Quantum Image Processing

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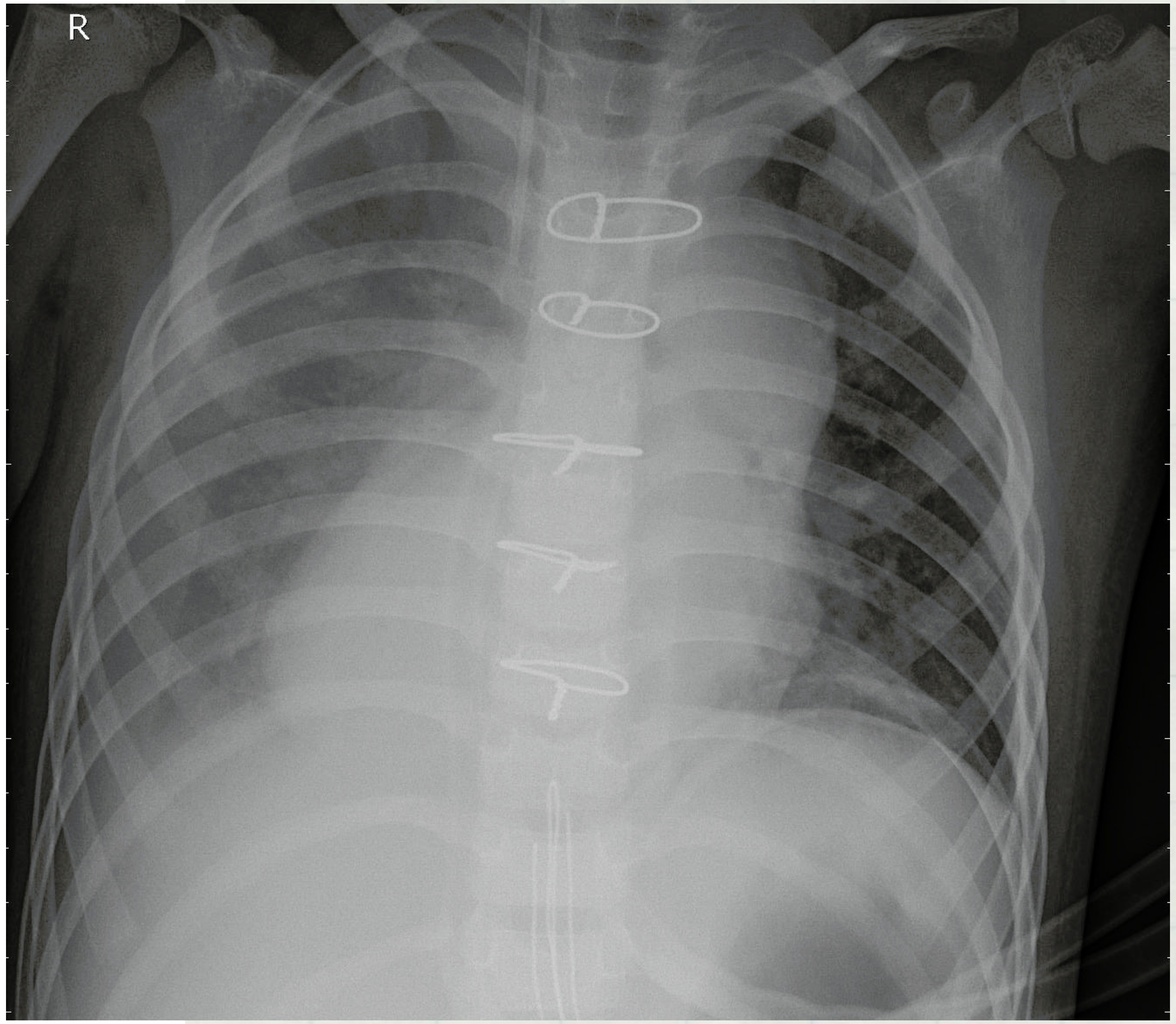
2021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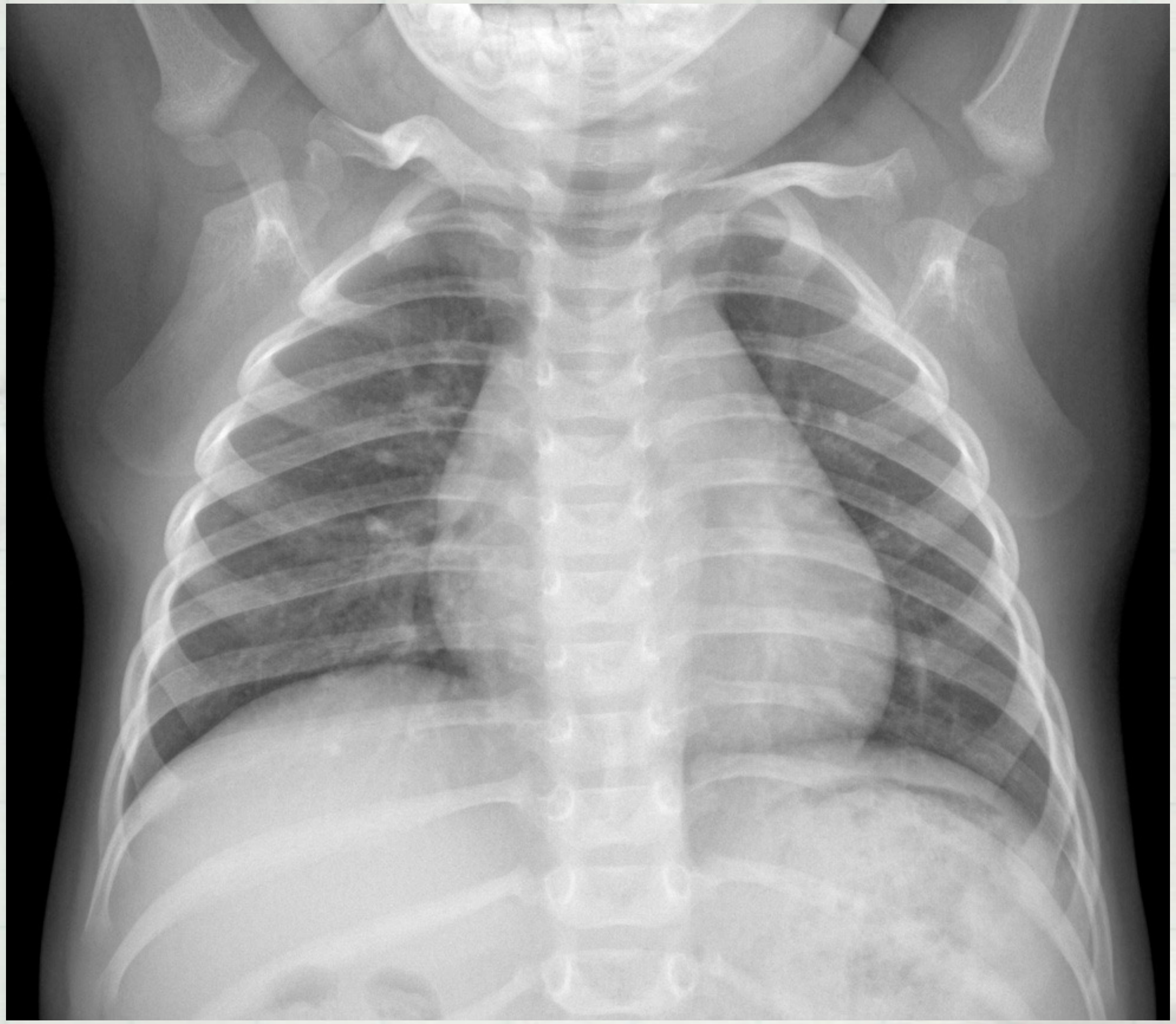
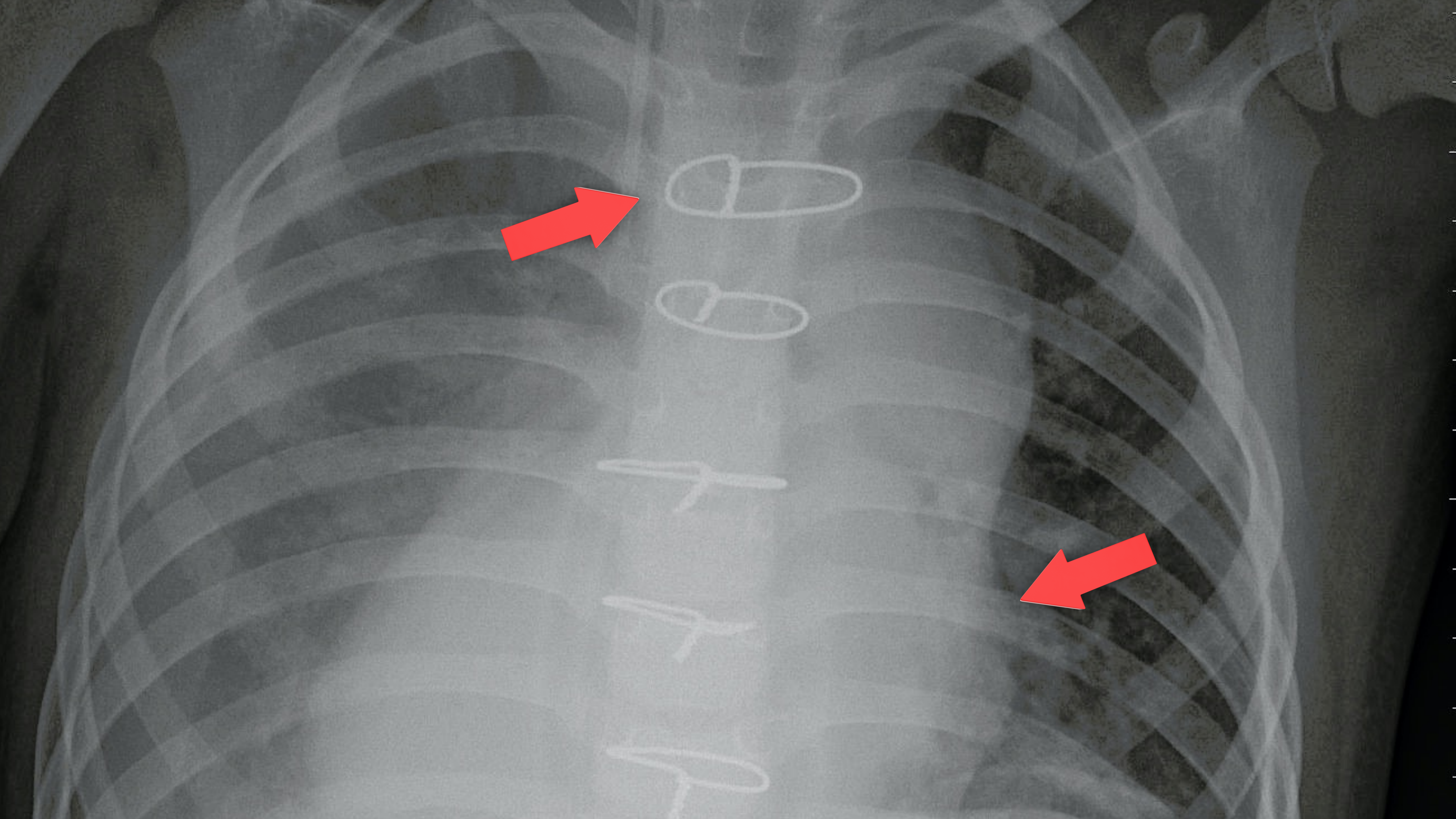
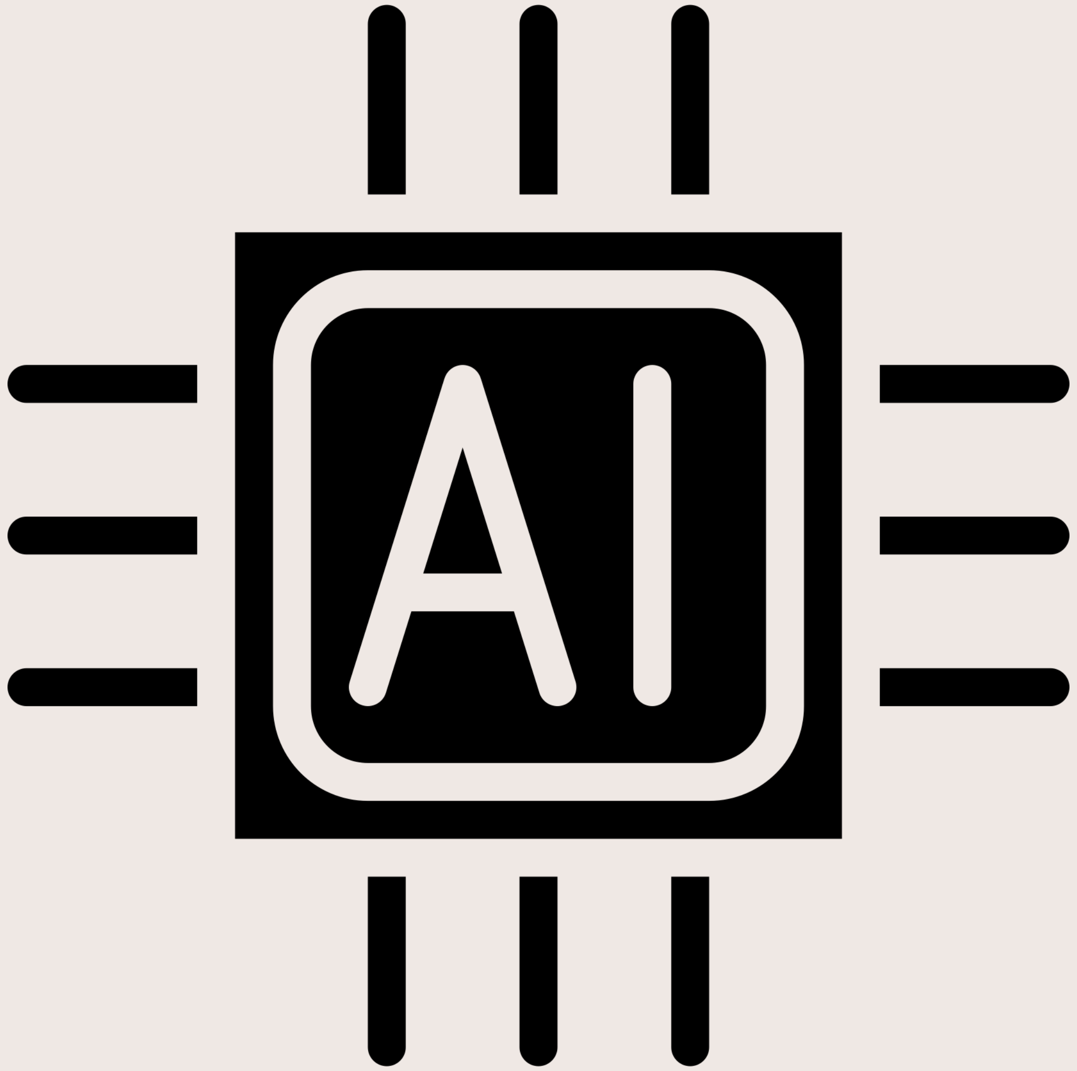
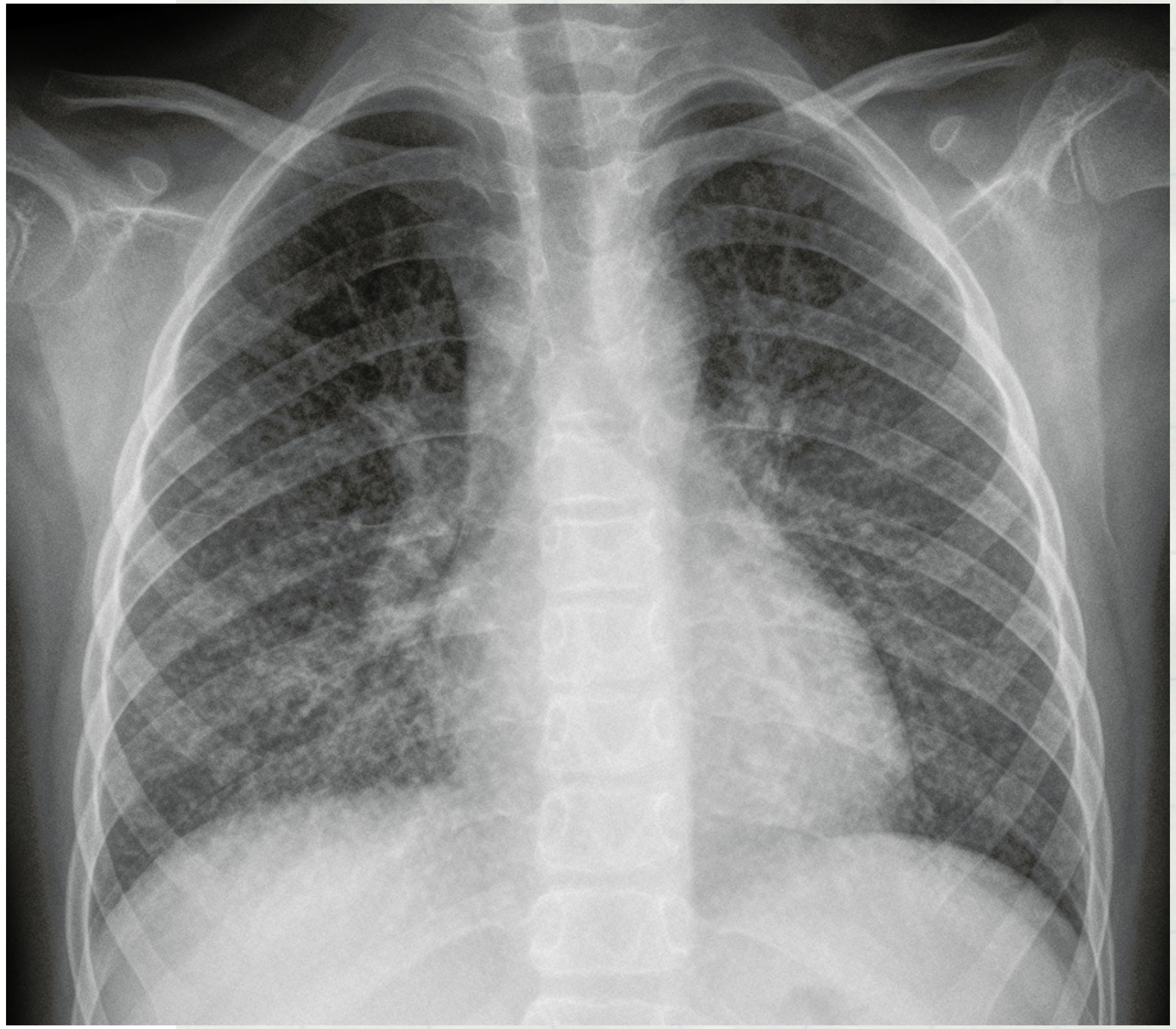




Current Solution





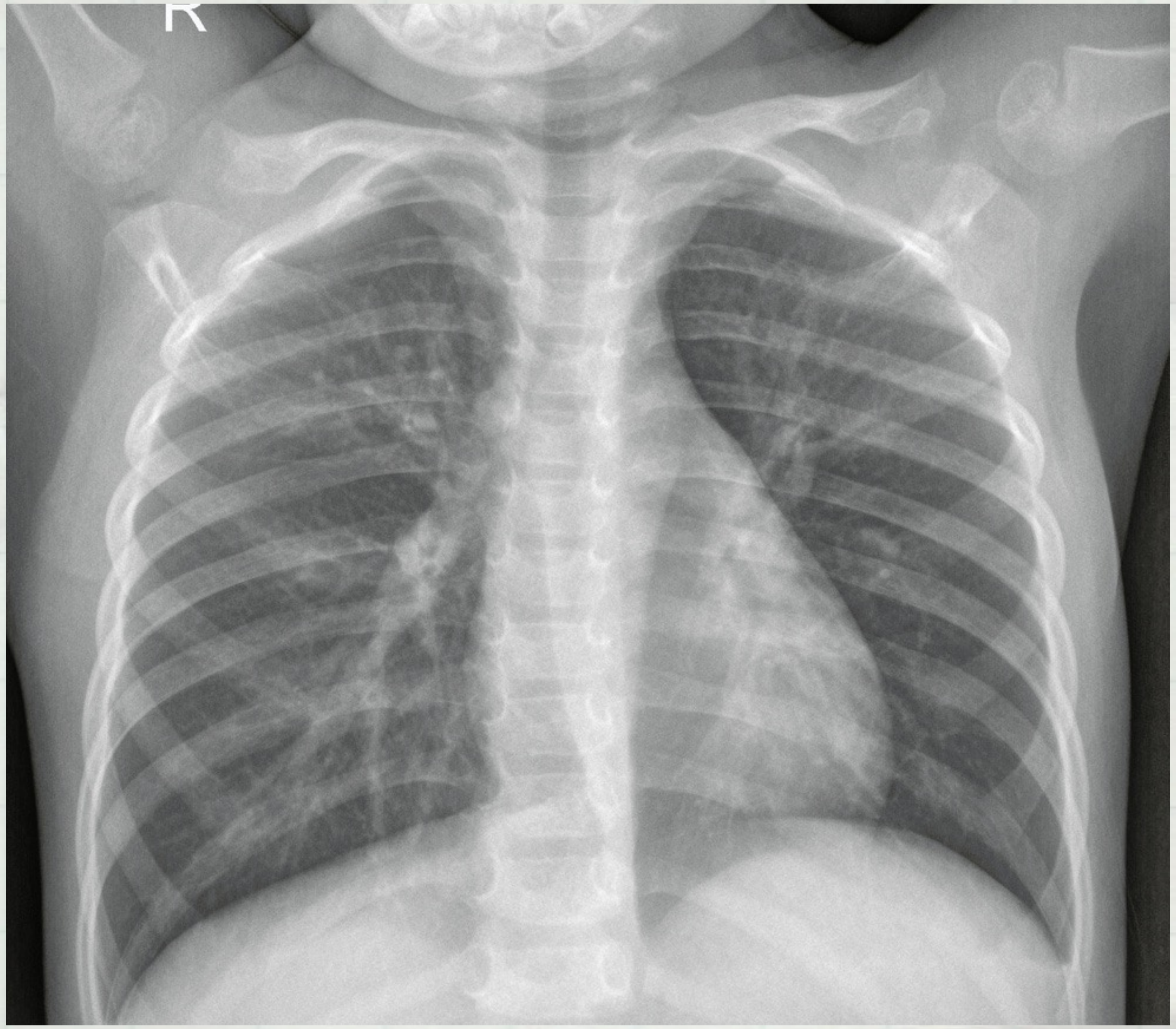

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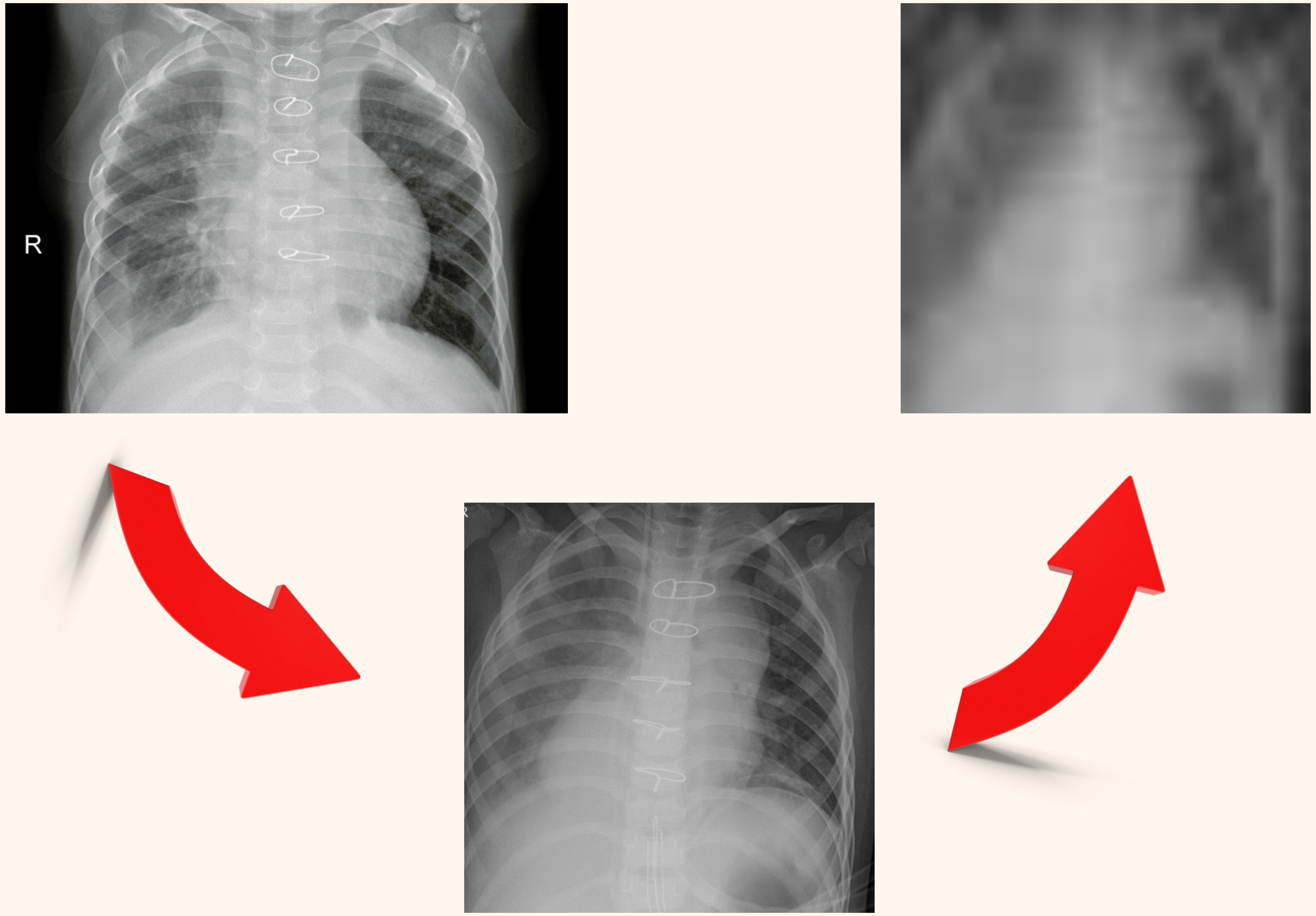
Image Matching with Qiskit

1. Image Preparation



What?

Grey scale

Square

32x32 pixels (10qbits)

Why?

#qubits <32

#gates (depth)

2. Quantum Encoding FRQI

$$|I(\theta)\rangle = \frac{1}{2^n} \sum_{i=0}^{2^{2n}-1} (\cos\theta_i \,|0\rangle + \sin\theta_i \,|1\rangle) \otimes |i\rangle$$

$$\theta_i \in \left[0, \frac{\pi}{2}\right], i = 0, 1, \cdots, 2^{2n} - 1$$

The FRQI state is a normalized state from the equation to the left and is made of two parts:

- color information encoding
- associated pixel position encoding

A 2x2 image would have the following graph.

Corresponding θ angles (color encoding) and associated kets (position encoding).

$\theta_0, \|00\rangle$	$\theta_1, \|01\rangle$
$\theta_2, \|10\rangle$	$\theta_3, \|11\rangle$

2. Quantum Encoding FRQI

What?

Classical bit / pixels $\longrightarrow$ qubits

Why?

Advantage. m pixels $\longrightarrow$ n = log2 (m) qubits

But

Data loading: m gates $\longrightarrow$ m pixels

2. Quantum Encoding FRQI

Alternative: Log Concave

- Reduce #gates
- Assumption: log concave probability distribution
- Classical probability distribution mapped to probability amplitude of quantum states.

Encoding	Classical	Quantum FRQI	Quantum Log concave
Pixels	m bits	$\log_2 m$ qubits	$\log_2 m$ qubits
Gates	-	m	$\log_2 m$

3. Quantum edge detection

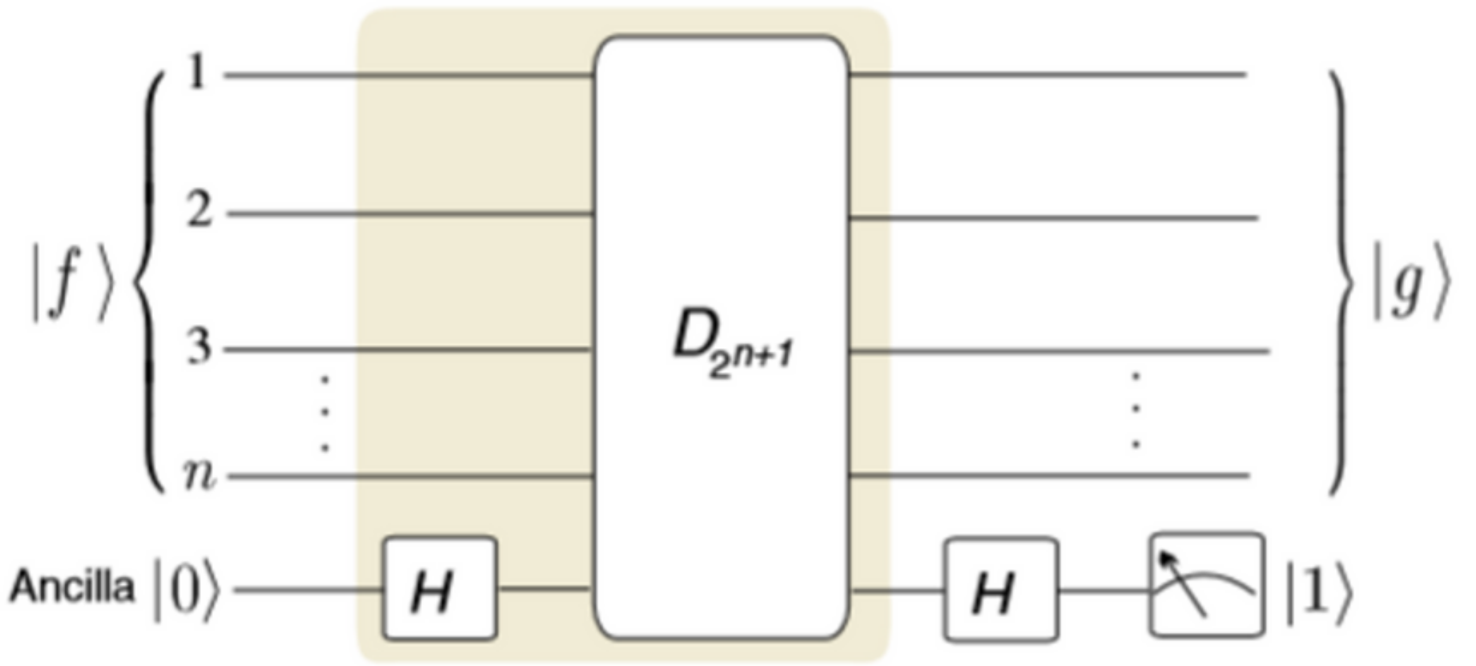


FIG. 9. Quantum circuit for the QHED algorithm with an auxiliary qubit. H is a Hadamard gate, and $D_{2^{n+1}}$ is an amplitude permutation operation for $n+1$ qubits.

Source: Yao, X. W., Wang, H., Liao, Z., Chen, M. C., Pan, J., Li, J., ... & Zheng, W. (2017). Quantum image processing
and its application to edge detection: Theory and experiment. Physical Review X, 7(3), 031041.

3. What is an edge?

$$\alpha = [0,\ 0,\ 0,\ 1,\ 1,\ 1,\ 0,\ 0,\ 0],$$

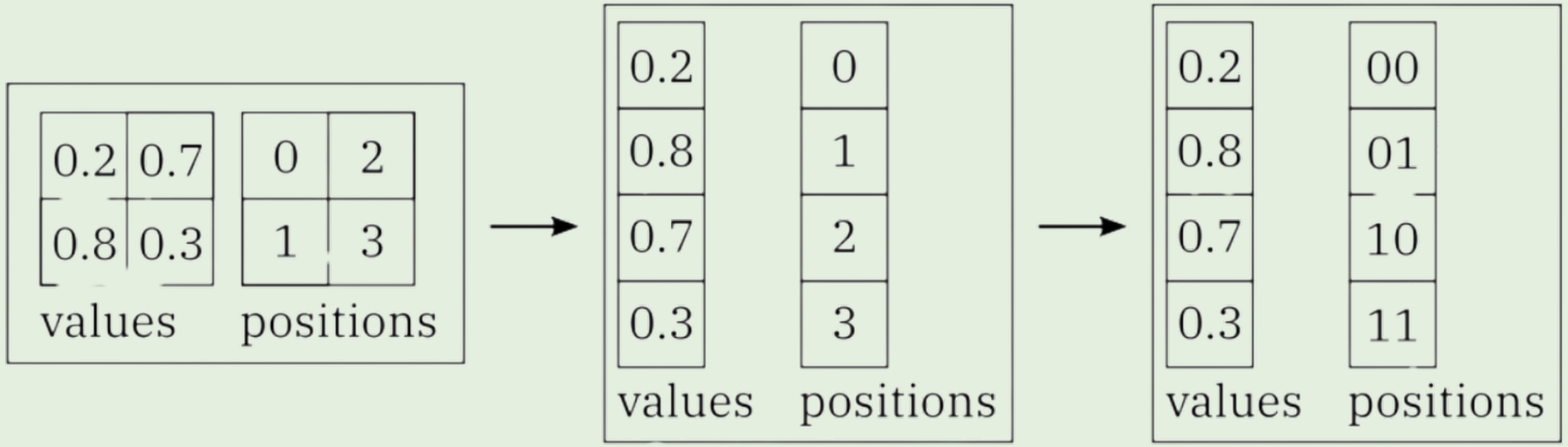
$$\Delta\alpha = [0,\ 0,\ 1,\ 0,\ 0,\ -1,\ 0,\ 0,\ 0]$$

The Delta A is the difference of a pixel's nearest neighboring pixels

The differences (Delta A) take on non-zero values where there are changes (edges) in the original image.

So, a Delta A indicates an edge.

3. Image into statevector

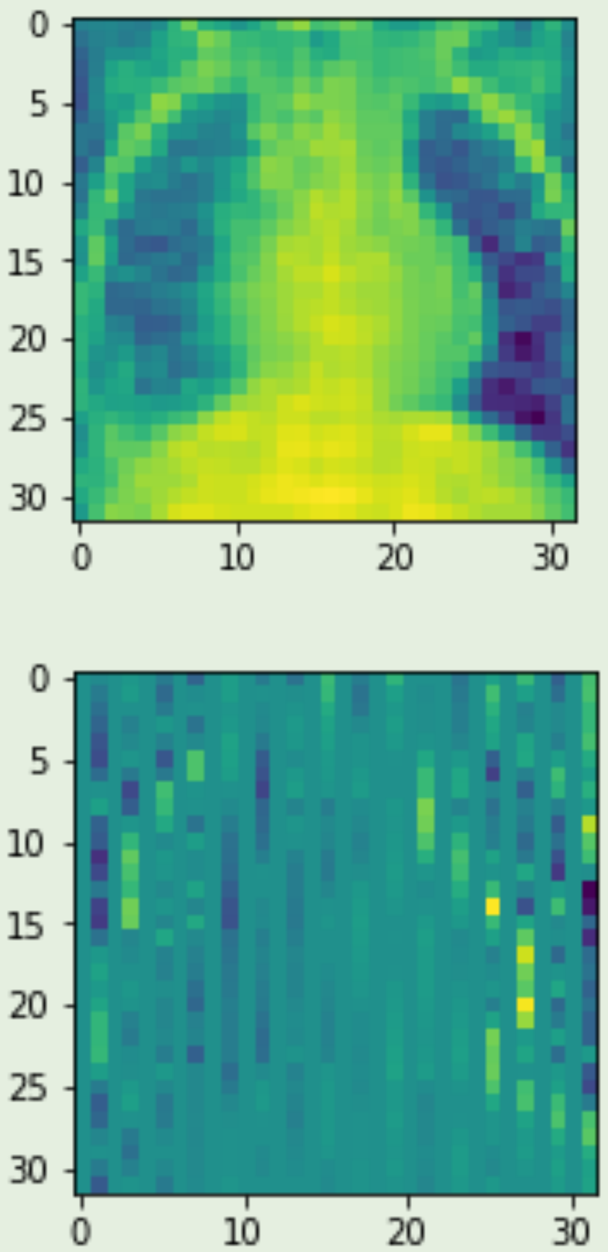


The image begins as a series of values corresponding to pixel positions. As you unravel the matrices to form vectors, you rewrite the pixels from decimals to binary.

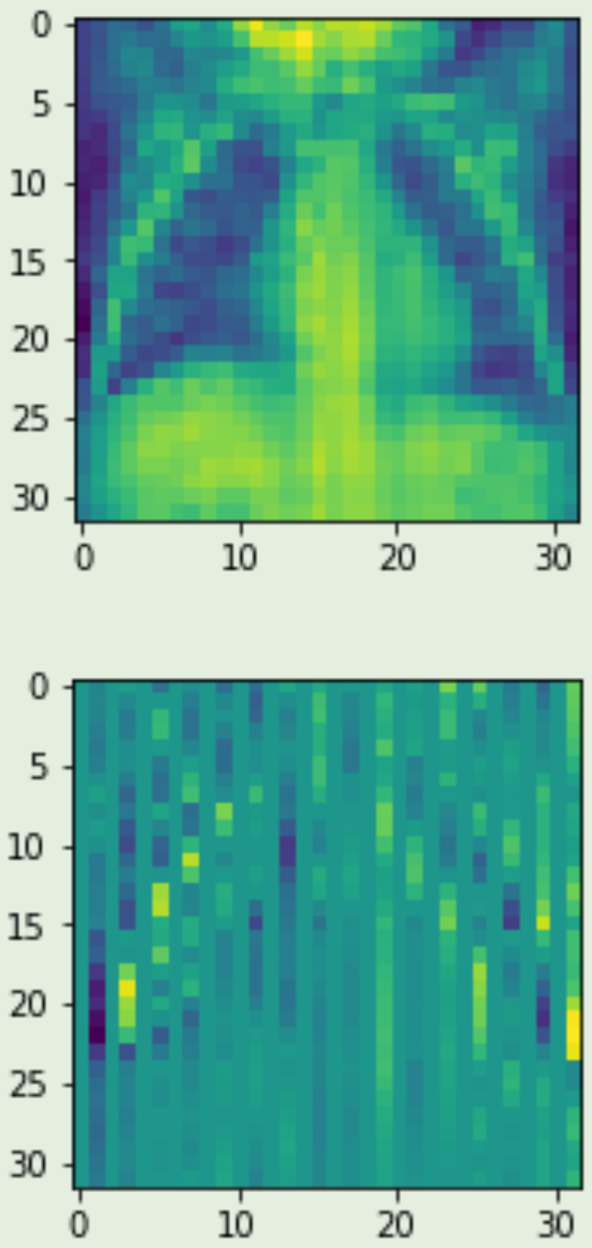
That eventually corresponds to the quantum state of the system.

$$|\text{image}\rangle = \frac{0.2|00\rangle + 0.8|01\rangle + 0.7|10\rangle + 0.3|11\rangle}{\sqrt{0.2^2 + 0.8^2 + 0.7^2 + 0.3^2}}$$

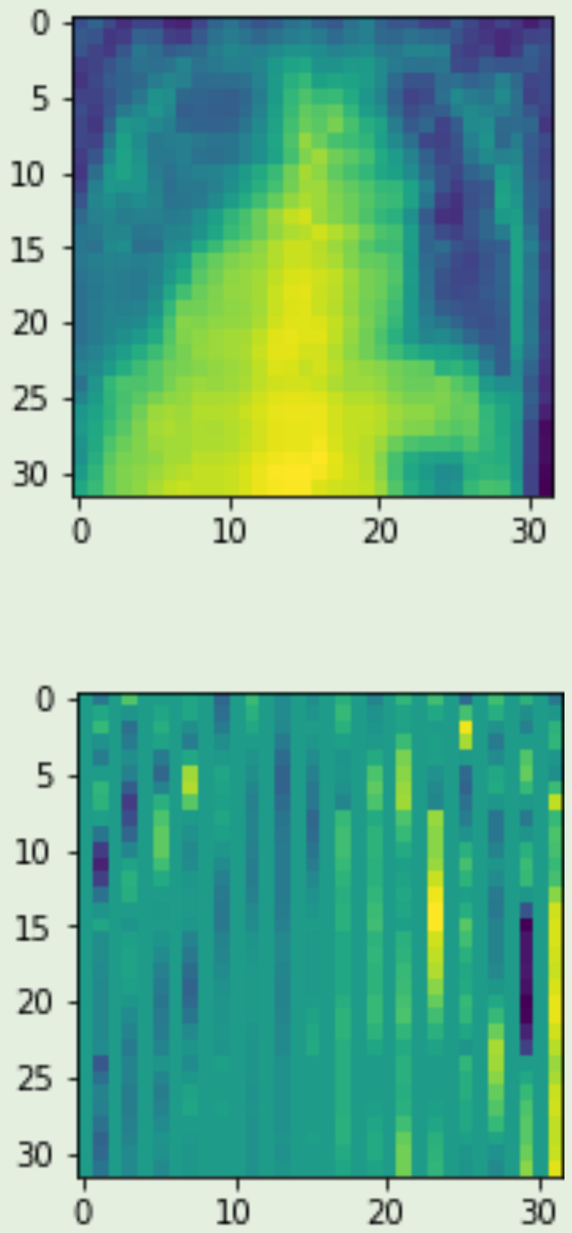
3. Results



TEST



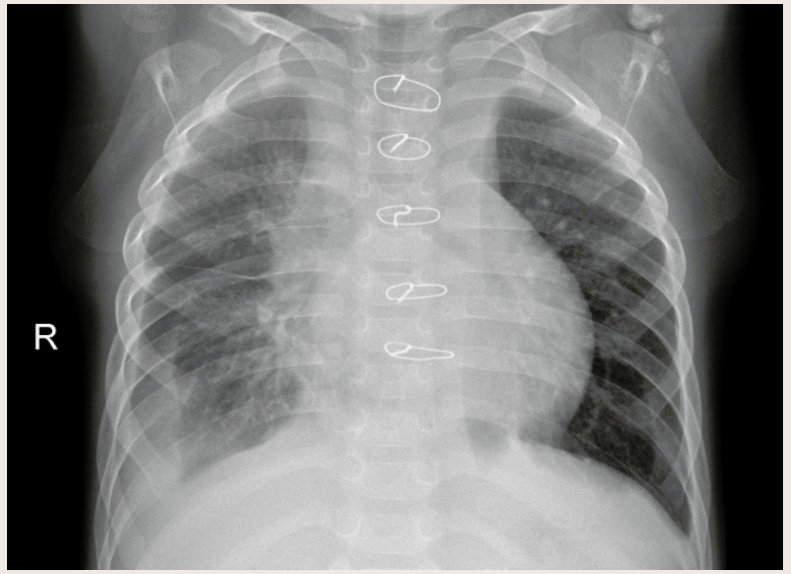
NORMAL



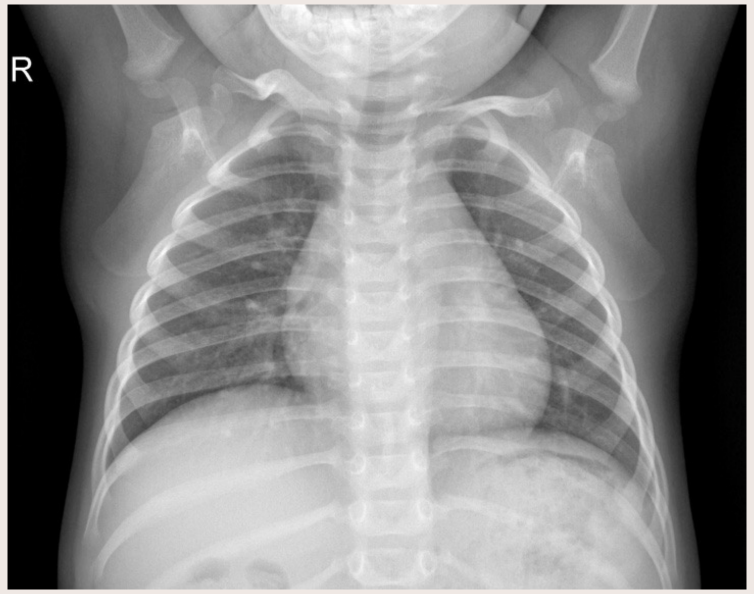
PNEUMONIA

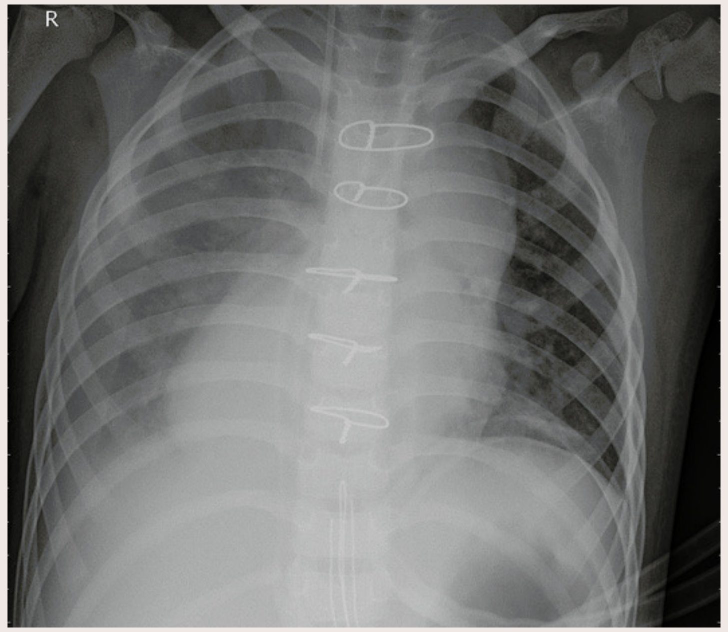
4. Quantum Matching

Problem Picture

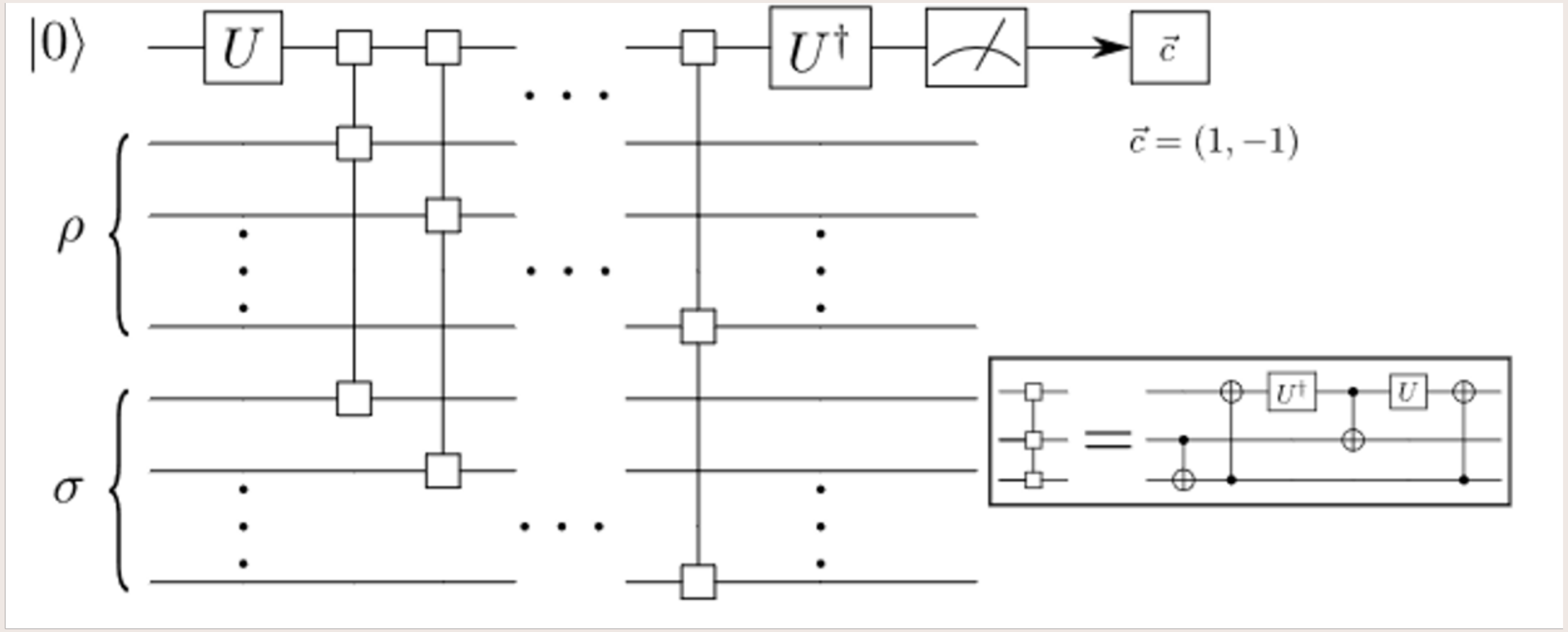


Two Options



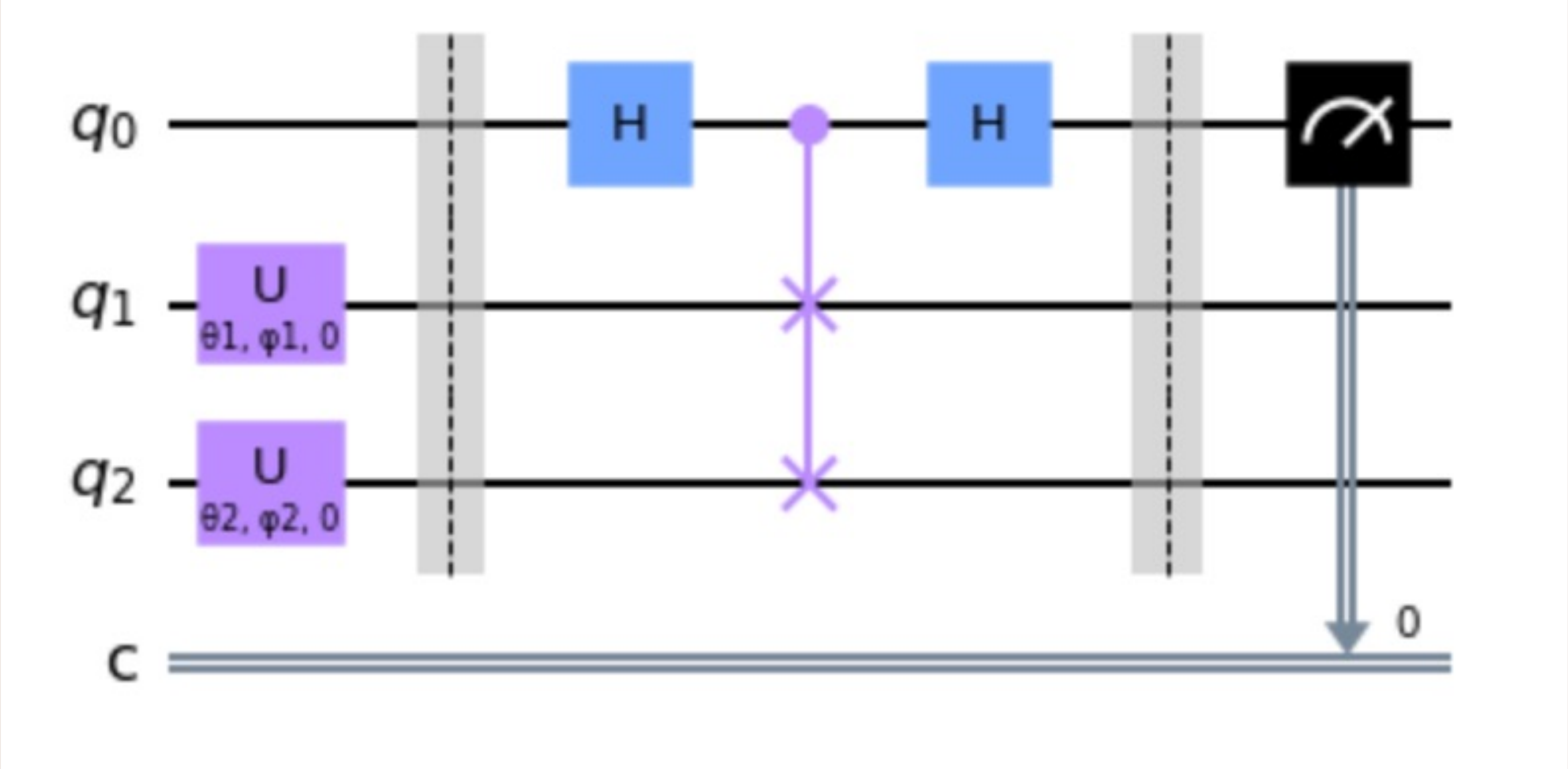


4. The Circuit



Source: Cincio, L., Subaşı, Y., Sornborger, A. T., & Coles, P. J. (2018). Learning the quantum algorithm for state overlap. New Journal of Physics, 20(11), 113022.

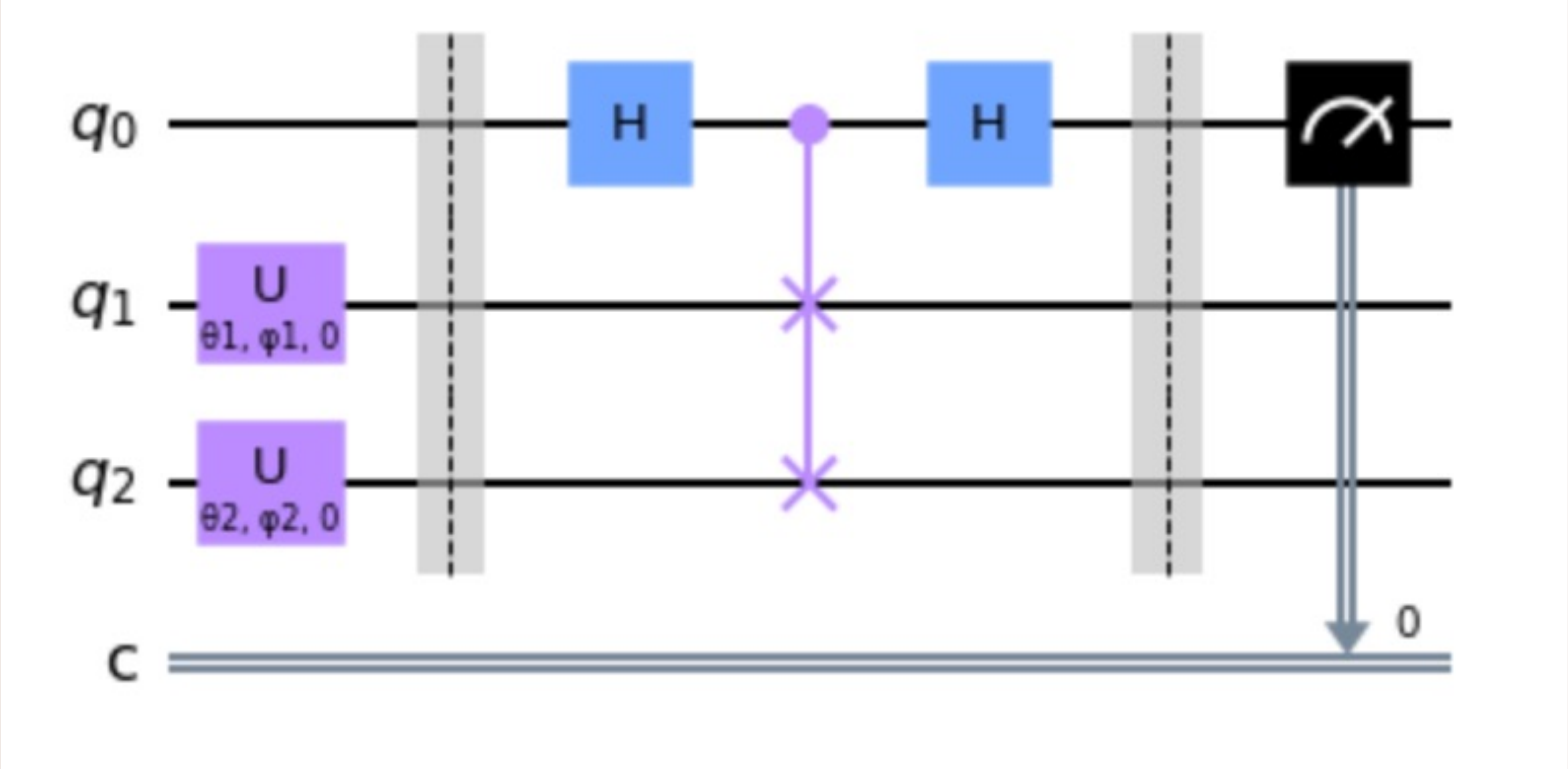
4. My Circuit



The qubits used to encode both the test and reference images represent the density matrices for each image.

These density matrices can then be compared via a quantum based similarity test.

4. SWAP Test

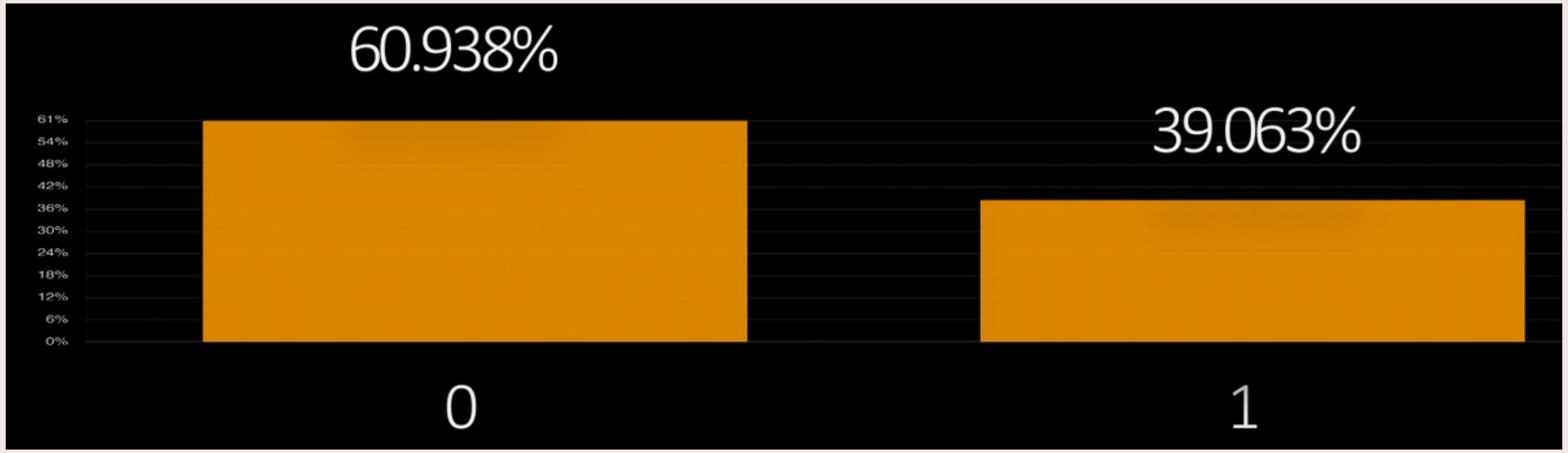


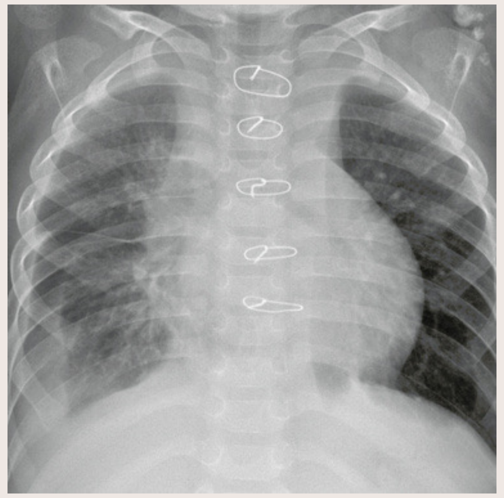
Two of these components have the ancilla in the |1> state, two have it in |0>; the probability of measuring |1> is related to the inner product of the input states.

If the states are parallel, we always measure 0 (useful for results later). Otherwise, there's a nonzero chance of measuring 1.

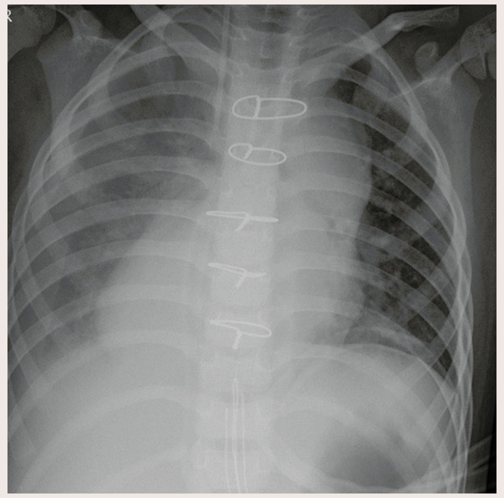
4. Results

Shots 1024
Simulation time taken 34m 4.8s





Problem Image

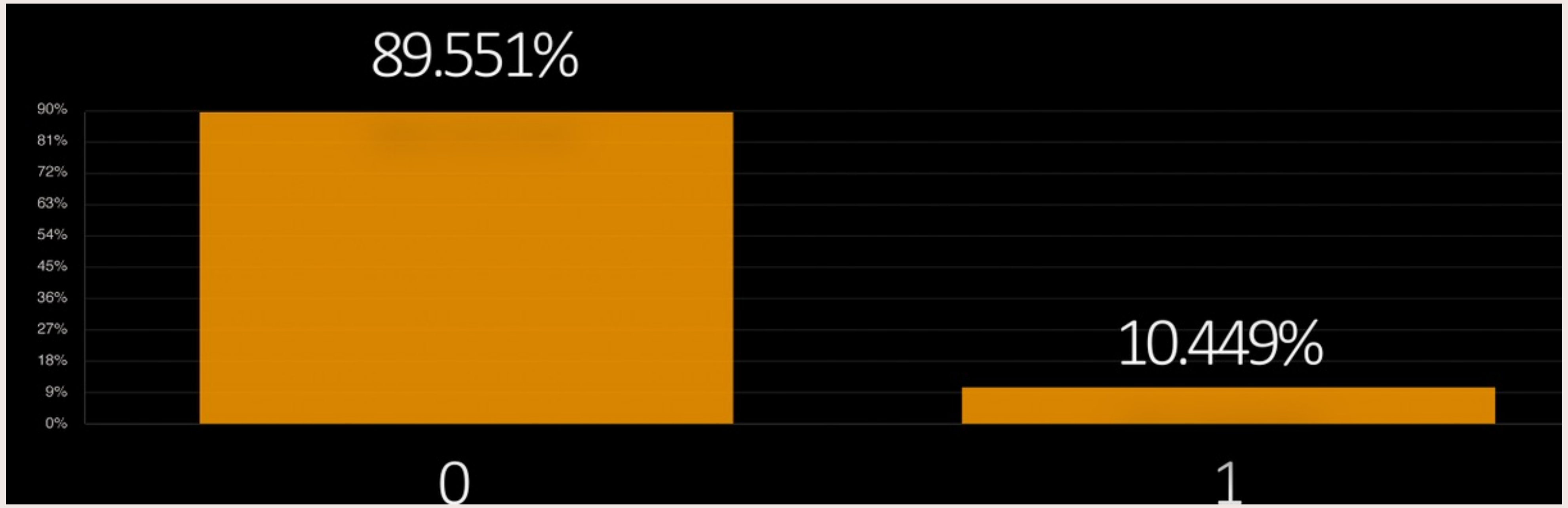


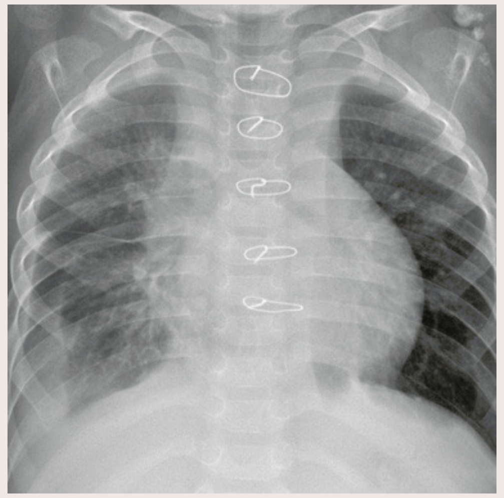
SWAP Image

4. Results

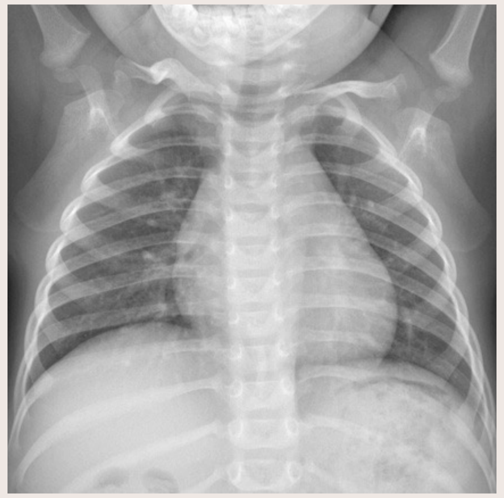
1 2 3 4

Shots 1024
Simulation time taken 30m 18.5s





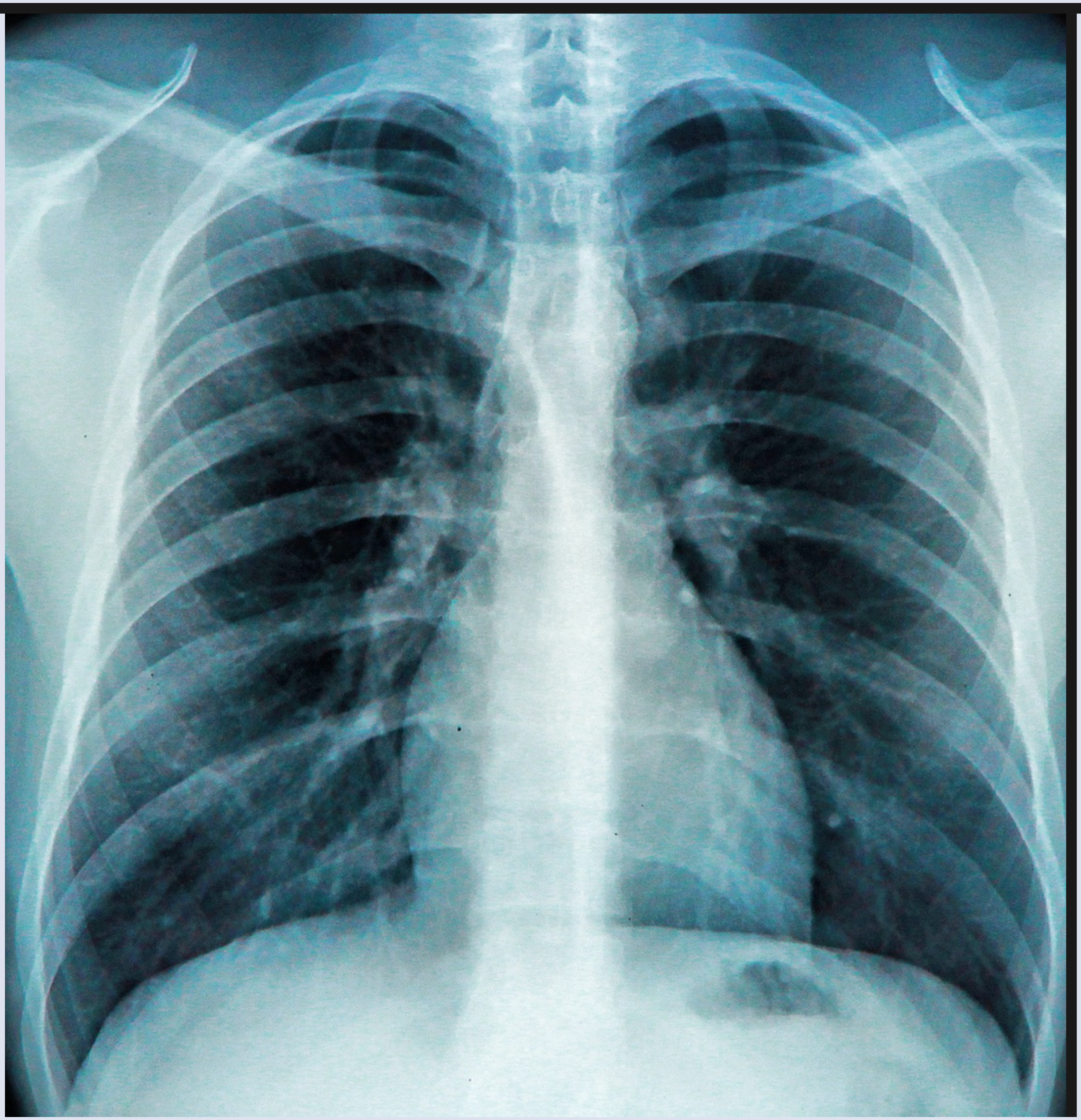
Problem Image



SWAP Image

Qiskit Implementation

Conclusion



- Algorithm showed that the patient was more similar to one who had pneumonia as opposed to not
- Classical AI still possesses an advantage with image similarity through deep learning. However, advances in hardware may change that.
- Further research involves mapping the images on near-term algorithms such as QAOA or VQE
- The algorithm can be applied to other forms of medical images such as tumors

References

[1] Yao, X. W., Wang, H., Liao, Z., Chen, M. C., Pan, J., Li, J., ... & Zheng, W. (2017).
 Quantum image processing and its application to edge detection: Theory and experiment. Physical Review X, 7(3), 031041.

[2] Le, P. Q., Dong, F., & Hirota, K. (2011).
A flexible representation of quantum images for polynomial preparation, image compression, and processing operations.
Quantum Information Processing, 10(1), 63-84.

[3] Le, Q. P., Fangyang, D., Yoshinori, A., & Kaoru, H. (2009).
Flexible representation of quantum images and its computational complexity analysis. I
In 日本知能情報ファジィ学会 ファジィ システム シンポジウム 講演論文集
第 25 回ファジィ システム シンポジウム (pp. 185-185). 日本知能情報ファジィ学会

[4] Yuan, Suzhen & Venegas-Andraca, Salvador & Wang, Yuchan & Luo, Yuan & Mao, Xuefeng. (2019).
Quantum Image Edge Detection Algorithm. International Journal of Theoretical Physics. 10.1007/s10773-019-04166-9.

[5] Gómez-Moreno, H., Maldonado-Bascón, S., López-Ferreras, F., Acevedo-Rodríguez, F. J., & Martín-Martín, P. (2001).
Edge detection by using the support vector machines. training, 2, 3. [6] Cincio, L., Subaşı, Y., Sornborger, A. T., & Coles, P. J. (2018).
Learning the quantum algorithm for state overlap. New Journal of Physics, 20(11), 113022.