JPEG Image Compression

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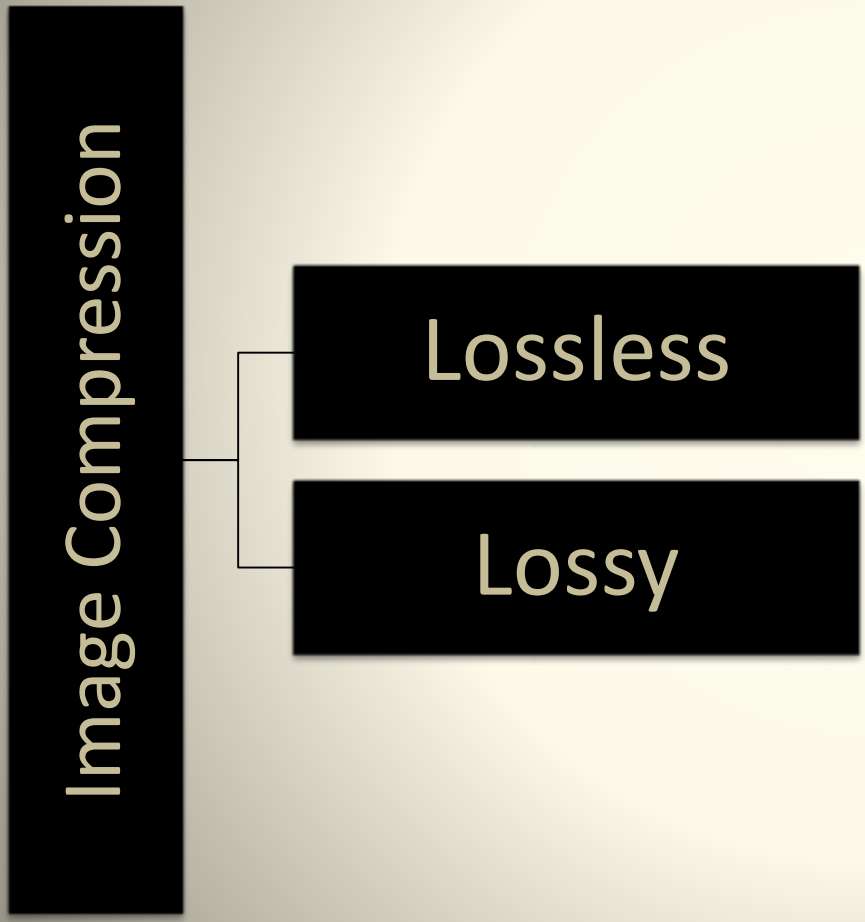
What is Image Compression?

The objective of image compression is to reduce irrelevant and redundant image data in order to be able to store or transmit data in an efficient form.

Types



- **Lossless** image compression is a compression algorithm that allows the original image to be perfectly reconstructed from the original data.
- **Lossy** image compression is a type of compression where a certain amount of information is discarded which means that some data are lost and hence the image cannot be decompressed with 100% originality.

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 colours 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.

we eliminate ↑ freq. → why?

What is JPEG compression?

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

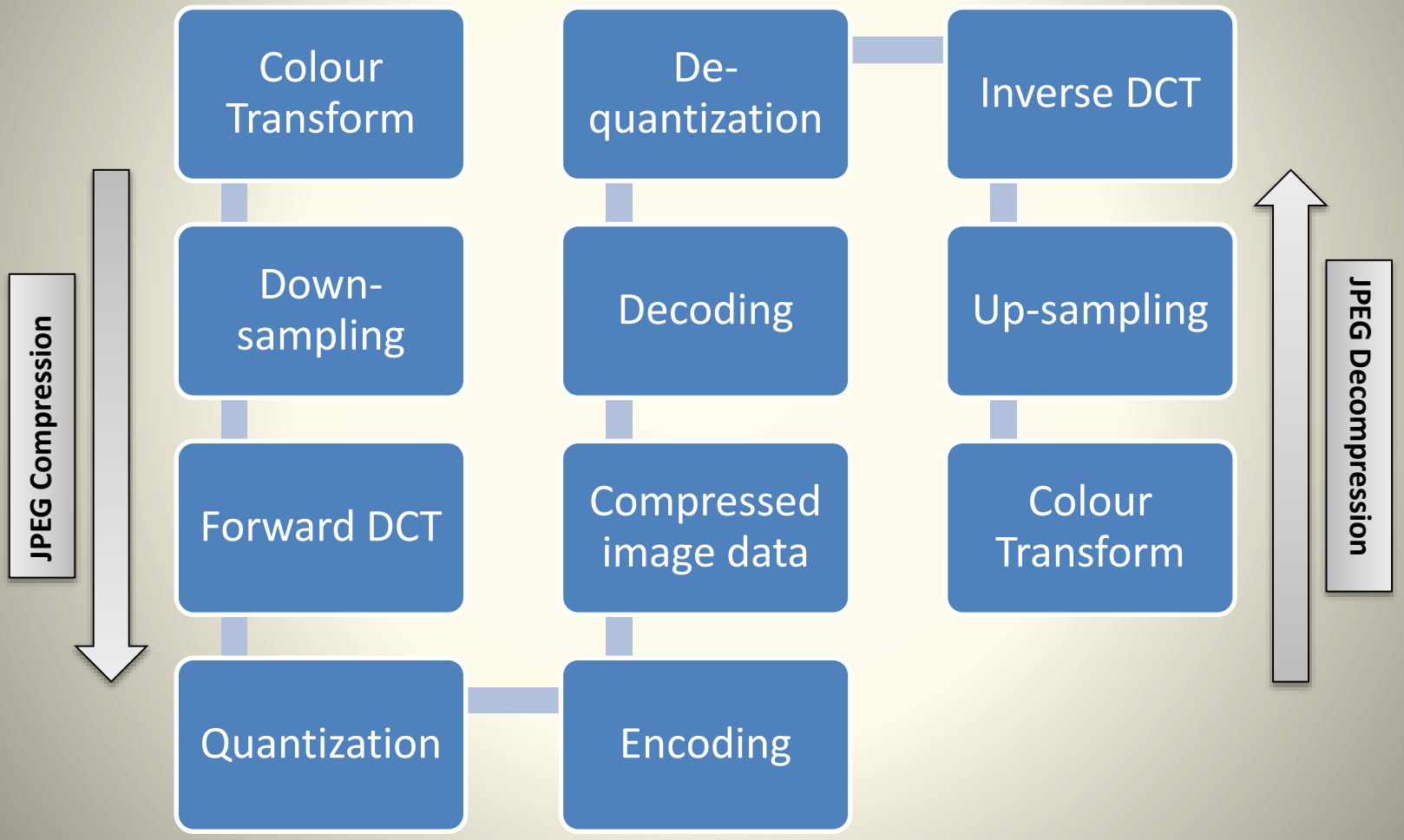
↳ this can be changed right ?

Why JPEG?

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

- A large majority of useful 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 x 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.

JPEG Schematic



Algorithm

- **Splitting**: Split the image into 8 x 8 non-overlapping pixel blocks. If the image cannot be divided into 8-by-8 blocks, then you can add in empty pixels around the edges, essentially zero-padding the image.
- **Colour Space Transform** from [R,G,B] to [Y,Cb,Cr] & Subsampling.
- **DCT**: Take the Discrete Cosine Transform (DCT) of each 8-by-8 block.
- **Quantization**: quantize the DCT coefficients according to psycho-visually tuned quantization tables.
- **Serialization**: by zigzag scanning pattern to exploit redundancy.
- **Vectoring**: Differential Pulse Code Modulation (**DPCM**) on DC components
- Run Length Encoding (**RLE**) on AC components
- **Entropy Coding**:
  - Run Length Coding
  - Huffman Coding or Arithmetic Coding

Step I - Splitting

The input image is divided into smaller blocks having 8 x 8 dimensions, summing up to 64 units in total. Each of these units is called a ***pixel***, which is the smallest unit of any image.

Original image

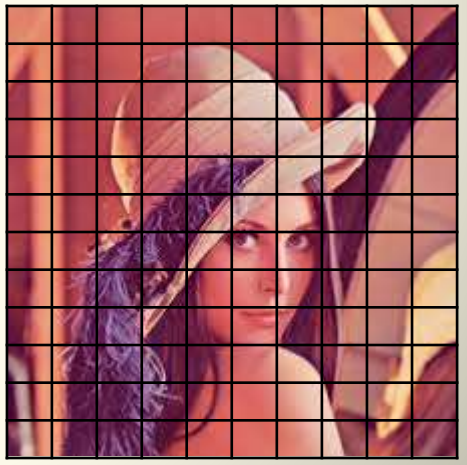


Image split into multiple 8x8 pixel blocks

Step II - RGB to YCbCr conversion

- JPEG makes use of [Y,Cb,Cr] model instead of [R,G,B] model.
- The precision of colors suffer less (for a human eye) than the precision of contours (based on luminance)

Simple color space model: [R,G,B] per pixel

JPEG uses [Y, Cb, Cr] Model

Y = Brightness

Cb = Color blueness

Cr = Color redness

how we know span is same?

Colour conversion

8x8 pixel
1 pixel = 3 components

MCU with sampling factor (1, 1, 1)

$$Y = 0.299R + 0.587G + 0.114B$$
$$Cb = -0.1687R - 0.3313G + 0.5B + 128$$
$$Cr = 0.5R - 0.4187G - 0.0813B + 128$$

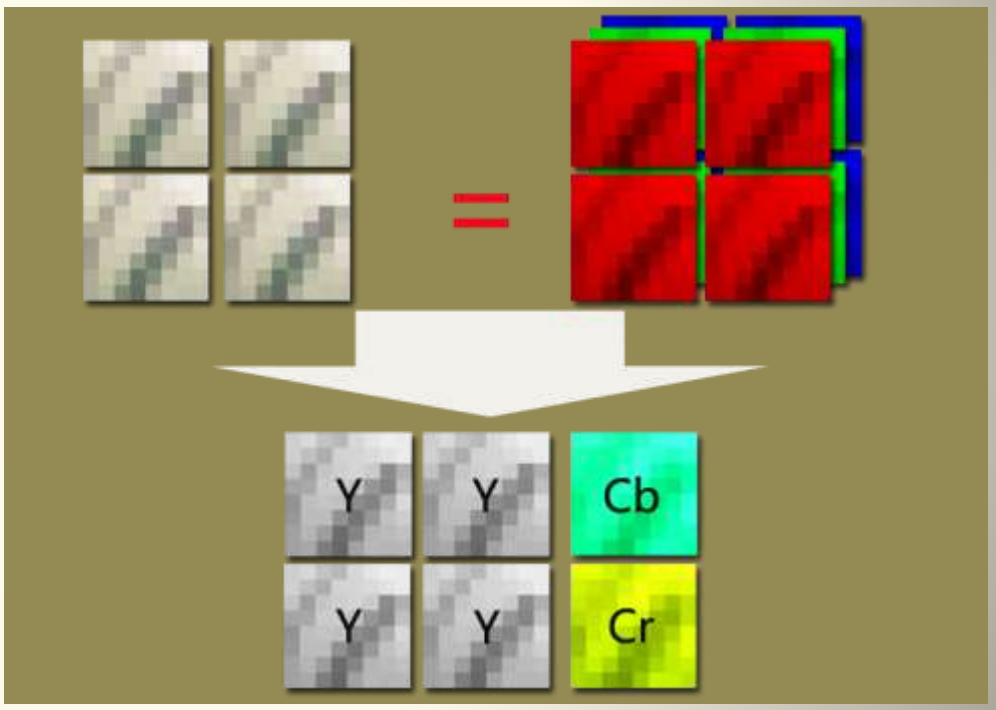
wow!

Down-sampling

Y is taken for every pixel, and Cb, Cr are taken for a block of 2x2 pixels.

4 blocks
16 x16 pixel

MCU with sampling factor
(2, 1, 1)



MCU = Minimum Coded Unit (smallest unit that can be coded)
Data size reduces to half.

Step III - Forward DCT

- The DCT uses the cosine function, therefore not interacting with complex numbers at all.
- DCT converts the information contained in a block(8x8) of pixels from ***spatial*** domain to the ***frequency*** domain.

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.

NOTE: USE FFT INSTEAD OF DCT

DCT Formula

- 1-D DCT –

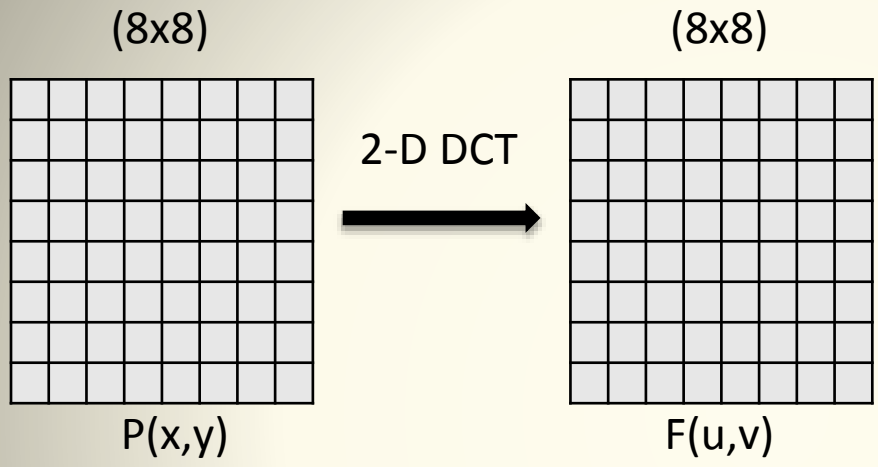
$$F(w) = \frac{a(u)}{2} \sum_{n=0}^{N-1} f(n) cos \frac{(2n+1)w\pi}{16}$$

- But the image matrix is a 2-D matrix. So we can either apply 1-D DCT to the image matrix twice. Once row-wise, then column wise, to get the DCT coefficients. Or we can apply the standard 2-D DCT formula for JPEG compression. If the *input matrix* is *P(x,y)* and the *transformed matrix* is *F(u,v) or G(u,v)* then the DCT for the 8 x 8 block is computed using the expression:-

- 2-D DCT –

$$G_{u,v} = \frac{1}{4}\alpha(u)\alpha(v) \sum_{x=0}^{7} \sum_{y=0}^{7} g_{x,y} cos \left[\frac{(2x+1)u\pi}{16}\right] cos \left[\frac{(2y+1)v\pi}{16}\right]$$

DC and AC components



F(0,0) is called the ***DC component*** and the rest of P(x,y) are called ***AC components***.

- For *u = v = 0* the two cosine terms are 0 and hence the value in the location *F[0,0]* of the transformed matrix is simply a function of the summation of all the values in the input matrix.
- This is ***the mean*** of all 64 values in the matrix and is known as the **DC coefficient.**
- Since the values in all the other locations of the transformed matrix have a frequency coefficient associated with them they are known as **AC coefficients.**

Step IV - 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.
- Why Quantization?
  - To reduce the number of bits per sample.
- Two types:
  - **Uniform quantization**
    - q(u,v) is a constant
  - **Non-uniform quantization**
    - Custom quantization tables can be put in image/scan header.
    - JPEG Standard defines two default quantization tables, one each for luminance and chrominance.

Quantization

Standard Formula: $\widehat{F}(\mathrm{u}, v) = \boldsymbol{round}\left(\frac{\mathrm{F(u,v)}}{\mathrm{Q(u,v)}}\right)$

- F(u,v) represents a *DCT coefficient*, Q(u,v) is *quantization matrix*, and $\hat{\mathrm{F}}(\mathrm{u}, \mathrm{v})$ represents the *quantized DCT coefficients* to be applied for successive entropy coding.
- The quantization step is the major information losing step in JPEG compression.
- For non-uniform quantization, there are 2 psycho-visually tuned quantization tables each for luminance (Y) and chrominance (Cb,Cr) components defined by jpeg standards.

Quantization

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 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

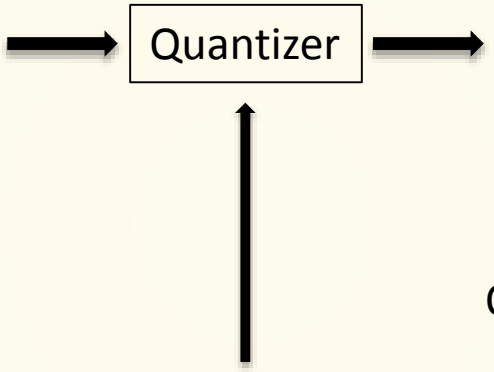
The Chrominance Quantization Table

- The entries of Q(u,v) tend to have larger values towards the lower right corner. This aims to introduce more loss at the higher spatial frequencies.
- The tables above show the default Q(u,v) values obtained from psychophysical studies with the goal of maximizing the compression ratio while minimizing perceptual losses in JPEG images.

Quantization - Example

160	80	47	39	5	3	0	0
65	53	48	8	5	2	0	0
58	34	6	4	2	0	0	0
40	7	6	1	1	0	0	0
8	4	0	0	0	0	0	0
5	2	0	0	0	0	0	0
3	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0

DCT Coefficients F(u,v)



16	7	4	2	0	0	0	0
5	4	3	0	0	0	0	0
4	2	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Quantized Coefficients $\hat{F}(u,v)$

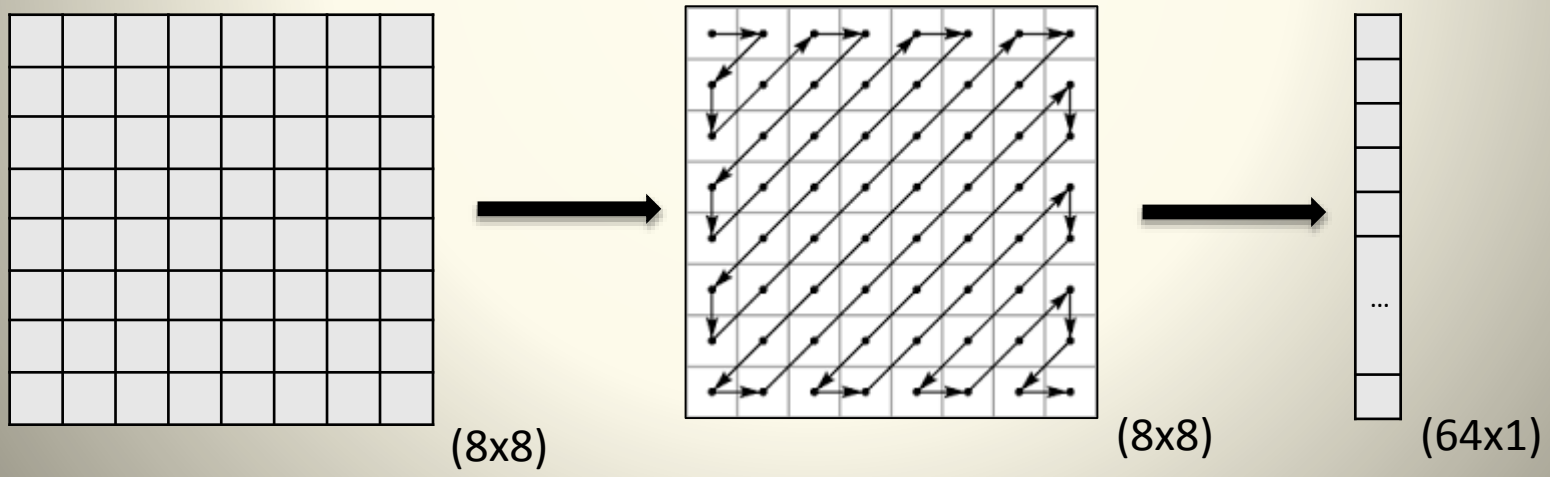
16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Quantization Table Q(u,v)

Each element of F(u,v) is divided by the corresponding element of Q(u,v) and then rounded off to the nearest integer to get the $\hat{F}(u,v)$ matrix.

Step V – Zig-Zag Scan

- Maps 8 x 8 matrix to a 1 x 64 vector.
- Why zigzag scanning?
  - To group low frequency coefficients at the top of the vector and high frequency coefficients at the bottom.
- In order to exploit the presence of the large number of zeros in the quantized matrix, a zigzag of the matrix is used.

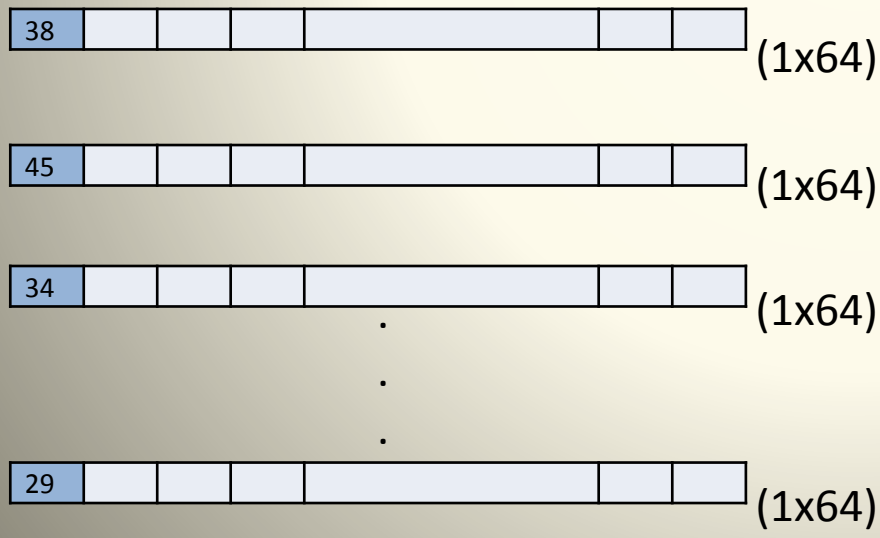


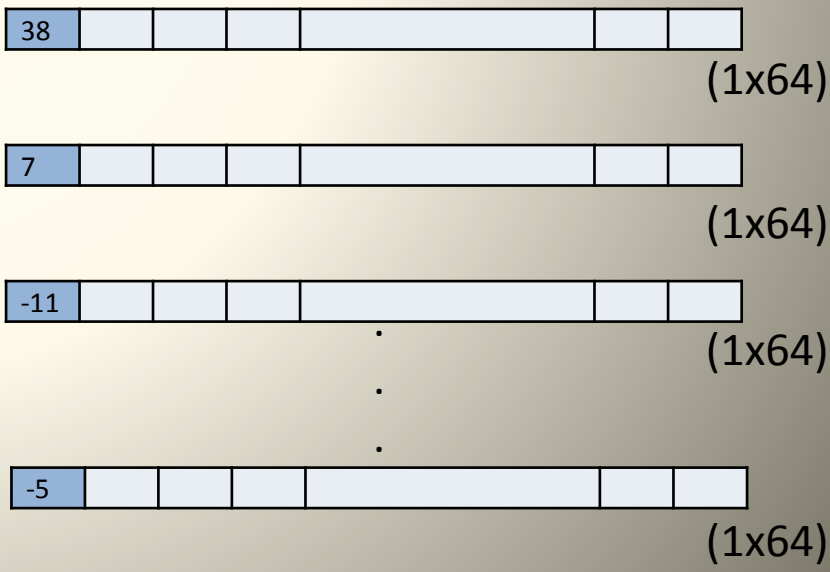
End Product:

(1x64)

Step VI – Vectoring: DPCM on DC component

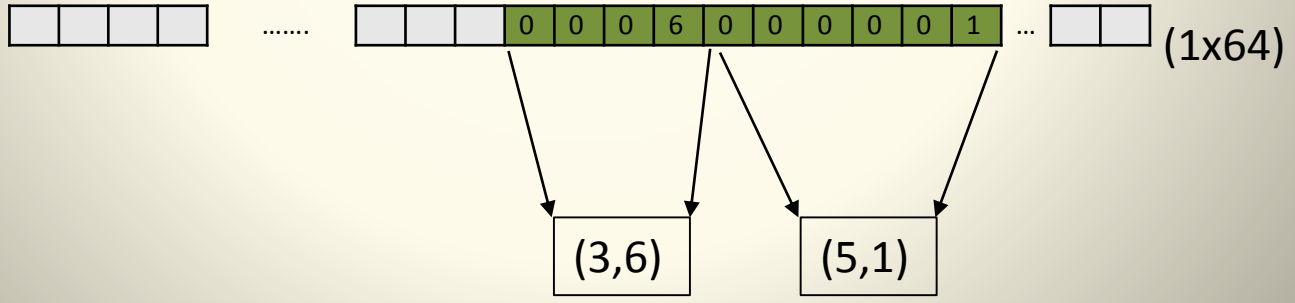
- Differential Pulse Code Modulation (DPCM) is applied to the DC component.
- DC component is large and varies, but often close to previous value.
- DPCM encodes the difference between the current and previous 8x8 block.
- The entropy coding operates on a 1-dimensional string of values (vector). However the output of the quantization matrix is a 2-D matrix and hence this has to be represented in 1-D form. This is known as ***Vectoring***.
- Example:-





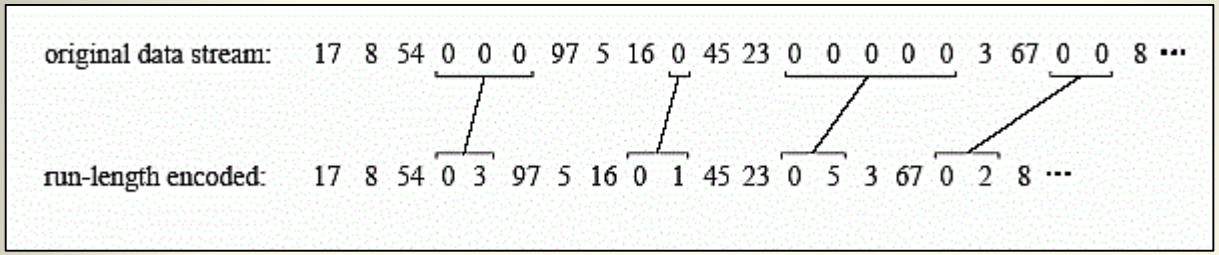
Step VII - RLE on AC components

- Run Length Encoding (RLE) is applied to the AC components.
- 1x63 vector (AC) has lots of zeros in it.
- Encoded as (***skip, value***) pairs, where *skip* is the number of zeros preceding a non-zero value in the quantized matrix, and *value* is the actual coded value of the non-zero component.
- (0,0) is sent as end-of-block (EOB) sentinel value and the zeros after that are discarded. Only the number of zeros is taken note of.

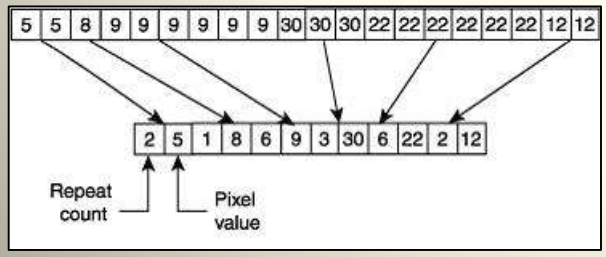


RLE Examples

Example 1-



Example 2-



The 1x64 vector is reduced in terms of bits by grouping the elements as groups of (repeat count,pixel value).

Step VIII – Huffman Coding

- DC and AC components finally need to be represented by a smaller number of bits
- Why Huffman Coding?
  - Significant levels of compression can be obtained by replacing long strings of binary digits by a string of much shorter code words.
- How?
  - The length of each code word is a function of its relative frequency of occurrence.
- Normally a table of code words is used with the set of code words pre-computed using the Huffman Coding Algorithm.
- In Huffman Coding, each DPCM-coded DC coefficient is represented by a pair of symbols : *(Size, Amplitude)*
- where *Size* indicates number of bits needed to represent the coefficient and *Amplitude* contains actual bits.

Huffman Coding: DC Components

- DC Components are coded as (*Size,Value*). The look-up table for generating code words for Value is as given below:-

SIZE	Value	Code
0	0	---
1	-1,1	0,1
2	-3, -2, 2,3	00,01,10,11
3	-7,…, -4, 4,…, 7	000,…, 011, 100,…111
4	-15,…, -8, 8,…, 15	0000,…, 0111, 1000,…, 1111
.		.
.		.
11	-2047,…, -1024, 1024,… 2047	…

Table 1: Huffman Table for DC components *Value* field

Huffman Coding – DC Components

- The look-up table for generating code words for *Size* is as given below:-

SIZE	Code Length	Code
0	2	00
1	3	010
2	3	011
3	3	100
4	3	101
5	3	110
6	4	1110
7	5	11110
8	6	111110
9	7	1111110
10	8	11111110
11	9	111111110

Table 2: Huffman Table for DC components *Size* field

Huffman DC Coding - Example

- If the DC component is 48, and the previous DC component is 52. Then the difference between the 2 components is (48-52) = -4.
- Therefore it is Huffman coded as: 100011
- 011: The codes for representing -4 (Table 1.)
- 100: The size of the value code word is 3. From Table 2, code corresponding to 3 is 100.

Huffman Coding: AC Components

- AC components are coded in two parts:
  - **Part1:** (**RunLength/SIZE**)
    - **RunLength:** The length of the consecutive zero values [0..15]
    - **SIZE:** The number of bits needed to code the *next* nonzero AC component's value. [0-A]
    - (0,0) is the End Of Block (EOB) for the 8x8 block.
    - **Part1** is Huffman coded (see Table 3)
  - **Part2: (Value)**
    - **Value:** Is the actual value of the AC component.(Table 1)

Run/ SIZE	Code Length	Code
0/0	4	1010
0/1	2	00
0/2	2	01
0/3	3	100
0/4	4	1011
0/5	5	11010
0/6	7	1111000
0/7	8	11111000
0/8	10	1111110110
0/9	16	1111111110000010
0/A	16	1111111110000011

Table 3(a)

Run/ SIZE	Code Length	Code
1/1	4	1100
1/2	5	11011
1/3	7	1111001
1/4	9	111110110
1/5	11	11111110110
1/6	16	1111111110000100
1/7	16	1111111110000101
1/8	16	1111111110000110
1/9	16	1111111110000111
1/A	16	1111111110001000
… 15/A	More	Such rows

Table 3(b)

Example of Run Length Encoding

original bit stream: `000000111111111111110000000000000111111111` (42 bits)

a run of 6 0-bits *a run of 14 1-bits*

Representing each run in the original bit stream as a pair **b : n** (where b is 0 or 1 to indicate the contents of the run, and n is the length of the run) produces:

sequence of runs: 0:6, 1:14, 0:13, 1:9

resulting 5-bit bytes: 00110, 11110, 01101, 11001

compressed bit stream: `001101111001101110001` (20 bits)

Merits of JPEG Compression

- Works with colour and grayscale images, but not with binary images.
- Up to 24 bit colour images (Unlike GIF)
- Target photographic quality images (Unlike GIF)
- Suitable for many applications e.g., satellite, medical, general photography, etc.

Thank you