“Quantum Image Scaling Using Nearest Neighbor Interpolation”

Nan Jiang · Luo Wang

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Done By :

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INTRODUCTION

- Image scaling refers to the **resizing of a digital image**
- In the case of **up scaling** there is multiplication of pixels by a scaling ratio and in **down scaling** there is a visible quality loss.
- One of the simpler ways of increasing image size is **Nearest Neighbor Interpolation**
- Involves **replacing every pixel with the nearest pixel** in the output.

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NEAREST NEIGHBOR SCALING

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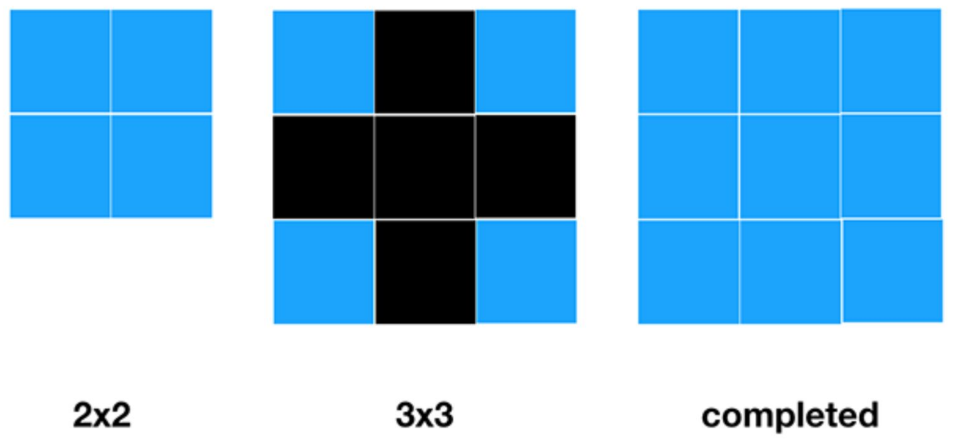


Example of Nearest Neighbor Scaling.

- This technique replaces every pixel with the **nearest pixel** in the output.
- When upscaling an image, **multiple pixels of the same color** will be **duplicated** throughout the image
- We have an image region of 2x2 blue pixels. When we upscale it to 3x3, we create 5 additional pixels, that have **no color associated** with it.
- Using Nearest Neighbor, the algorithm merely uses the **blue pixel's color to assign to the new pixels**.

PAPER CONTRIBUTION AND NOVELTY

- Although image scaling algorithms in classical image processing have been extensively studied, the **quantum versions are not that extensively explored**.
- In this paper, quantum algorithms and circuits are designed to realize the quantum image scaling based on the **improved novel enhanced quantum representation (INEQR)** for quantum images.
- Using this representation, quantum circuits are proposed for image scaling using nearest neighbor interpolation from $2^{n1} \times 2^{n2}$ to $2^{m1} \times 2^{m2}$.
- The quantum strategies developed in this paper initiate the research about **quantum image scaling**.

HOW TO REPRESENT A QUANTUM IMAGE?

There exist a number of ways to represent images as quantum qubits. Among these, **NEQR is posited to be the most appropriate** because:

- NEQR captures information about **colors** and **their corresponding positions** in an image into normalized quantum states: $|0\rangle$ or $|1\rangle$.
- These states can be accessed by using **NOT gates**, **CNOT gates** and other simple quantum gates.
- Colors and positions are all stored in **binary quantum sequences** which is similar to the representations of classical digital images.
- This makes it relatively easy to transplant **image processing algorithms** from **classical** computers to **quantum** computers.

HOW TO REPRESENT A QUANTUM IMAGE?

The gray range of image is 2^q , binary sequence -

$\mathbf{C^0_{YX}C^1_{YX} \ldots C^{q-2}_{YX}\ C^{q-1}_{YX}}$ encodes the gray-scale value f (Y, X) of the corresponding pixel (Y, X).

$$\mathbf{f\,(Y, X) = C^0_{YX}C^1_{YX} \ldots C^{q-2}_{YX}\ C^{q-1}_{YX}},\quad C^k_{YX} \in \{0, 1\},\ f\,(Y, X) \in 0, 1, \ldots, 2^q - 1$$

According to the NEQR, a $2^n \times 2^n$ quantum image can be written as the form shown below:

$$|I\rangle = \frac{1}{2^n} \sum_{Y=0}^{2^n-1} \sum_{X=0}^{2^n-1} |f(Y, X)\rangle |YX\rangle = \frac{1}{2^n} \sum_{Y=0}^{2^n-1} \sum_{X=0}^{2^n-1} \bigotimes_{i=0}^{q-1} |C^i_{YX}\rangle |YX\rangle$$

$$|YX\rangle = |Y\rangle|X\rangle = |y_0 y_1 \ldots y_{n-1}\rangle |x_0 x_1 \ldots x_{n-1}\rangle,\ \ y_i, x_i \in \{0, 1\}$$

Therefore, NEQR needs **q + 2n qubits** to represent a **$2^n \times 2^n$ image** with gray range 2^q .

HOW TO REPRESENT A QUANTUM IMAGE?

NEQR deals with quantum images having **$2^n \times 2^n$ pixels.**

However, if **$rx \neq ry$**, the size of the scaled image will **not** be in the form of $2^n \times 2^n$.

In order to solve the problem, the **improved NEQR (INEQR)** is proposed to represent quantum images having **$2^{n1} \times 2^{n2}$ pixels** as shown below:

$$|I\rangle = \frac{1}{2^{\frac{n_1+n_2}{2}}} \sum_{Y=0}^{2^{n_1}-1} \sum_{X=0}^{2^{n_2}-1} |f(Y,X)\rangle |YX\rangle = \frac{1}{2^{\frac{n_1+n_2}{2}}} \sum_{Y=0}^{2^{n_1}-1} \sum_{X=0}^{2^{n_2}-1} \bigotimes_{i=0}^{q-1} |C_{YX}^{i}\rangle |YX$$

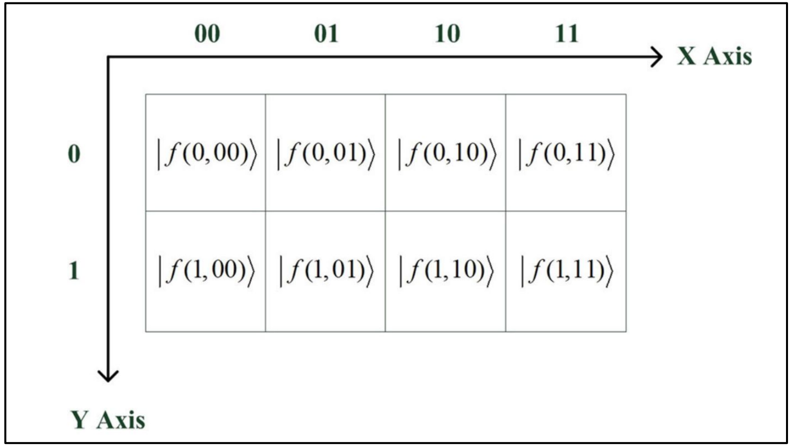
$$|YX\rangle = |Y\rangle|X\rangle = |y_0 y_1 \ldots y_{n_1-1}\rangle |x_0 x_1 \ldots x_{n_2-1}\rangle, \;\; y_i, x_i \in \{0, 1\}$$

SCALING A QUANTUM IMAGE

To scale a $2^{n1} \times 2^{n2}$ quantum image to $2^{m1} \times 2^{m2}$ the **scaling ratio taken is $2^{m1-n1} \times 2^{m2-n2}$.**

Based on the INEQR, (Y, X), f (Y, X) and (Y', X'), f '(Y', X') are employed to notate the **color** and **site information** of the original and the scaled image.

Using INEQR, the Image is represented as:

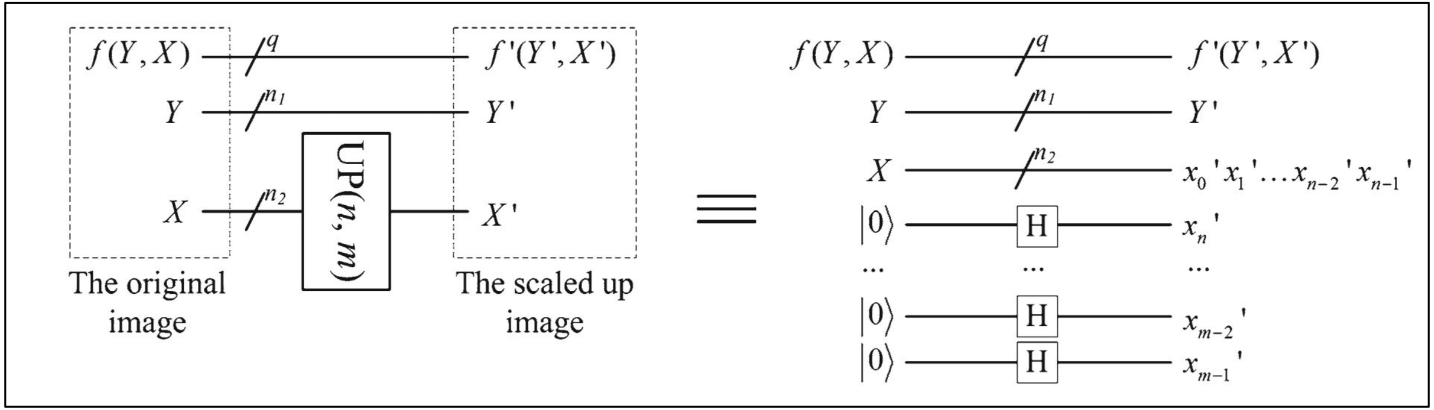


UPSCALING A QUANTUM IMAGE

To upscale an image in INEQR representation, we follow a 2 step approach:

- Prepare m − n |0> qubits as the new position qubits of X axis.
- Add m − n Hadamard gates to derive x'_n, x'_{n+1},..., x'_{m-2}, x'_{m-1}.

The Hadamard gates make |0> and |1> **appear with equal probability**.

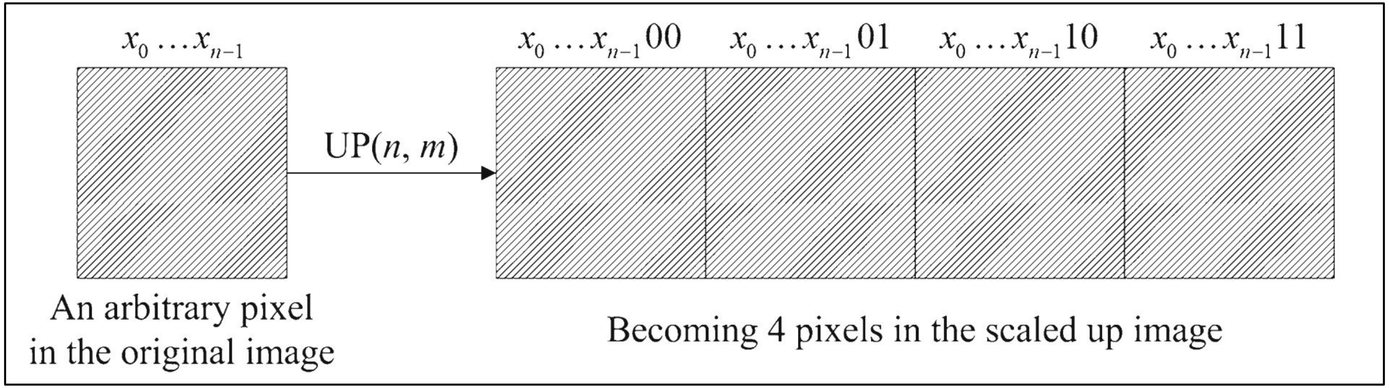


UPSCALING A QUANTUM IMAGE

Here every pixel $|x_0x_1 \ldots x_{n-2}x_{n-1}>$ in the original image becomes

rx = 2^{m-n} pixels= $|x_0x_1 \ldots x_{n-2}x_{n-1}\ 0 \ldots 0>, \ldots, |x_0x_1 \ldots x_{n-2}x_{n-1}\ 1 \ldots 1>$

and the **color value of all the rx pixels are equal**. This means that every pixel in the original image is **repeated rx times** as shown below:



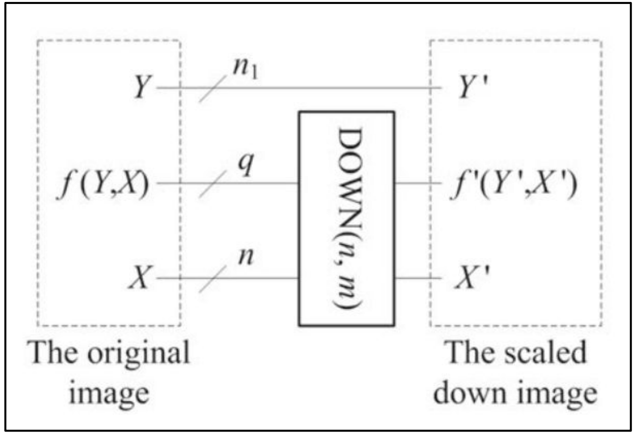
DOWNSCALING A QUANTUM IMAGE

- In the original image, the **location information** of a pixel is $|x_0x_1 \ldots x_{m-1}\ x_m\ x_{m+1} \ldots\ x_{n-2}x_{n-1}\ \rangle$
- We divide it into two parts: $|x_0x_1 \ldots x_{m-1}\ \rangle$ and $|\ x_{m+1} \ldots\ x_{n-2}x_{n-1}\ \rangle$ and they have the following characteristics:
- **All the pixels** that belong to one group **have the same** $|x_0x_1 \ldots x_{m-1}\ \rangle$ and it is equal to the label of the group, i.e., the location information of the pixel in the scaled down image that the group produced.
- The colour value of X' in the scaled down image is **equal to the colour** value of $|x'_0x'_1 \ldots x'_{m-1}\ 10\ldots0\rangle$, i.e., $x_mx_{m+1} \ldots x_{n-1} = 10 \ldots 0$.

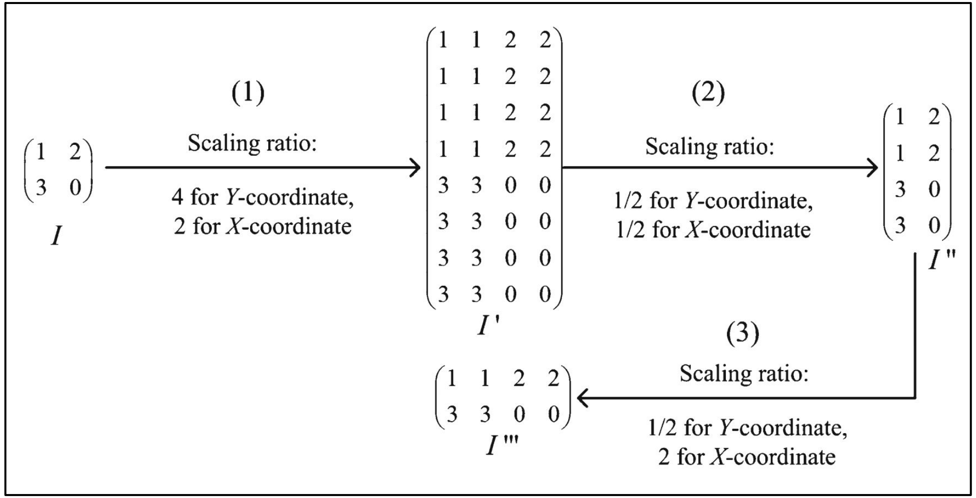
DOWNSCALING A QUANTUM IMAGE

The steps to **downscale** an image in INEQR are:

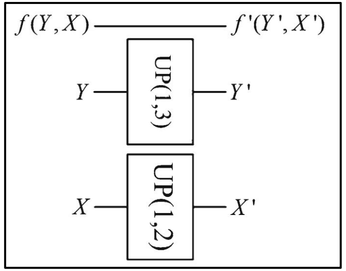
- Add q |0> qubits as the **new color qubits** and m |0 > qubits as the new X position qubits of the scaled down image.
- Add **m Hadamard gates** to derive $\mathbf{x_0\ x_1\ ...\ x_{m-2}x_{m-1}}$
- Using CNOT gates, copy f (Y, X) to f ‘(Y’ , X’) when $\mathbf{x_m\ x_{m+1}\ ...\ x_{n-1} = 10\ ...\ 0.}$



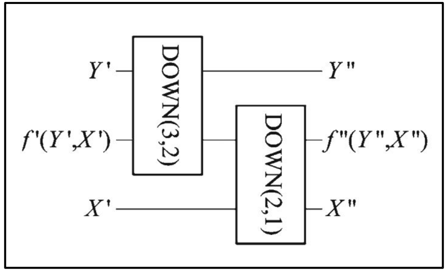
EXAMPLES



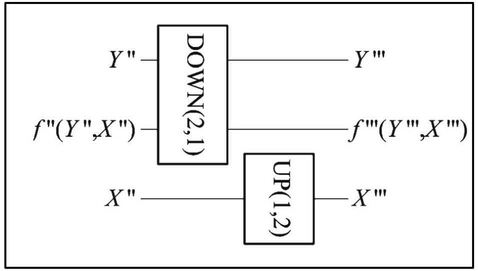
(1)



(2)

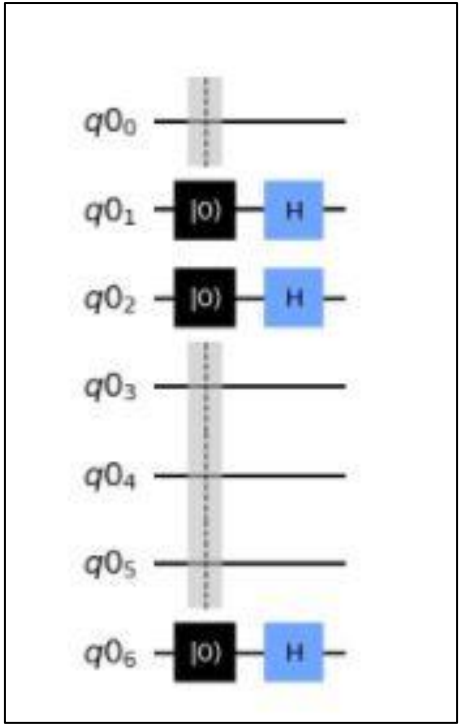


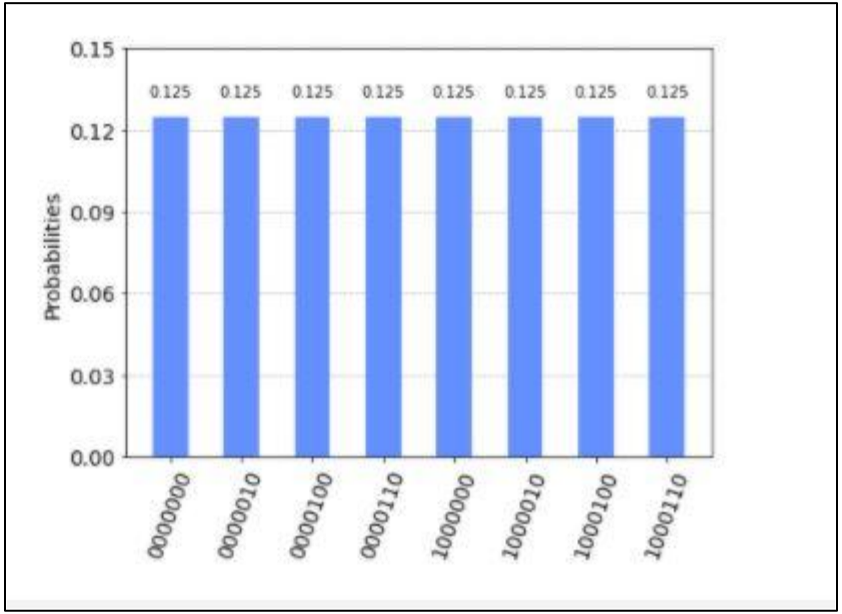
(3)



SIMULATION OF UP SCALING

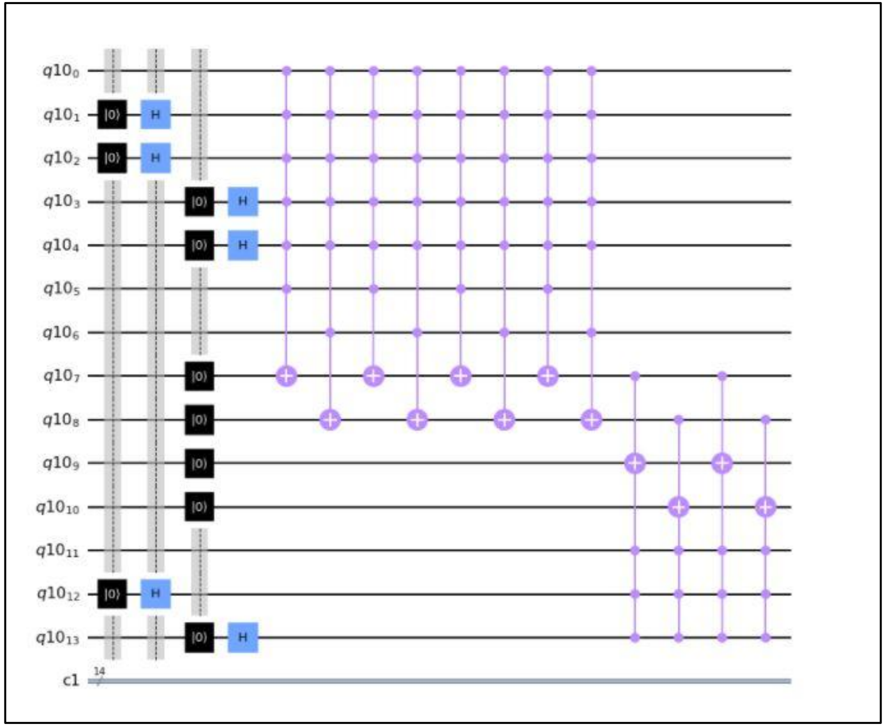
(1) Here we take n_1 and $n_2 = 1$, $q = 2$; $ry = 4$ and $rx = 2 \rightarrow m1 = 3$ and $m2 = 2$

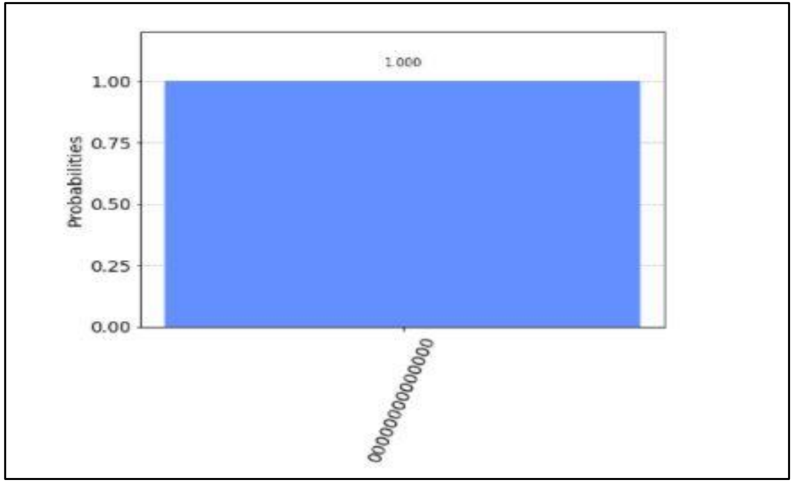




SIMULATION OF DOWN SCALING

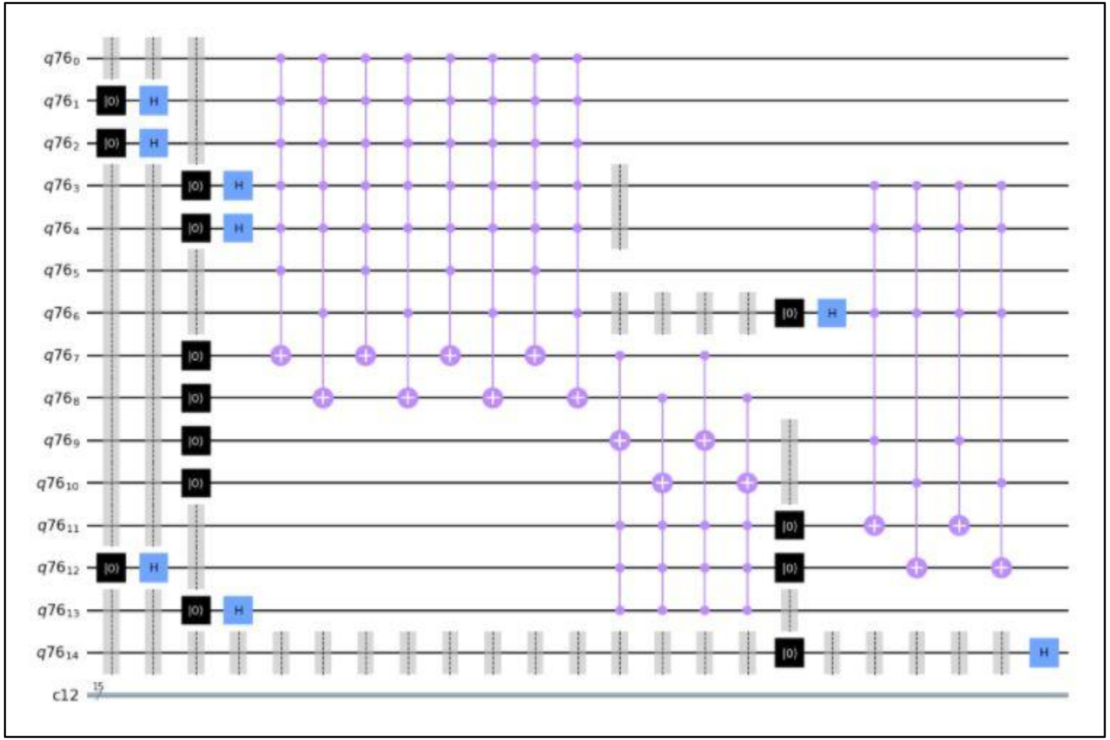
(2) Here we took the output of upscaling with ry = rx = $^{1}/_{2} \rightarrow$ m1' = 2 and m2' = 1.

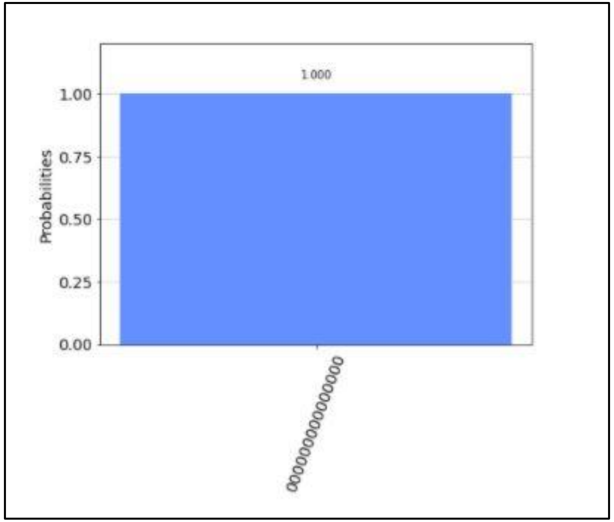




SIMULATION OF UP AND DOWN SCALING

(3) Here we took the output of down scaling with ry = $^1/_2$,rx = 2→m1''= 1& m2''= 2





CONCLUSION

This paper has successfully achieved the following objectives:

- **Improved NEQR** to store a quantum image from $2^n \times 2^n$ to $2^{n1} \times 2^{n2}$.
- Give a QIP algorithm that can **change the size of images** for the first time.
- Start the research of **quantum image scaling**.

FUTURE SCOPE

- Implementation of more complex scaling algorithms, that is using **bilinear** and **bicubic** interpolation.
- Quantum counterparts to classical image processing transforms like **restoration** and **enhancement.**
- Design quantum image scaling methods if the scale ratio is **not** in the form 2^r .

“Quantum Image Scaling Using Nearest Neighbor Interpolation” - *Nan Jiang · Luo Wang*

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Abstract

Although image scaling algorithms in classical image processing have been extensively studied and widely used as basic image transformation methods, the quantum versions do not exist. Therefore, this paper proposes quantum algorithms and circuits to realize the quantum image scaling based on the improved novel enhanced quantum representation (INEQR) for quantum images. It is necessary to use interpolation in image scaling because there is an increase or a decrease in the number of pixels. The interpolation method used in this paper is nearest neighbor which is simple and easy to realize. First, NEQR is improved into INEQR to represent images sized $2^{n1} \times 2^{n2}$. Based on it, quantum circuits for image scaling using nearest neighbor interpolation from $2^{n1} \times 2^{n2}$ to $2^{m1} \times 2^{m2}$ are proposed. It is the first time to give the quantum image processing method that changes the size of an image. The quantum strategies developed in this paper initiate the research about quantum image scaling.

Objectives

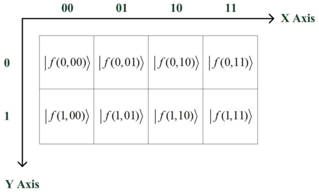
In this paper, a quantum correlative to image scaling is presented. We aim to perform image scaling using qubits to maximize efficiency in terms of speed and scalability. This research marks the start of image scaling using quantum computing. In this paper, we focus on image scaling which is a basic QIP algorithms. Image scaling is the process of resizing a digital image which has been extensively studied and widely used as a basic image transformation method in classical image processing field. However, no such strategies on quantum computers have emerged. We develop an improved version of NEQR to account for the constraint of not being able to represent images of rectangular dimensions. We implement a simple image scaling algorithm i.e Nearest Neighbor Interpolation. It is a crude method, but is used to demonstrate the applicability of Quantum Image Processing.

The main contributions are:

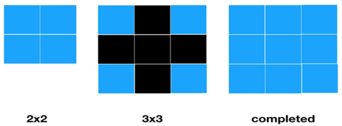
1. Improve NEQR to store a quantum image from 2n × 2n to 2n1 × 2n2 .
2. Give a QIP algorithm that can change the size of images for the first time.
3. Start the research of quantum image scaling.

Method

The approach begins by determining the best representation of a digital image in terms of quantum qubits. We improve upon an existing method for quantum representation. The image is represented using q + 2n qubits to represent a $2^n \times 2^n$ image with gray range 2^q. The below figure represents A 2 × 4 INEQR quantum image



Once the images are in this format, we develop an algorithm for Quantum Image Scaling. Nearest Neighbors Interpolation is a simple method applied in classical image processing using interpolation to create new or delete redundant pixels. It can either scale an image up or down.

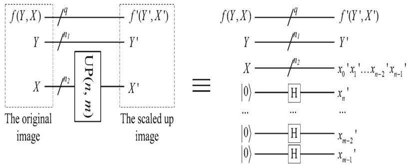


Example of Nearest Neighbor Scaling.

The quantum counterpart of this algorithm are divided into 2 subcategories.

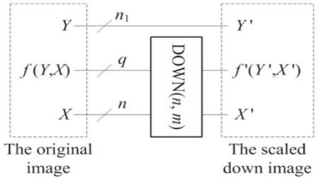
1) Upscaling

Here we expand the size of an image. The quantum circuit for image scaling up on one direction is notated by a quantum module UP(n, m) with n, m representing that an image is scaled up from 2^n to 2^m. We Prepare m − n|0> qubits as the new position qubits of X axis and add m − n Hadamard gates.



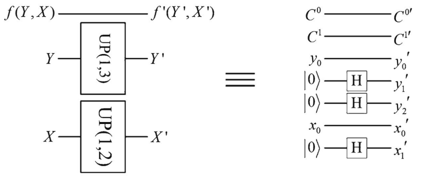
2) Downscaling

Here we shrink an image. We split the original image into groups of size”m” and map them to pixels in our processed image. All the pixels that belong to one group have the same $|x_0 x_1 \ldots x_{m-1}>$ and it is equal to the label of the group, i.e., the location information of the pixel in the scaled down image that the group produced.



Results

Quantum circuits have successfully been generated and have scaled the image based on pixel locations and intensities represented by qubits



The transformation carried out by the previous quantum circuit is shown below.

$$\underset{I}{\begin{pmatrix}1 & 2\\ 3 & 0\end{pmatrix}} \xrightarrow[\substack{4 \text{ for } Y\text{-coordinate,}\\ 2 \text{ for } X\text{-coordinate}}]{\substack{(1)\\ \text{Scaling ratio:}}} \underset{I'}{\begin{pmatrix}1&1&2&2\\1&1&2&2\\1&1&2&2\\1&1&2&2\\3&3&0&0\\3&3&0&0\\3&3&0&0\\3&3&0&0\end{pmatrix}}$$

Conclusion

In this paper, the quantum image scaling circuits using nearest neighbor are proposed which can scale images from $2^{n1} \times 2^{n2}$ to $2^{m1} \times 2^{m2}$. Firstly, NEQR is improved into INEQR to store a quantum image sized $2^{n1} \times 2^{n2}$. Then, quantum circuits that can scale a quantum image are proposed. Some examples of quantum circuits are given to illustrate the circuits more detailed.

Future work may include:

- Implementation of more complex scaling algorithms i.e bilinear, bicubic interpolation.
- Quantum counterparts to classical image processing transforms i.e restoration, enhancement.
- Design quantum image scaling methods if the scale ratio is not in the form of 2^r

References

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Thank You