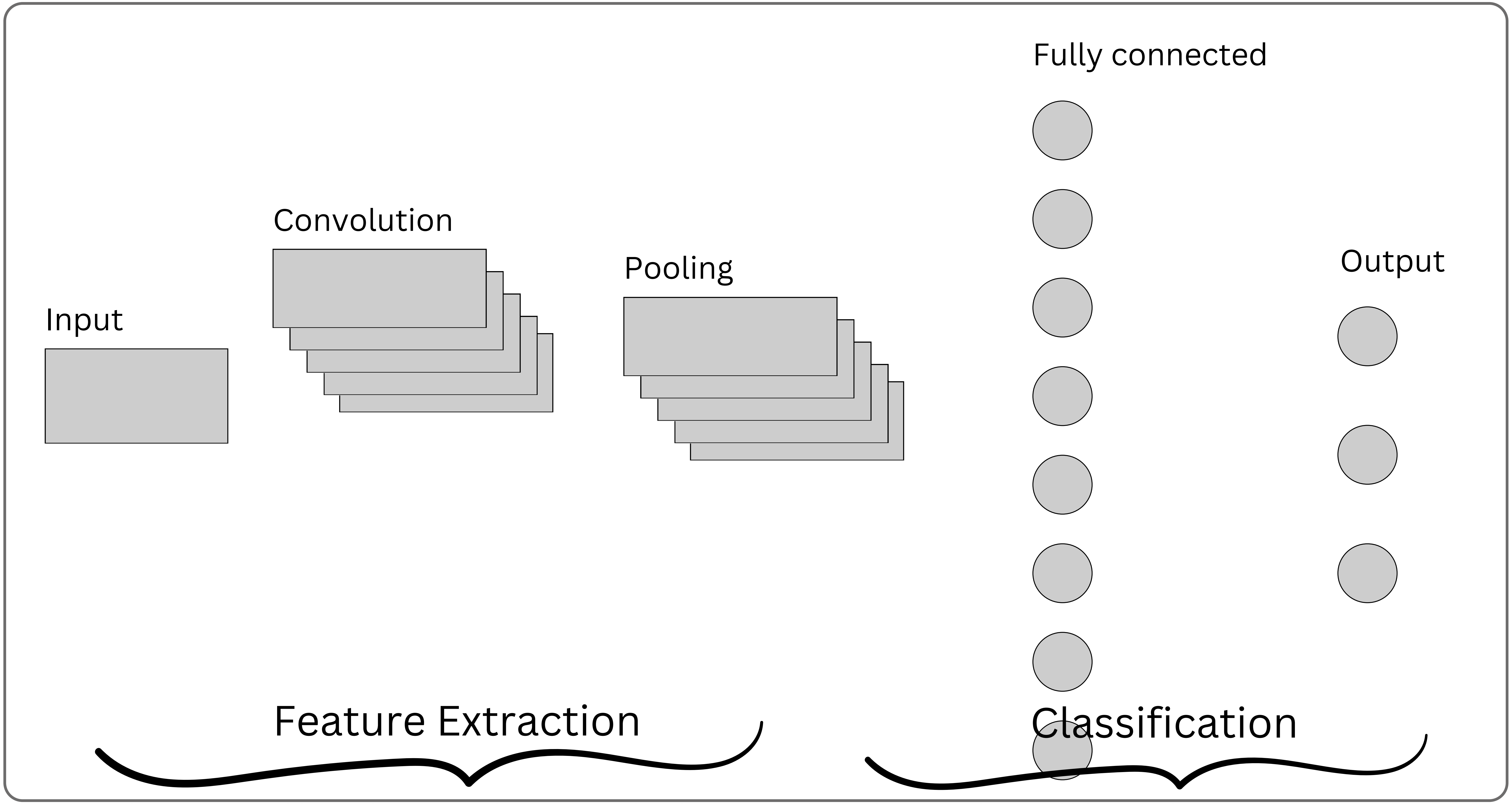
HQCNN

Why a HQCNN?

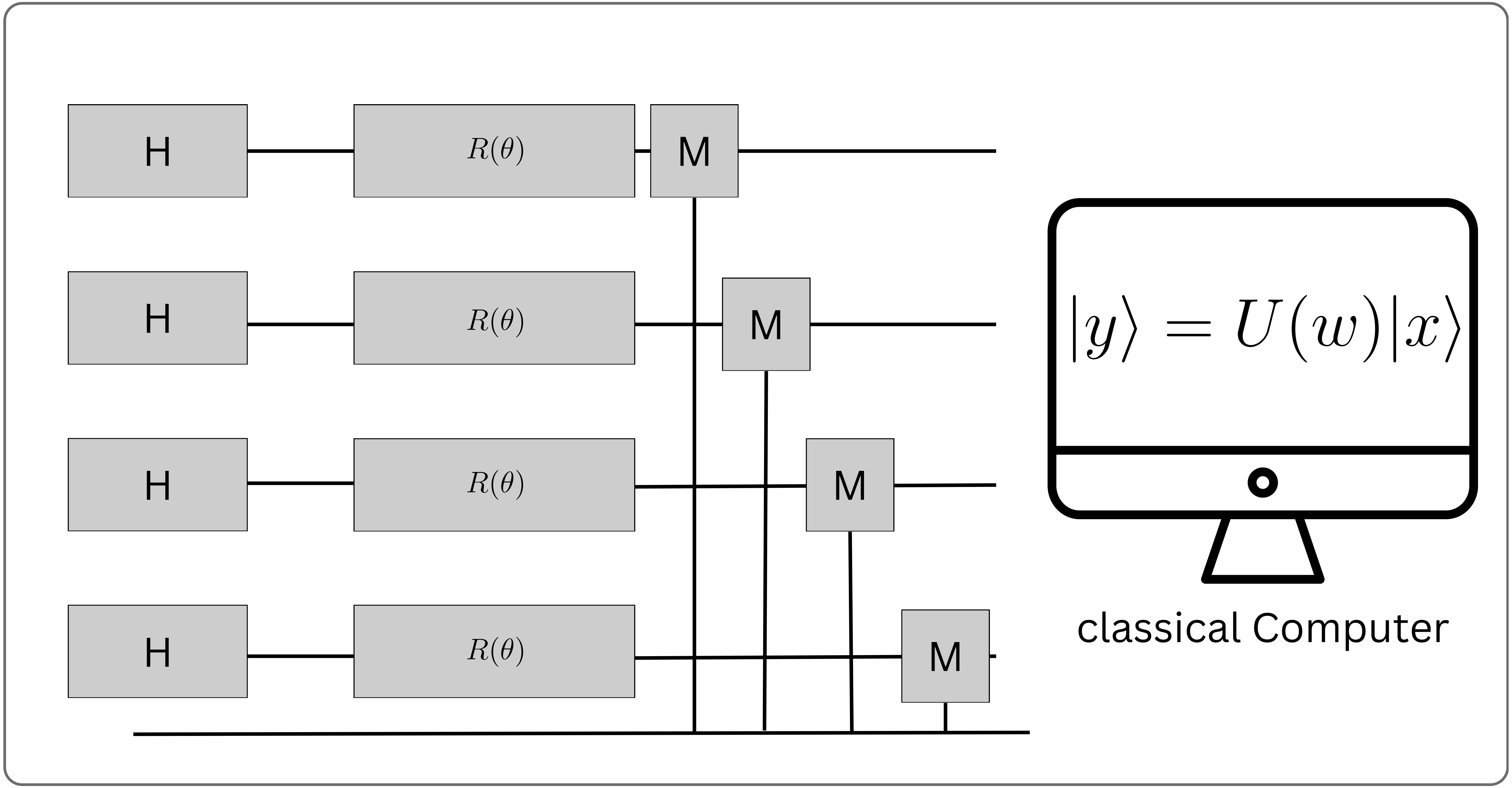
- testing CNN takes a long time
- slow inference time

What is a HQCNN?

- combines PQC with classical NN



Graphics inspired by: Ajlouni *et al. BMC Medical Imaging (2023) 23:126* https://doi.org/10.1186/s12880-023-01084-5



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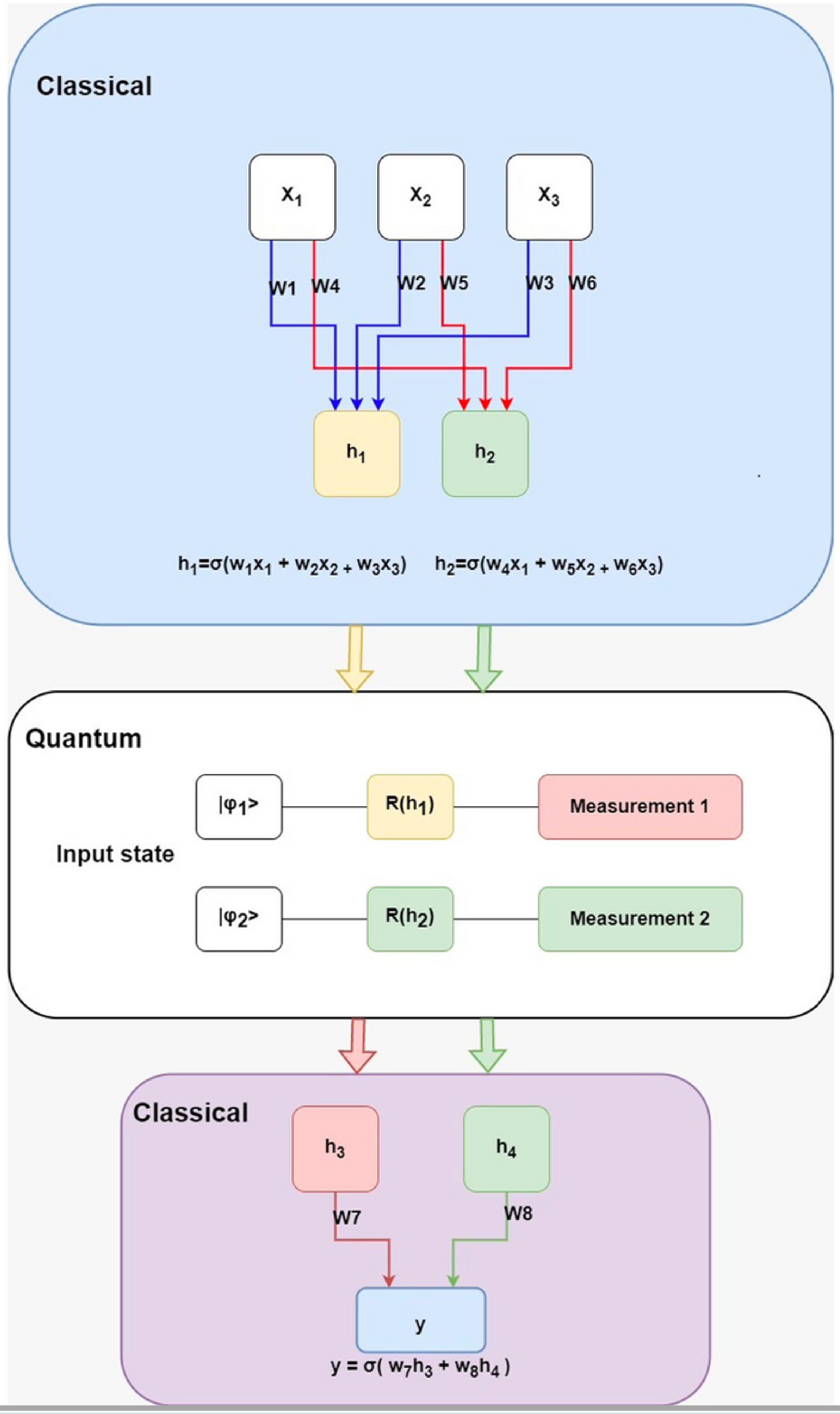
Why a HQCNN?

- Speed
- high-dimensional feature representation
- accuracy
- Robustness to noise



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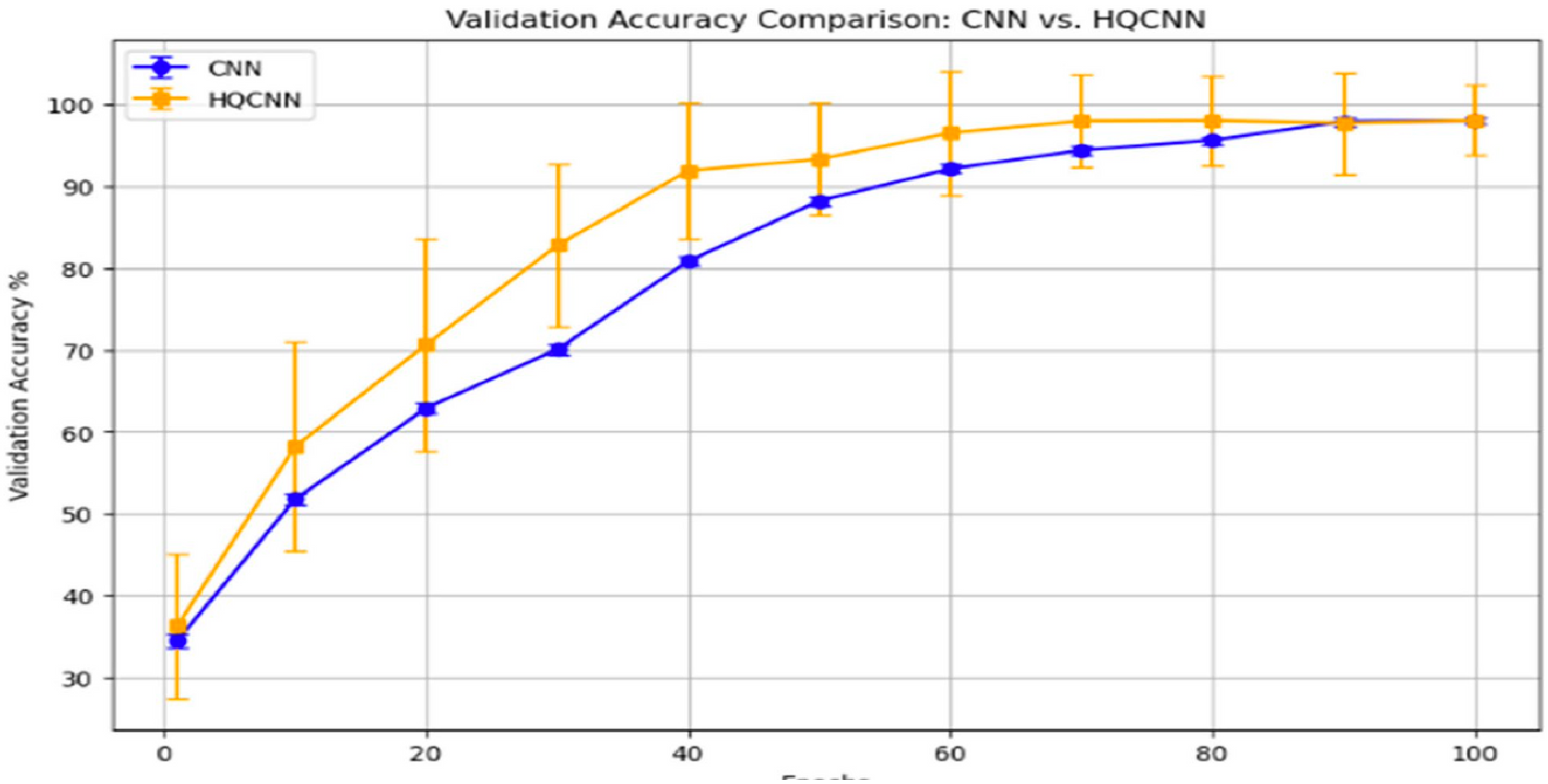
Test-results

- superior performances
- accuracy of 98.07% within 70 epochs

Table 10 Classification results of HQCNN and CNN models/

Dataset	Precision		Recall		F1 score	
	HQCNN	CNN	HQCNN	CNN	HQCNN	CNN
Kaggle Brain	97.74%	96.72%	97.33%	96.53	97.53%	96.62
REMBRANDT	96.86%	96.54	99.13%	98.91	97.98%	97.71



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CONCLUSION

- QC holds a huge potential for medical imaging
- many researches and studies ongoing
- still very much at the beginning
- combination of classical and quantum computing

QUESTIONS?

SOURCES

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