A REPORT ON

JPEG IMAGE COMPRESSION

Submitted by

211IT019 EKANK CHAPPARWAL

211IT062 SHIVAM SHARMA

211IT034 KRISHNA KUMAR

3rd Semester B.tech (IT)

Under the guidance of
Dr. Revanesh
Dept. of IT, NITK Surathkal

Department of Information Technology Engineering,

National Institute of Technology Karnataka, Surathkal

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Abstract :

Image compression is a crucial aspect of digital media, particularly when it comes to the internet. The need for image compression arises from the need to reduce the file size of images to make them more manageable, both in terms of storage and transmission.
With the increasing use of the internet and mobile devices, the need for fast and efficient image loading has become more important than ever.

Compressing images can greatly **reduce their file size**, making them **faster to load** and reducing the amount of data that needs to be transferred over the internet. This can help to improve the user experience, save on storage and bandwidth costs, and make it possible to use images in a wide range of applications, including websites, mobile apps, and video games.

Additionally, it also helps in **reducing the space** required to store the images, thus allowing more images to be stored in the same amount of space.

Types of Image Compression :

1. **Lossless Compression.**
2. **Lossy Compression.**

Lossless compression: Lossless compression methods do not lose any image data during the compression process. These methods are typically used for images that need to be preserved at the highest quality, such as medical images, technical drawings, and other images that require precise detail. Lossless compression methods include algorithms such as **run-length encoding and Huffman coding.**

Lossy compression: Lossy compression methods, on the other hand, do lose some image data during the compression process. This is usually done to achieve a much **higher compression ratio** than lossless methods. These methods are typically used for images that don't require precise detail, such as photographs, images on websites, and images in videos. Lossy compression methods include algorithms such as **Discrete Cosine Transform (DCT) and Fractal compression**. Lossy compression usually results in **less quality of the image but with a much smaller file size**.

It's worth noting that some image formats like **JPEG, JPEG 2000, WebP**, and others, use a combination of both lossless and lossy compression.

Introduction to the JPEG Image Compression Algorithm :

The **JPEG algorithm** uses a combination of techniques such as **Discrete Cosine Transform (DCT)**, quantization, subsampling, entropy coding and **run-length encoding** to compress the image data.

The DCT process transforms the image data from the spatial domain to the frequency domain, and separates the image data into individual frequency components, where the highest frequencies are the most important for image quality.

The quantization process reduces the precision of the DCT coefficients, resulting in lossy compression. Subsampling is used to reduce the resolution of the chrominance channels, and entropy coding is used to remove any redundancy in the data. Run-length encoding is used to further compress the image data by reducing the number of zeroes in the quantized DCT coefficients.

The JPEG standard provides several options for **controlling the compression ratio and image** quality, such as the quantization step, subsampling, and the types of entropy coding used. The decoding process is the reverse of the encoding process, it takes the compressed image data and converts it back into the original image.

JPEG is a **widely supported standard** and is used in a variety of applications such as digital cameras, mobile phones, and the internet. However, it's not suitable for images with high resolution or images with sharp edges and lines, as the lossy compression can cause visible artifacts in these types of images.

Methodology :

The methodology of the **JPEG image compression algorithm** includes the following Steps :

1) **Color space conversion** :

The image is stored in RGB format. While this colorspace is convenient for projecting the image on the computer screen, it does not isolate the **illuminance** and **color** of an image. The intensity of color is intermixed in the colorspace. The **YCbCr** is a more convenient colorspace for image compression because it separates the illuminance and the chromatic strength of an image..

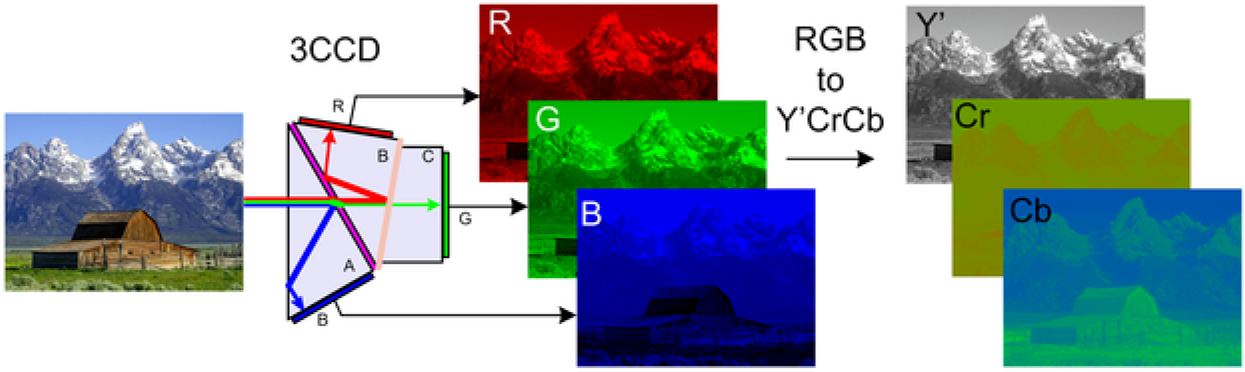
RGB stands for Red, Green, Blue, it's a color model in which red, green and blue light are added together in various ways to reproduce a broad array of colors .

YCbCr stands for luma (Y) and chroma (Cb and Cr) components. It's a color space used to represent images in digital video and still image systems. The YCbCr color space separates the image into a **luminance (Y) channel and two chrominance (Cb and Cr)** channels. The 'Y' channel represents the brightness (luma) of the image, while the Cb and Cr channels represent the color (chroma) of the image. The YCbCr color space is a "subtractive" color space, meaning that the more colors you remove, the closer you get to black.

$$\begin{cases} Y = 16 + \frac{65.738R}{256} + \frac{129.057G}{256} + \frac{25.064B}{256} & (1) \\ Cb = 128 - \frac{37.945R}{256} - \frac{74.494G}{256} + \frac{112.439B}{256} & (2) \\ Cr = 128 + \frac{112.439R}{256} - \frac{94.154G}{256} - \frac{18.285B}{256} & (3) \end{cases}$$

Equations (1) to (3): RGB to YCbCr conversion, source: [1]

The equations in the above Image converts any RGB format image into YCbCr image



Source : https://en.wikipedia.org/wiki/YCbCr#/media/File:CCD.png

The above image has the 3 Components of any image in RGB and YCbCr format

2) Subsampling:

It is a technique used in the JPEG image compression algorithm to reduce the resolution of the chrominance channels, Cb and Cr, in the YCbCr color space. The idea behind subsampling is that the **human visual system is less sensitive** to changes in chrominance (color) than to changes in luminance (brightness), so the chrominance channels can be compressed more than the luminance channel **without significantly impacting image quality.**

In the subsampling process, the chrominance channels are downsampled by a **factor of 2 or 4**, depending on the subsampling scheme used. This means that for every 4 pixels in the Cb and Cr channels, only 1 pixel is retained. The remaining pixels are discarded, resulting in a reduction of the total amount of data that needs to be compressed.

The most common subsampling schemes used in **JPEG are 4:4:4, 4:2:2 and 4:2:0**.

The above image describes about the different possible ways of subsampling the image pixels

Source :https://i0.wp.com/allhomecinema.com/storage/2020/11/Chroma-600x335-1.jpg?resize=600%2C335&ssl=1

a) 4:4:4 subsampling schemes b) 4:2:2 subsampling schemes c) 4:2:0 subsampling schemes in figure

3) The Discrete Cosine Transform (DCT) :

It is a mathematical technique used in the JPEG image compression algorithm to transform the image data from the spatial domain to the frequency domain. The DCT separates the image data into individual frequency components, with the highest frequencies being the most important for image quality.

The DCT process works by dividing the image into 8x8 blocks, called macroblocks, and then performing a **mathematical transformation on each block**, resulting in a set of frequency coefficients that represent the block.

DCT process has several advantages in JPEG image compression:

- The DCT coefficients are usually more sparse than the original pixel values, meaning that many of the coefficients are close to zero. This makes it possible to represent the same image with fewer bits.
- DCT also decorrelates the image data, meaning that the DCT coefficients are less correlated with each other than the original pixel values, resulting in better compression.
- The DCT process is reversible, meaning that the original image can be reconstructed from the DCT coefficients with minimal loss of information.

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

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

The actual **formula for the two-dimensional DCT** is shown above. The DCT formula looks somewhat intimidating at first glance but can be implemented with a relatively straightforward piece of code.

4) Quantization:

It is a technique used in the JPEG image compression algorithm to **reduce the precision of the DCT coefficients**, which represent the image in the frequency domain. The process of quantization involves dividing each DCT coefficient by a fixed value, called the quantization step, and then rounding the result to the nearest integer. This process reduces the precision of the DCT coefficients, **which results in lossy compression**.

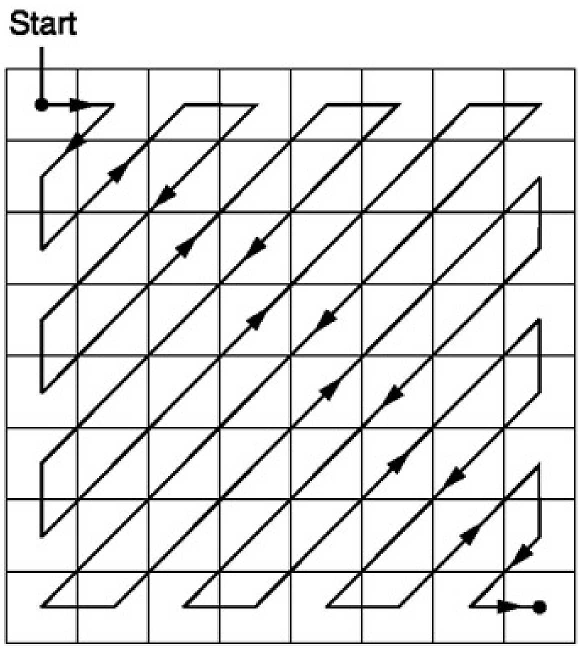
The quantization step is chosen such that the quantization **error is minimized**, while still achieving a high compression ratio. The **smaller the quantization step**, the **more precision is retained** in the DCT coefficients, resulting in a higher quality image but also a larger file size. The larger the quantization step, the less precision is retained in the DCT coefficients, resulting in a lower quality image but also a smaller file size.

The quantization step is typically chosen such that the most significant DCT coefficients, which represent the highest frequencies in the image and are the most important for image quality, are quantized with the smallest step size, and the **least significant DCT coefficients, which represent the lowest frequencies** in the image and are the least important for image quality, are quantized with the largest step size.

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

The Default Quantization Matrix :

5) Run-length encoding (RLE) is a **data compression method** that is used in JPEG image compression to reduce the number of zeroes in the quantized DCT coefficients. In RLE, runs of consecutive zeros are replaced with a single value representing the number of zeros in that run.
In JPEG image compression, RLE is typically used on the quantized DCT coefficients after they have been reordered using the **Zig-zag scan pattern**. This is because the Zig-zag scan pattern tends to group similar coefficients together, resulting in many runs of zeros in the quantized coefficients.
The RLE process works by iterating through the quantized DCT coefficients and counting the number of consecutive zeros in each run. When a non-zero coefficient is encountered, the run length and the non-zero coefficient are encoded and written to the output stream.



- ZIG-ZAG Scan Pattern used while Encoding

<u>About the ZIG-ZAG Scan Pattern</u> : The Zig-zag scan pattern is starting at the top-left corner of the block, and then moving through the block in a zigzag pattern, so that the first coefficient is followed by the second, then the ninth, the tenth, and so on, until all 64 coefficients have been visited.
This method makes the compression more efficient by grouping similar coefficients together and also makes it more robust to errors in the transmission of the compressed data, as the most important coefficients for the image quality are located at the beginning of the scan.

6) Decoding: The compressed image data can be decoded and reconstructed into the original image. In the following steps :-

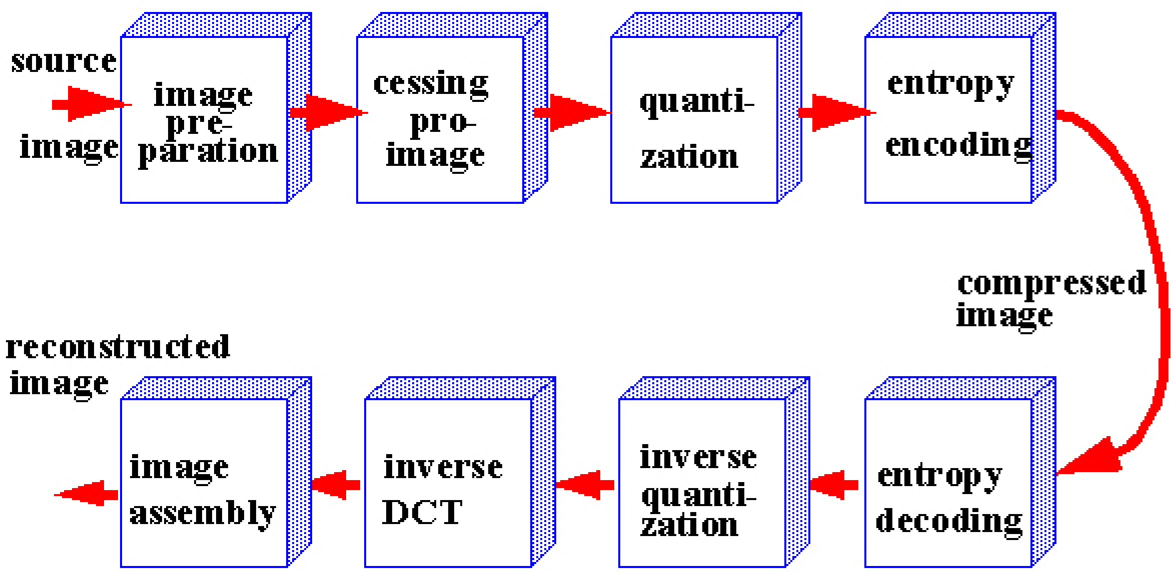
A. Run-length decoding: If RLE was used during the compression process, the run-length encoded data is decoded to regenerate the original sequence of quantized DCT coefficients.

B. Dequantization: The quantized DCT coefficients are multiplied by the quantization step to regenerate the original DCT coefficients.

C. Inverse Discrete Cosine Transform (IDCT): The DCT coefficients are transformed back into the spatial domain using the IDCT process, this recreates the image data.

D. Color space conversion: If the image was converted to the YCbCr color space during the compression process, it is converted back to the RGB color space.

After these steps, the original image is reconstructed, and the image quality can be affected by the amount of compression applied, quantization step, subsampling and the types of entropy coding used.



Source : https://www.site.uottawa.ca/~elsaddik/abedweb/applets/lessons/jpeg/Basics/basics.html

Results:

:  The Image Before Compression (Size ~2.2MB)

: The resulting Image after Compression (Size ~1.1MB)

Lossless Image Compression using RLE

Lossless image compression is a method of compressing digital images in such a way that the original image can be exactly reconstructed from the compressed data, with no loss of quality. The compressed data is a representation of the same information that was in the original image, but with a smaller file size.

Run-length encoding (RLE) is a lossless image compression technique that works by identifying and encoding repeating patterns of data. In the context of image compression, RLE can be used to compress the data of an image by identifying and encoding sequences of repeating pixels.
The basic idea behind RLE is to represent a sequence of repeating data as a single value and a count, rather than repeating the value multiple times.

The process of RLE can be broken down into the following steps:

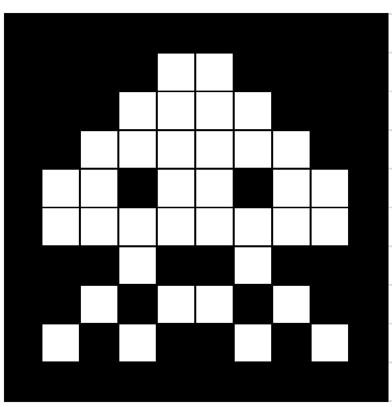
1. Identify the repeating patterns of pixels in the image. This can be done by scanning the image row by row, or column by column, and counting the number of consecutive pixels with the same value.

2. Encode the repeating patterns as a single value and a count. For example, if an image has a sequence of 100 consecutive pixels with the value "255, 255, 255" (white), the RLE encoded data would represent that sequence as "100, 255, 255, 255".

3. Store the encoded data in a file or other storage format.

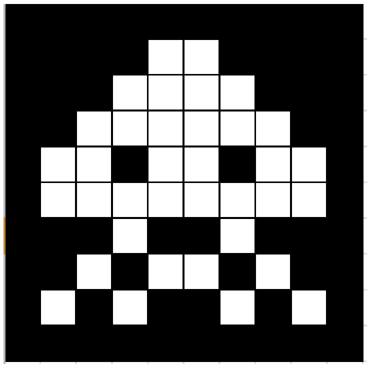
4. To decompress the image, the encoded data is read back in and the repeating patterns are reconstructed by repeating the value the specified number of times.

Uncompressed image



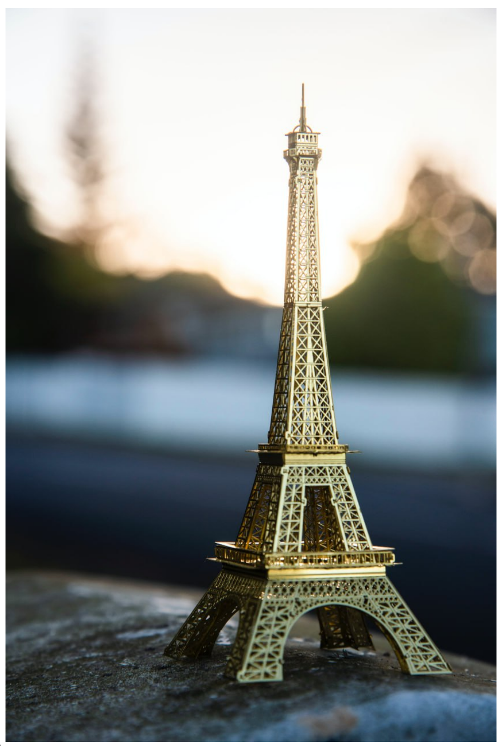
1111111111
1111001111
1110000111
1100000011
1001001001
1000000001
1110110111
1101001011
1010110101
1111111111

Image compressed with RLE



101
412041
314031
216021
11201120112011
118011
3110211031
21101120111021
1110111021101110111
101

Results :



The size of image before compression : **2.46MB**
The size of image after compression : **2.12MB**

Note : The quality of image remains same before and after compression

Conclusion : JPEG is a widely used image compression standard that allows for the efficient storage and transmission of digital images. The JPEG algorithm uses a combination of techniques such as Discrete Cosine Transform (DCT), quantization, subsampling, entropy coding and run-length encoding to compress the image data.

DCT is used to transform the image data from the spatial domain to the frequency domain, and quantization is used to reduce the precision of the DCT coefficients, resulting in lossy compression. Subsampling is used to reduce the resolution of the chrominance channels, and entropy coding is used to remove any redundancy in the data.
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