Introduction to Multimedia Computing

Image Compression

Topics

- Compression types
  - Lossless compression
  - Lossy compression
- Redundancy/redundancy types
- Lossless image compression methods
  - Lossless jpeg
- Lossy image compression methods
  - JPEG
    - Cosine Transform and Quantization
    - Entropy Encoding

Image Compression Types (recap)

- Image compression algorithms are classified in two groups:
  - Lossless algorithms:
    - The decompressed image and the original image are exactly the same (no data loss)
  - Lossy algorithms:
    - Decompressed image and the original image are different but generally the difference is not noticeable

Data Redundancy (recap)

- Definition: If some parts of data are stored repeatedly, or can be derived from other parts, the data is said to be redundant

- e.g. If the pixels of a region in an image have the same color, we do not need to store the color value for all of them.

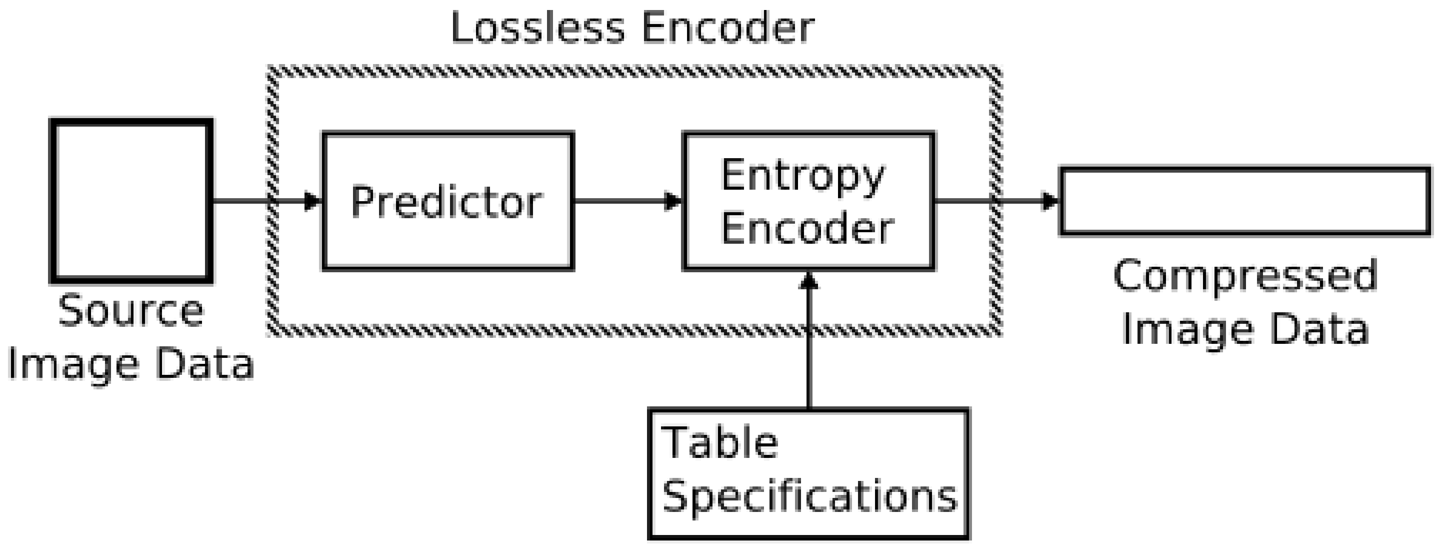
Redundancy Types

- Visual Redundancy
- Spatial Redundancy
- Temporal Redundancy
- Stochastic Redundancy

JPEG Standard

- The name "JPEG" stands for Joint Photographic Experts Group
- Jpeg was developed by one of two sub-groups of ISO/IEC Joint Technical Committee in 1992
- Jpeg was approved in September 1992 as **ITU-T Recommendation T.81**

Lossless JPEG

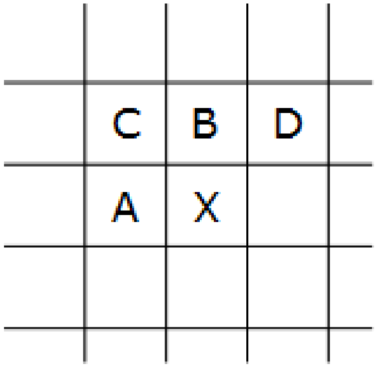


Lossless JPEG

- Lossless JPEG uses differential pulse code modulation (DPCM).
- The predictor finds the difference of each pixel with its neighbors.
- The difference is coded (using entropy coding)

Lossless JPEG

- The image is scanned from top to bottom and from left to right
- Neighbors of a pixel should be coded before the pixel itself.
- Neighbors of a pixel (X) are shown below.



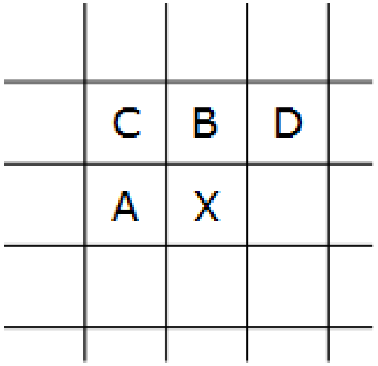
Example

112	110	111	109	108	108
110	104	111	19	19	20
113	107	109	21	18	18

112	2	-1	2	1	0
110	6	-7	92	0	-1
113	6	-2	88	3	0

Coding of a Pixel

Selection-value	Prediction
0	No prediction
1	A
2	B
3	C
4	A + B – C
5	A + (B – C)/2
6	B + (A – C)/2
7	(A + B)/2



- Compression rate is about 50%. Lossless JPEG is mainly used in medical images

Lossy Image Compression

Motivation:

- Compression rates of the lossless algorithms are about 30%.
- This rate is not enough for large images

Solution:

- Using lossy image compression.
- In lossy compression, decompressed image and the original image are different but generally the difference is not noticeable

Lossy JPEG

- Jpeg standard uses:
  - Visual redundancy
  - Spatial redundancy
  - Stochastic redundancy

To compress an image

Visual Redundancy

- Human visual system is less sensitive to color than intensity.
- JPEG standard stores less color information than intensity
- To separate color information from intensity, RGB data is converted into YCbCr

Color space transformation

- RGB values of the pixels are converted to YCbCr

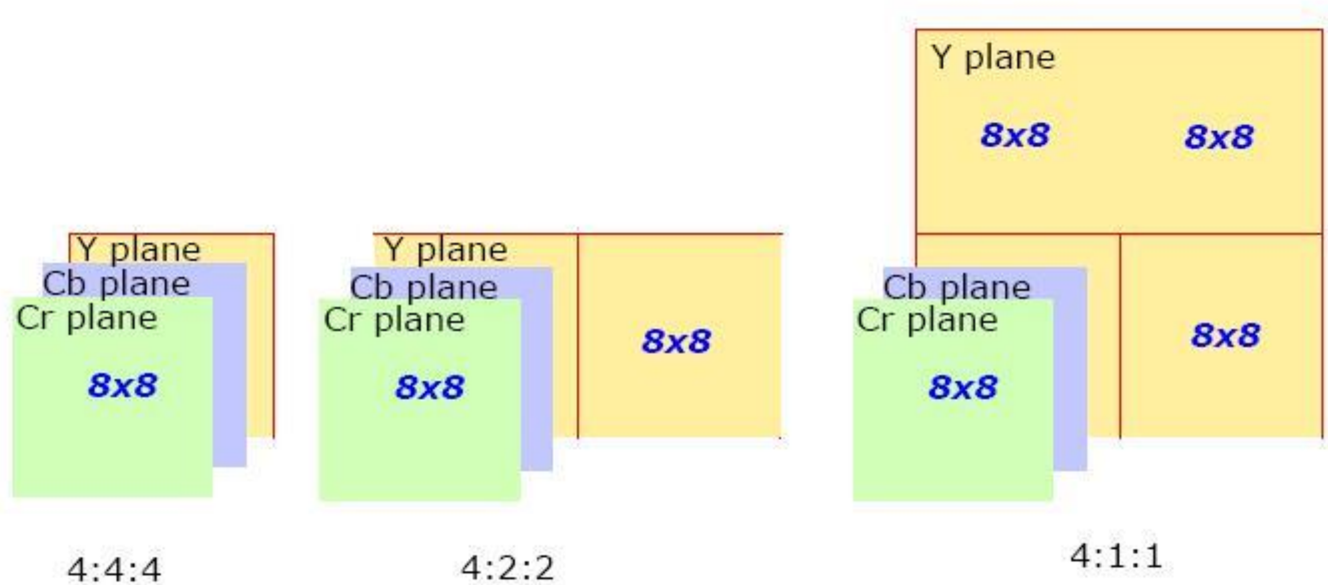
$$\begin{bmatrix} Y \\ \text{Cb} \\ \text{Cr} \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Dividing Image into Blocks

- The image is divided into blocks of 16x16 pixels called macro-blocks
- Color transformation from RGB to YCbCr is done for each macro-block
- Down-samples Cb and Cr
- 16x16 macro-blocks are further divided into four 8x8 blocks

Down Sampling (1)

- Cb and Cr components are down-sampled as shown below.



Down Sampling (2)

23	144	16	55
45	16	11	78
67	35	5	90
101	133	35	42
122	98	55	134

57	40
84	43

Effect of Removing Visual Redundancy

- Each macro-block consists of three components (Y, Cb, Cr)
- Each component has 4 blocks
- Each macro-block contains 3x4=12 blocks

- After down-sampling (4:1:1), a macro-block has 4 (Y) + 1 (Cb) + 1 (Cr) = 6 blocks
- This is equal to 50% compression

Spatial Redundancy

- If neighboring pixels are close in color, the signal has low frequency
- If neighboring pixels are very different, the image contains high frequency
- Discrete Cosine Transform (DCT) is used to separate low frequency from high frequency data

Discrete cosine transform

- Cosine transform is applied to each block after down-sampling.

$$G_{u,v} = \alpha(u)\alpha(v) \sum_{x=0}^{7} \sum_{y=0}^{7} g_{x,y} \cos\left[\frac{\pi}{8}\left(x+\frac{1}{2}\right)u\right] \cos\left[\frac{\pi}{8}\left(y+\frac{1}{2}\right)v\right]$$

where

$$\alpha_p(n) = \begin{cases} \sqrt{\frac{1}{8}}, & \text{if } n = 0 \\ \sqrt{\frac{2}{8}}, & \text{otherwise} \end{cases}$$

Quantization

- DCT coefficients are rounded to integer numbers.
- Then quantization is done using a quantization table.

$$B_{j,k} = \text{round}\left(\frac{G_{j,k}}{Q_{j,k}}\right)$$

- B is the quantized value, G is the coefficient and Q is quantization table value.

Quantization Example

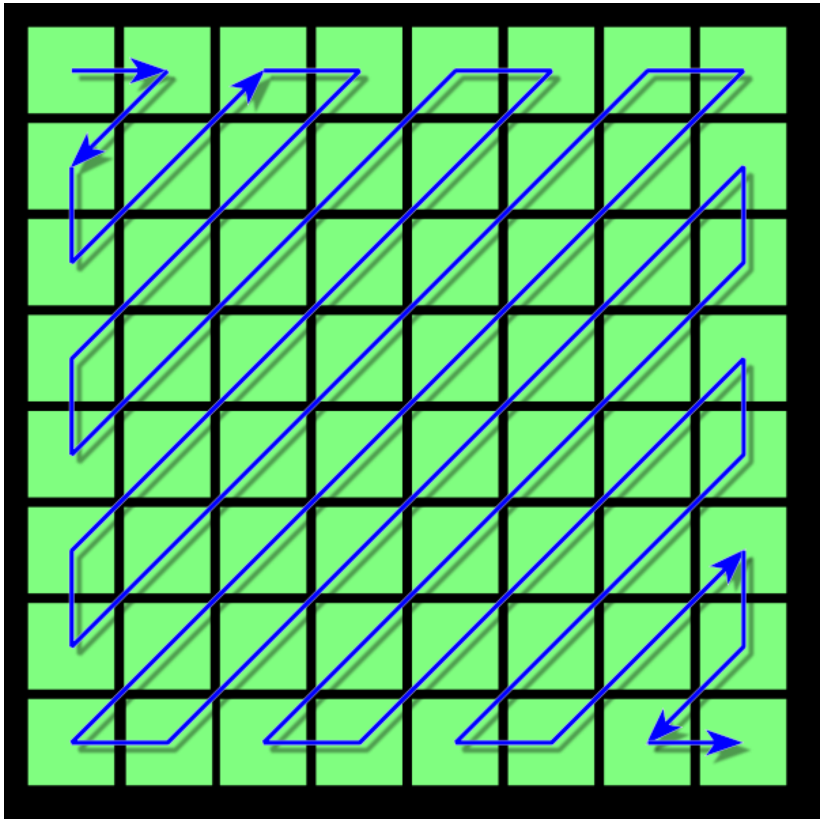
$$G \begin{bmatrix} -415 & -30 & -61 & 27 & 56 & -20 & -2 & 0 \\ 4 & -22 & -61 & 10 & 13 & -7 & -9 & 5 \\ -47 & 7 & 77 & -25 & -29 & 10 & 5 & -6 \\ -49 & 12 & 34 & -15 & -10 & 6 & 2 & 2 \\ 12 & -7 & -13 & -4 & -2 & 2 & -3 & 3 \\ -8 & 3 & 2 & -6 & -2 & 1 & 4 & 2 \\ -1 & 0 & 0 & -2 & -1 & -3 & 4 & -1 \\ 0 & 0 & -1 & -4 & -1 & 0 & 1 & 2 \end{bmatrix}$$

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

$$B \begin{bmatrix} -26 & -3 & -6 & 2 & 2 & -1 & 0 & 0 \\ 0 & -2 & -4 & 1 & 1 & 0 & 0 & 0 \\ -3 & 1 & 5 & -1 & -1 & 0 & 0 & 0 \\ -4 & 1 & 2 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Zig-zag coding

- The quantized coefficients are listed after a zig-zag tracing. The list has many zeros at the end



Effect of Removing Spatial Redundancy

- The quantized coefficients at the right bottom corner correspond to high frequency content

- After zig-zag scanning, high frequency coefficients are at the end of the list.

- The zeros at the end of the list are not stored.

Code Blocks

- Code blocks after zig-zag coding are created by the number of zeros and the non zero value coming after them.

  <number of zeros, nonzero value>
- e.g. 304000500000006

  (0,3), (1,4), (3,5), (7,6)

Entropy coding

- The code blocks after zig-zag scaning are coded using a stochastic or entropy coding method to store less number of bits.
- In entropy coding less number of bits are assigned to the codes that are repeated more. (variable length codes)
- The Huffman method is used for variable length coding.

Image Quality

- JPEG image quality depends on
  - Down sampling type (4:4:4, 4:2:2, 4:1:1)
  - Quantization matrix (If values of the quantization matrix are large, more zeros are resulted, and more data is lost.)
- Higher compression rate causes lower quality of the image

Sample Coded Data

139	144	149	153	155	155	155	155
144	151	153	156	159	156	156	156
150	155	160	163	158	156	156	156
159	161	162	160	160	159	159	159
159	160	161	162	162	155	155	155
161	161	161	161	160	157	157	157
162	162	161	163	162	157	157	157
162	162	161	161	163	158	158	158

(a) source image samples

235.6	-1.0	-12.1	-5.2	2.1	-1.7	-2.7	1.3
-22.6	-17.5	-6.2	-3.2	-2.9	-0.1	0.4	-1.2
-10.9	-9.3	-1.6	1.5	0.2	-0.9	-0.6	-0.1
-7.1	-1.9	0.2	1.5	0.9	-0.1	0.0	0.3
-0.6	-0.8	1.5	1.6	-0.1	-0.7	0.6	1.3
1.8	-0.2	1.6	-0.3	-0.8	1.5	1.0	-1.0
-1.3	-0.4	-0.3	-1.5	-0.5	1.7	1.1	-0.8
-2.6	1.6	-3.8	-1.8	1.9	1.2	-0.6	-0.4

(b) forward DCT coefficients

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

(c) quantization table

15	0	-1	0	0	0	0	0
-2	-1	0	0	0	0	0	0
-1	-1	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

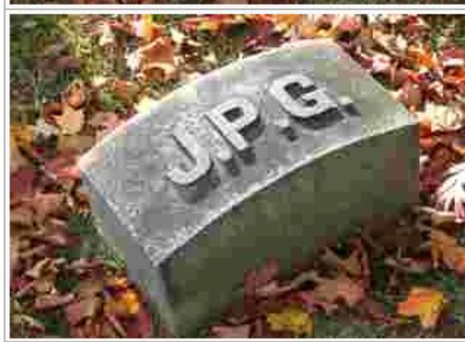
(d) normalized quantized coefficients

240	0	-10	0	0	0	0	0
-24	-12	0	0	0	0	0	0
-14	-13	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

(e) denormalized quantized coefficients

144	146	149	152	154	156	156	156
148	150	152	154	156	156	156	156
155	156	157	158	158	157	156	155
160	161	161	162	161	159	157	155
163	163	164	163	162	160	158	156
163	164	164	164	162	160	158	157
160	161	162	162	162	161	159	158
158	159	161	161	162	161	159	158

(f) reconstructed image samples

Image	Quality	Size (bytes)	Compression ratio
	Higher quality (Q = 100)	83,261	2.6:1
	High quality (Q = 50)	15,138	15:1
	Medium quality (Q = 25)	9,553	23:1
	Low quality (Q = 10)	4,787	46:1

JPEG Coding Algorithm

- The encoding process steps of JPEG:
  - The color of the pixels in the image is converted from RGB to YCbCr
  - The resolution of the Cb and Cr data is reduced, usually by a factor of 2. (Down-sampling)
  - The macro-blocks are split into blocks of 8×8 pixels, and for each block, each of the Y, Cb, and Cr data undergoes a discrete cosine transform (DCT).
  - The DCT coefficients are quantized and zig-zag scanned.
  - The resulting data for all 8×8 blocks is further compressed with a loss-less stochastic algorithm.

Questions?