

AI in Image Processing

*A Project Report Submitted
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Bachelor of Technology

by

Kaushal Kishore
(111601008)

under the guidance of

Dr. Chandra Shekar



**INDIAN INSTITUTE
OF TECHNOLOGY
PALAKKAD**

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

CERTIFICATE

*This is to certify that the work contained in this thesis entitled “**AI in Image Processing**” is a bonafide work of **Kaushal Kishore (Roll No. 111601008)**, carried out in the Department of Computer Science and Engineering, Indian Institute of Technology Palakkad under my supervision and that it has not been submitted elsewhere for a degree.*

Dr. Chandra Shekar

Assistant Professor

Department of Computer Science & Engineering

Indian Institute of Technology Palakkad

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Write acknowledgements, if you want to.

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Chapter 1

Introduction

Image processing libraries these days (eg. Open CV) uses the conventional methods which have the possibility to be outperformed by methods which leverage the power of artificial intelligence. Some recent research have shown that some of these AI based methods are able to perform atleast as good as conventional approaches. The aim of this project is to implement, apply and possibly improve upon the existing approaches in Digital Image Processing and Computer Vision. These common tasks can include (not limited to) applications like: Image Compression, Denoising, Super Resolution, Flow Estimation, Object Detection, etc.

1.1 Image Processing

Image processing is manipulating an image in order to enhance it or extract information from it. It is widely used in medical visualization, biometrics, self-driving vehicles, gaming, surveillance, and law enforcement. It can be used in various ways: visualization, restoration, information retrieval, pattern recognition, etc.

General approach of image processing involves eight key phases: image acquisition, image enhancement, image restoration, color space transformation, compression or decom-

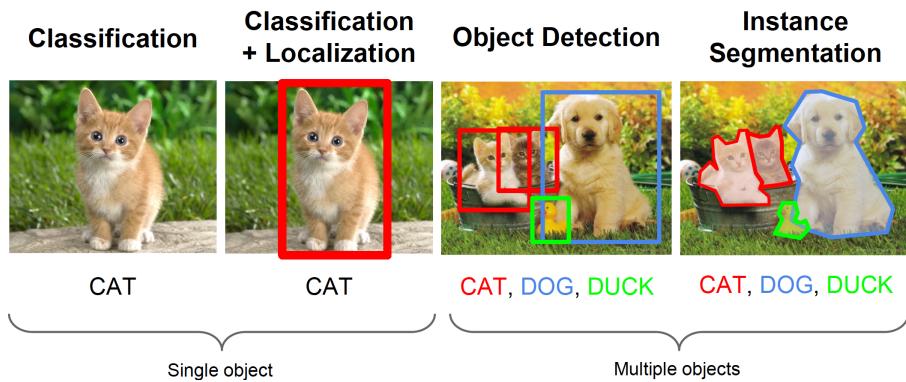


Fig. 1.1: Examples of pattern recognition

Source: www.cs.cornell.edu

expression, morphological processing, recognition, and representation. It is very difficult to carry out these steps manually on a very big data, this is where AI and ML algorithms become very helpful.

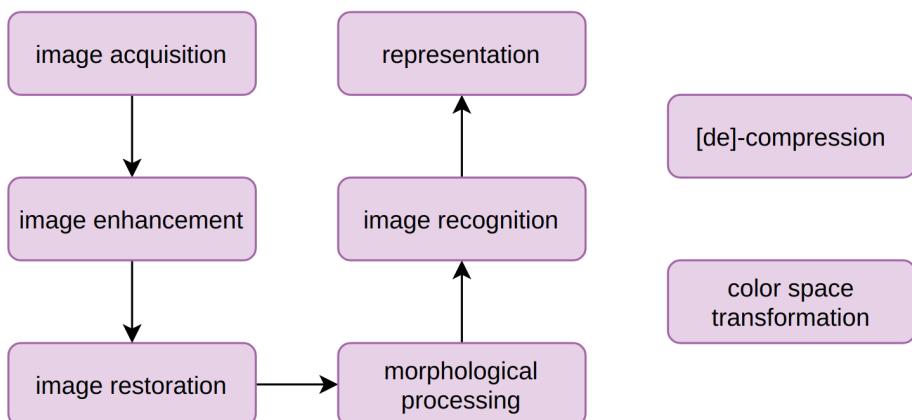


Fig. 1.2: Key phases of image processing

1.2 Recent advances

Modern AI algorithms have enabled computer to perform detection, segmentation, recognition, compression, extraction, generation, and discrimination. Every year a state of the art model is invented to solve the existing problem in a better way. It is now an established fact that machines are now better than humans in counting, classifying and segmenting instances.

1.3 Organization of The Report

Chapter 2

Image Compression

A data compression algorithm transforms the data to occupy a less space. The original data is encoded by a program called encoder, to a compressed representation using a fewer number of bits. Decoder is responsible for decompressing the compressed representation.

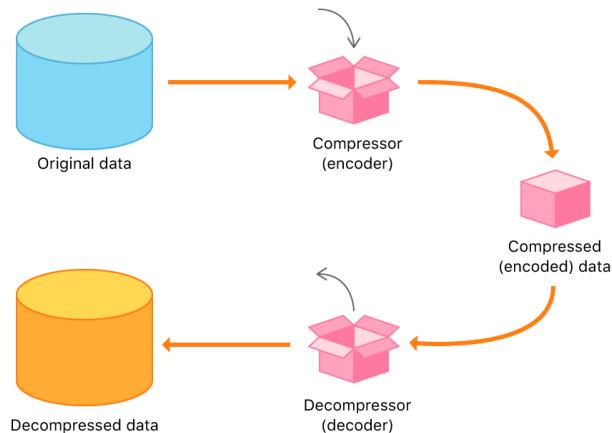


Fig. 2.1: Compression phases

Source: <https://developer.apple.com/documentation/compression>

Image compression is very crucial in order to reduce the size of disk space used as well as reduce the amount of internet bandwidth used while loading images. It's also important to compress images for people accessing the internet via low bandwidth connections.

2.1 Lossy vs. Lossless

The compression technique where the decompressed data is exactly same as original data is called as lossless compression otherwise it is known as lossy compression technique because some information is lost during coding-encoding phase. Two well-known codecs for image compression are JPEG and PNG. PNG is lossless and JPEG is lossy.

Lossy	Lossless
A compression that permits reconstruction only of an approximation of the original data, though usually with an improved compression rate.	A class of data compression that allows the original data to be perfectly reconstructed from the compressed data.
Reduces the quality.	Does not reduce the quality.
Data reduction is higher.	Data reduction is lower.
Commonly used to compress multimedia data such as audio (MP3), video and image (JPEG) files.	Used commonly for text, data files, etc.

Table 2.1: Lossy vs. Lossless

2.2 Dimensionality Reduction PCA

Principal components analysis (PCA) is one of a family of techniques for taking high-dimensional data, and using the dependencies between the variables to represent it in a more tractable, lower-dimensional form, without losing too much information. PCA is one of the simplest and most robust ways of doing such dimensionality reduction.

PCA is mathematically defined as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by some scalar projection of the data comes to lie on the first coordinate (called the first principal component),

the second greatest variance on the second coordinate, and so on.

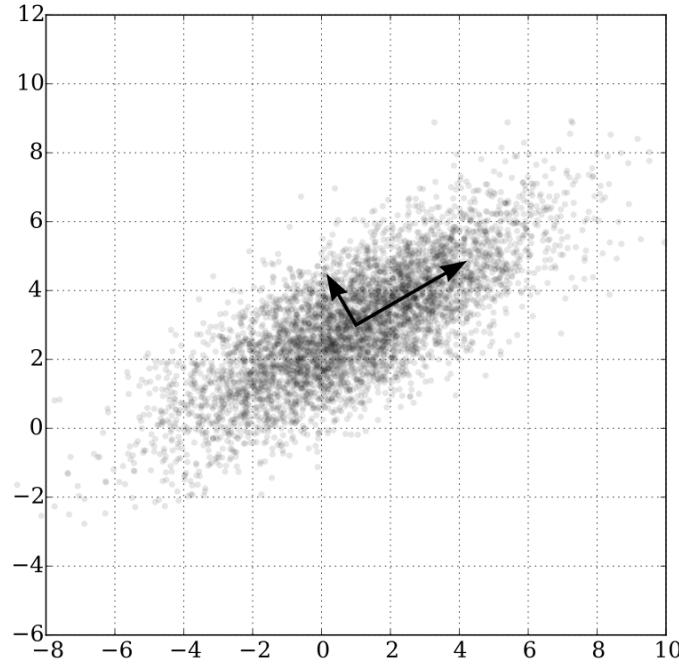


Fig. 2.2: PCA of a multivariate Gaussian distribution centered at (1,3) with a standard deviation of 3 in roughly the (0.866, 0.5) direction and of 1 in the orthogonal direction.

Source: https://en.wikipedia.org/wiki/Principal_component_analysis

Let W be a $d \times d$ matrix whose columns are the principal components of X . The transformation $T = XW$ maps a data vector $x_{(i)}$ from an original space of d variables to a new space of d variables which are uncorrelated over the dataset. However, not all the principal components need to be kept. Keeping only the first L principal components, produced by using only the first L eigenvectors, gives the truncated transformation:

$$T_L = XW_L$$

where the matrix T_L now has n rows but only L columns. In other words, PCA learns a linear transformation $t = W^T x, x \in \Re^d, t \in \Re^L$, where the columns of $d \times L$ matrix W form an orthogonal basis for the L features (the components of representation t) that are decorrelated. By construction, of all the transformed data matrices with only L columns,

this score matrix maximises the variance in the original data that has been preserved, while minimising the total squared reconstruction error $\|TW^T - T_L W_L^T\|_2^2$ or $\|X - X_L\|_2^2$.

The basic steps for computing the PCA is as follows:

1. Standardize the d-dimensional dataset.
2. Construct the covariance matrix.
3. Decompose the covariance matrix into its eigenvectors and eigenvalues.
4. Sort the eigenvalues by decreasing order to rank the corresponding eigenvectors.
5. Select L eigenvectors which correspond to the L largest eigenvalues, where L is the dimensionality of the new feature subspace $L \leq d$.
6. Construct a projection matrix W_L from the "top" L eigenvectors.
7. Transform the d -dimensional input dataset X using the projection matrix W_L to obtain the new L -dimensional feature subspace.

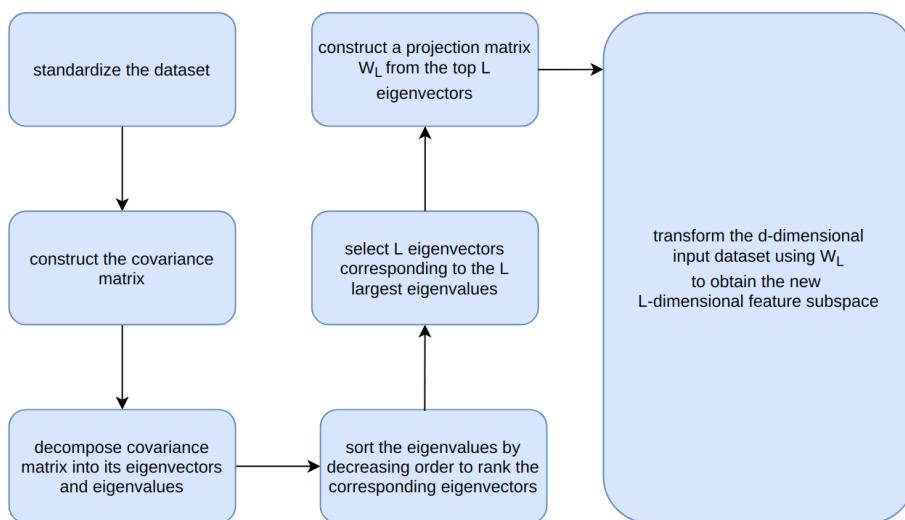


Fig. 2.3: Steps for dimensionality reduction using PCA

2.3 Image compression using PCA

We will follow the steps mentioned in the previous section for dimensionality reduction using PCA. The results of the experiments are tabulated below:

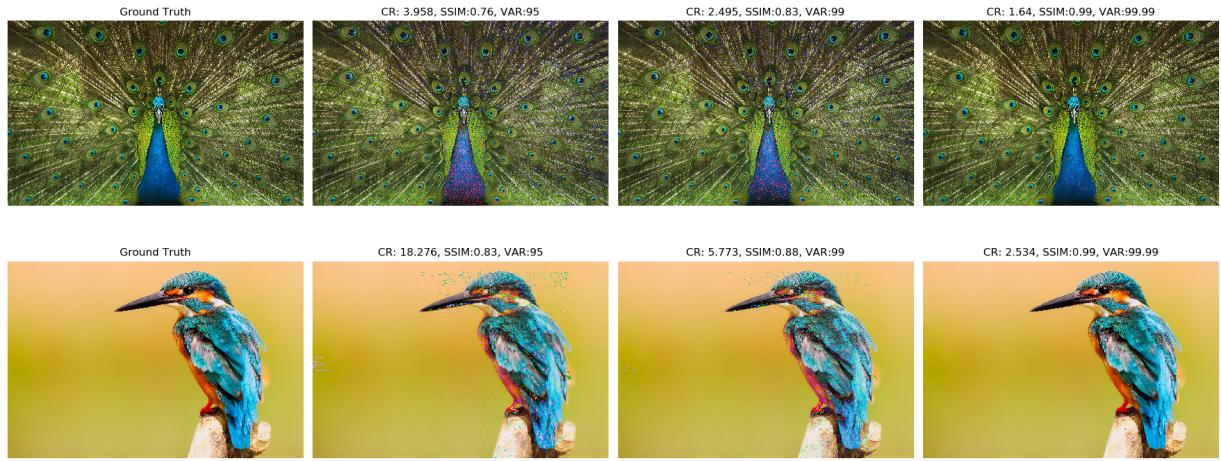


Fig. 2.4: CR = Compression Ratio, SSIM = Structural Similarity Index, VAR = Variance. Results of compression using the PCA method. Higher variance leads to more number of principal components and higher is the reconstructed image quality and lower the compression rate.

Code for the above test can be found here: [@KishoreKaushal/ImageCompression/](#)

It is clear from the above experiment that higher variance leads to more number of principal components and higher is the reconstructed image quality and lower the compression rate. Infact, the first L principal components is selected to get atleast the given number of variance.

In the next chapter we will discuss the JPEG compression algorithm.

Chapter 3

JPEG

3.1 Overview

JPEG, which stands for Joint Photographic Experts Group (the name of the committee that created the JPEG standard) is a lossy compression algorithm for images. A lossy compression scheme is a way to inexactly represent the data in the image, such that less memory is used yet the data appears to be very similar. This is why JPEG images look almost the same as the original images they were derived from most of the time unless the quality is reduced significantly, in which case there will be visible differences.

The JPEG algorithm takes advantage of the fact that humans can't see colors at high frequencies. These high frequencies are the data points in the image that are eliminated during the compression. JPEG compression also works best on images with smooth colour transitions.

JPEG is a commonly used method of lossy compression for digital images. The degree of compression can be adjusted, allowing a the tradeoff between storage size and image quality with a compression ratio 10:1 but with little perceptible loss in image quality.



Fig. 3.1: A photo of a European wildcat with the compression rate decreasing and hence quality increasing, from left to right.

Source: <https://en.wikipedia.org/wiki/JPEG>

3.2 Algorithm

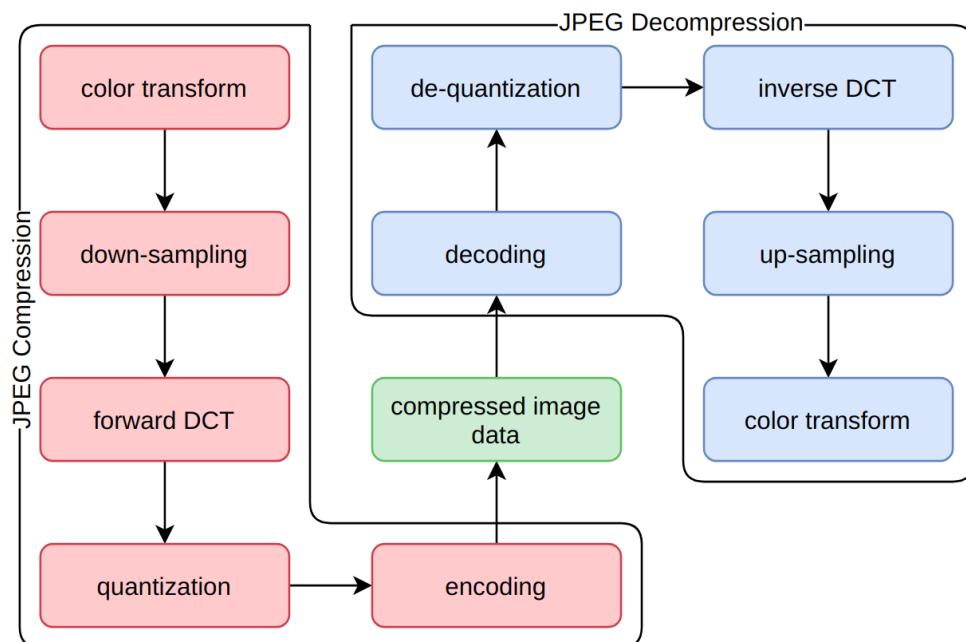


Fig. 3.2: JPEG Schematic

3.2.1 Splitting

JPEG uses transform coding, it is largely based on the following observations:

- Usually image contents change relatively slowly across images, i.e., it is unusual for intensity values to alter up and down several times in a small area, for example, within an 8×8 image block. A translation of this fact into the spatial frequency domain, implies, generally, lower spatial frequency components contain more information than the high frequency components which often correspond to less useful details and noises.
- Experiments suggest that humans are more immune to loss of higher spatial frequency components than loss of lower frequency components. Human vision is insensitive to high frequency components.

Hence, first step is to split the image into 8×8 blocks non-overlapping pixel blocks. If the image cannot be divided into 8×8 blocks then the block is zero padded.

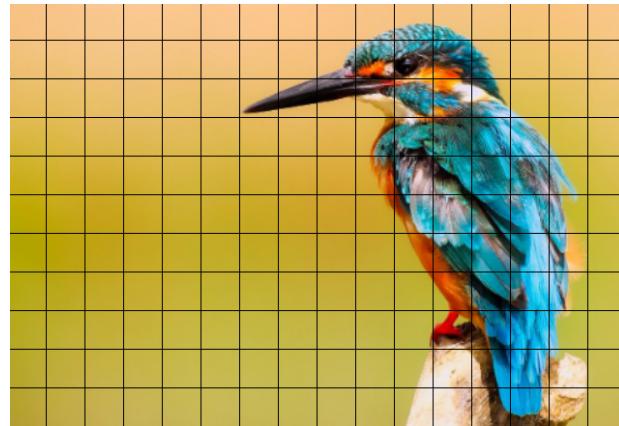


Fig. 3.3: Splitting into 8×8 blocks

3.2.2 Color Space Transform

JPEG makes use of $[Y, Cb, Cr]$ model instead of $[R, G, B]$ model. There is a reason for using the color space. The human eye is more sensitive to luminance than to chrominance.

$Y = 0.299R + 0.587G + 0.114B$
$Cb = -0.1687R - 0.3313G + 0.5B + 128$
$Cr = 0.5R - 0.4187G - 0.0813B + 128$
$R = Y + 1.402(Cr - 128)$
$G = Y - 0.34414(Cb - 128) - 0.71414(Cr - 128)$
$B = Y + 1.772(Cb - 128)$

Table 3.1: RGB and YCbCr conversion table

3.2.3 Down-sampling

After the color space transformation, the image is downsampled. Downsampling happens in such a way that Y is taken for each pixel whereas Cb and Cr are taken for 2×2 blocks.

Sometimes this step is not carried out (baseline JPEG).

3.2.4 Discrete Cosine Transform

The key to the JPEG baseline compression process is a mathematical transformation known as the Discrete Cosine Transform (DCT). The DCT is in a class of mathematical operations that includes the well known Fast Fourier Transform (FFT), as well as many others. The basic purpose of these operations is to take a signal and transform it from one type of representation to another. For example, an image is a two-dimensional signal that is perceived by the human visual system. The DCT can be used to convert the signal (spatial information) into numeric data (“frequency” or “spectral” information) so that the image’s information exists in a quantitative form that can be manipulated for compression.

The DCT is performed on a $N \times N$ square matrix of pixel values, and it yields a $N \times N$ square matrix of frequency coefficients. (In practice, N most often equals 8 because a larger block, though would probably give better compression, often takes a great deal of time to perform DCT calculations, creating an unreasonable tradeoff. As a result, DCT implementations typically break the image down into more manageable 8×8 blocks.) The

DCT formula 3.1 looks somewhat intimidating at first glance but can be implemented with a relatively straightforward piece of code.

$$DCT[i, j] = \frac{1}{\sqrt{2N}} C[i] C[j] \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} I[x, y] \cos\left[\frac{(2x+1)i\pi}{2N}\right] \cos\left[\frac{(2y+1)j\pi}{2N}\right] \quad (3.1)$$

where $C(x) = \frac{1}{\sqrt{2}}$ if $x = 0$, else 1 if $x > 0$

Below are two matrices representing the DCT input 3.2 and DCT output blocks 3.3 from a gray-scale image. Each element of the 8-pixel-by-8-pixel input matrix contains the value of the pixel at the corresponding (x, y) location. These integer values are fed to the DCT algorithm, creating the output matrix shown below it. Each element of the output matrix is a coefficient by which the waveform of the corresponding spatial frequency is multiplied in the decomposition of the image sample.

$$\begin{bmatrix} 140 & 144 & 147 & 140 & 140 & 155 & 179 & 175 \\ 144 & 152 & 140 & 147 & 140 & 148 & 167 & 179 \\ 152 & 155 & 136 & 167 & 163 & 162 & 152 & 172 \\ 168 & 145 & 156 & 160 & 152 & 155 & 136 & 160 \\ 162 & 148 & 156 & 148 & 140 & 136 & 147 & 162 \\ 147 & 167 & 140 & 155 & 155 & 140 & 136 & 162 \\ 136 & 156 & 123 & 167 & 162 & 144 & 140 & 147 \\ 148 & 155 & 136 & 155 & 152 & 147 & 147 & 136 \end{bmatrix} \quad (3.2)$$

Why DCT? Human vision is insensitive to high-frequency components, due to which it is possible to treat the data corresponding to high frequencies as redundant. To segregate the raw image data on the basis of frequency, it needs to be converted into frequency domain, which is the primary function of DCT.

$$\begin{bmatrix} 1209 & -17 & 14 & -8 & 23 & -9 & -13 & -18 \\ 20 & -34 & 26 & -9 & -10 & 10 & 13 & 6 \\ -10 & -23 & -1 & 6 & -18 & 3 & -20 & 0 \\ -8 & -5 & 14 & -14 & -8 & -2 & -3 & 8 \\ -3 & 9 & 7 & 1 & -10 & 17 & 18 & 15 \\ 3 & -2 & -18 & 8 & 8 & -3 & 0 & -6 \\ 8 & 0 & -2 & 3 & -1 & -7 & -1 & -1 \\ 0 & -7 & -2 & 1 & 1 & 4 & -6 & 0 \end{bmatrix} \quad (3.3)$$

3.2.5 Coefficient Quantization

Humans are unable to see aspects of an image that are at really high frequencies. Since taking the DCT allows us to isolate where these high frequencies are, we can take advantage of this in choosing which values to preserve. By multiplying the DCT matrix by some mask, we can zero out elements of the matrix, thereby freeing the memory that had been representing those values. The resultant quantize matrix will only preserve values at the lowest frequencies up to a certain point.

$$DCT_q[i, j] = \left\lfloor \frac{DCT[i, j]}{Q[i, j]} \right\rfloor \quad (3.4)$$

In Eq. 3.4 Q is the quantization matrix. JPEG Standard defines two default quantization tables, one each for luminance and chrominance. From the formula, one can notice the smaller DCT coefficients of high-frequency elements divided by the larger quantum values will most often result in the high-frequency coefficients being rounded down to zero.

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Table 3.2: Luminance Quantization Table

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

Table 3.3: Chrominance Quantization Table

The quantization step is the major information losing step in JPEG compression.

3.2.6 Encoding

The final step of the JPEG image compression process is to compress the quantized DCT values. This is done through a three-part procedure detailed below.

First, the DC coefficient is changed from absolute value to a relative value – relative to the DC coefficient in the previous 8×8 block, that is. Since adjacent blocks in an image

exhibit a high degree of correlation, coding the DC term of a given block as the difference from the previous DC term typically produces a very small number that can be stored in a fewer number of bits.

Second, reorder the DCT block in a zig-zag sequence. Because so many coefficients in the DCT image are truncated to zero values during the coefficient quantization stage, the zeros are handled differently than non-zero coefficients. They are coded using a Run-Length Encoding (RLE) algorithm. RLE gives a count of consecutive zero values in the image, and the longer the runs of zeros, the greater the compression. One way to increase the length of runs is to reorder the coefficients in the zig-zag sequence shown in the diagram below. This way, the JPEG algorithm moves through the block selecting the highest value elements first and eventually working its way to the lowest value elements, thus optimizing the effect of RLE.

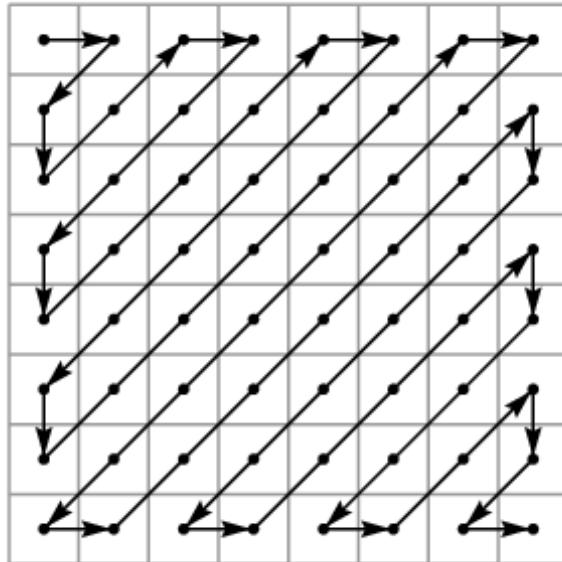


Fig. 3.4: Reorder the DCT block in a zig-zag sequence
Source: freecodecamp.org/

Third, Entropy Encoding. Finally, the JPEG algorithm outputs the DCT block's elements using an entropy encoding mechanism that combines the principles of RLE and Huffman encoding. The output of the entropy encoder consists of a sequence of three

tokens, repeated until the block is complete. The three tokens are the run length, the number of consecutive zeros that precede the current non-zero element in the DCT output matrix; the bit count, the number of bits used to encode the amplitude value that follows, as determined by the Huffman encoding scheme; and the amplitude, the amplitude of the DCT coefficient.

The final output that results from JPEG compression can be mathematically reversed and decompressed to produce an image that, to a computer, lacks defining data, but to a human eye, it appears identical to the original image.

3.3 Conclusion

In this chapter, we proposed a distributed algorithm for construction of xyz. The complexity of this algorithm is $O(n \log n)$. Next chapter presents another distributed algorithm which has linear time complexity based on xyz.

Chapter 4

Algorithm II

The algorithm presented in previous chapter has $O(n)$ time complexity. We further propose another distributed algorithm in this chapter based on xyz which has linear time complexity.

4.1 Construction

Write ...

4.2 Improved Method

Write...

4.3 Conclusion

In this chapter, we proposed another distributed algorithm for XYZ. This algorithm has both time complexity of $O(n)$ where n is the total number of nodes. In next chapter, we conclude and discuss some of the future aspects.

Chapter 5

Conclusion and Future Work

write results of your thesis and future work.

References