Introduction to JPEG Compression Process

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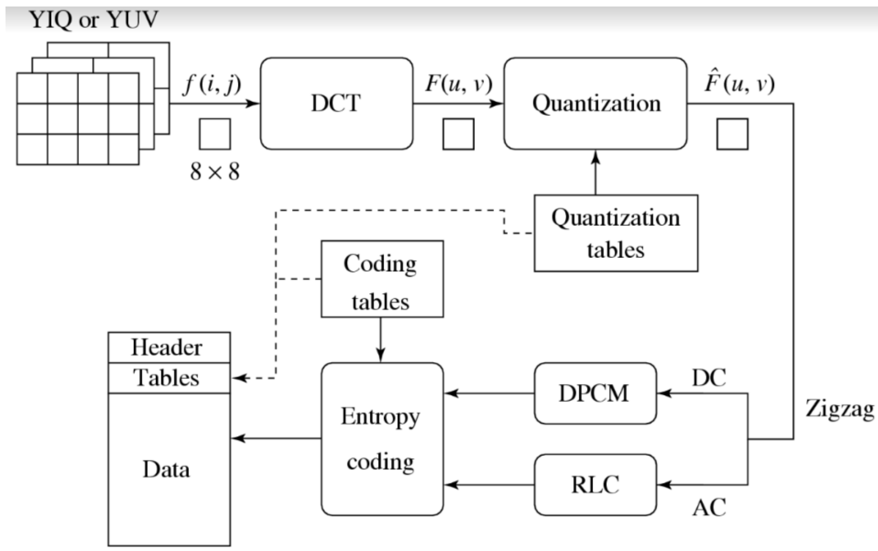

Figure 1: JPEG Compression Flowchart

1 Introduction

JPEG compression is a widely used method for compressing images. It reduces data size by removing redundant and irrelevant information, while preserving image quality to an acceptable level. This document explains each step in the JPEG compression process.

2 Steps in JPEG Compression

2.1 Color Conversion (YIQ or YUV)

JPEG compression begins with converting the RGB color space to YIQ or YUV color spaces. This separates luminance (Y) from chrominance (U and V), allowing more efficient compression since the human eye is more sensitive to brightness than color details.

2.2 Image Block Splitting (8x8 blocks)

The image is divided into 8×8 blocks of pixels. Each block is processed independently, making it easier to apply localized transformations and reduce computational complexity.

2.3 Discrete Cosine Transform (DCT)

For each 8×8 block, a **Discrete Cosine Transform (DCT)** is applied, converting spatial information $f(i, j)$ into frequency information $F(u, v)$.

The DCT for an 8×8 block is defined as:

$$F(u,v) = \frac{1}{4}\alpha(u)\alpha(v)\sum_{i=0}^{7}\sum_{j=0}^{7} f(i,j)\cos\left(\frac{(2i+1)u\pi}{16}\right)\cos\left(\frac{(2j+1)v\pi}{16}\right)$$

where:

- $f(i,j)$ is the pixel value at position (i,j),
- $F(u,v)$ is the DCT coefficient at position (u,v),
- $\alpha(x)$ is a scaling factor:

$$\alpha(x) = \begin{cases} \frac{1}{\sqrt{2}} & \text{if } x = 0 \\ 1 & \text{otherwise} \end{cases}$$

DCT separates the image into different frequency components, with $F(0,0)$ representing the DC (average) component and the rest representing higher frequencies.

2.4 Quantization

Quantization reduces the precision of high-frequency components, as the human eye is less sensitive to these frequencies. Each DCT coefficient $F(u,v)$ is divided by a corresponding value in a quantization table $Q(u,v)$ and then rounded to the nearest integer:

$$\hat{F}(u,v) = \text{round}\left(\frac{F(u,v)}{Q(u,v)}\right)$$

This step introduces loss by discarding less important data, making it a key step in achieving compression.

2.5 Zigzag Scanning

The quantized DCT coefficients are reordered in a **zigzag pattern**, which prioritizes low-frequency components and groups zero-valued high-frequency components together. This arrangement improves the efficiency of subsequent encoding steps.

2.6 Differential Pulse Code Modulation (DPCM) for DC Coefficients

The DC component $\hat{F}(0,0)$ of each block is encoded using **Differential Pulse Code Modulation (DPCM)**. Instead of encoding the DC value directly, the difference between the current and previous block's DC values is encoded:

$$\text{DC}_{\text{difference}} = \text{DC}_{\text{current}} - \text{DC}_{\text{previous}}$$

This approach reduces the number of bits needed to encode the DC component, as adjacent blocks usually have similar DC values.

2.7 Run-Length Coding (RLC) for AC Coefficients

The AC coefficients (all non-DC coefficients) are encoded using **Run-Length Coding (RLC)**, which compresses sequences of zeros by representing them as pairs. Each pair consists of a count of zeros followed by the next non-zero coefficient.

For example, a sequence like $[0, 0, 0, 5]$ could be encoded as $(3, 5)$, where 3 is the number of zeros, and 5 is the next non-zero coefficient.

2.8 Entropy Coding

The final step in JPEG compression is **Entropy Coding** using methods such as **Huffman coding** or **Arithmetic coding**. This further compresses the data by encoding frequent symbols with shorter codes and less frequent symbols with longer codes.

Huffman coding assigns binary codes to each symbol based on its frequency, minimizing the average code length required to store the image data.

3 Summary of Key Equations

- **DCT Transformation**:

$$F(u,v) = \frac{1}{4}\alpha(u)\alpha(v)\sum_{i=0}^{7}\sum_{j=0}^{7} f(i,j)\cos\left(\frac{(2i+1)u\pi}{16}\right)\cos\left(\frac{(2j+1)v\pi}{16}\right)$$

- **Quantization**:

$$\hat{F}(u,v) = \mathrm{round}\left(\frac{F(u,v)}{Q(u,v)}\right)$$

- **DPCM for DC Coefficients**:

$$\mathrm{DC}_{\mathrm{difference}} = \mathrm{DC}_{\mathrm{current}} - \mathrm{DC}_{\mathrm{previous}}$$

4 Conclusion

JPEG compression is an efficient image compression technique that combines frequency transformation, quantization, and entropy coding. By removing redundancies and irrelevant information, JPEG achieves significant data compression with minimal perceptible loss of quality.