Damascus University
Faculty of information engineering
Fourth year

MultiMedia Systems
Fifth Lecture
JPEG

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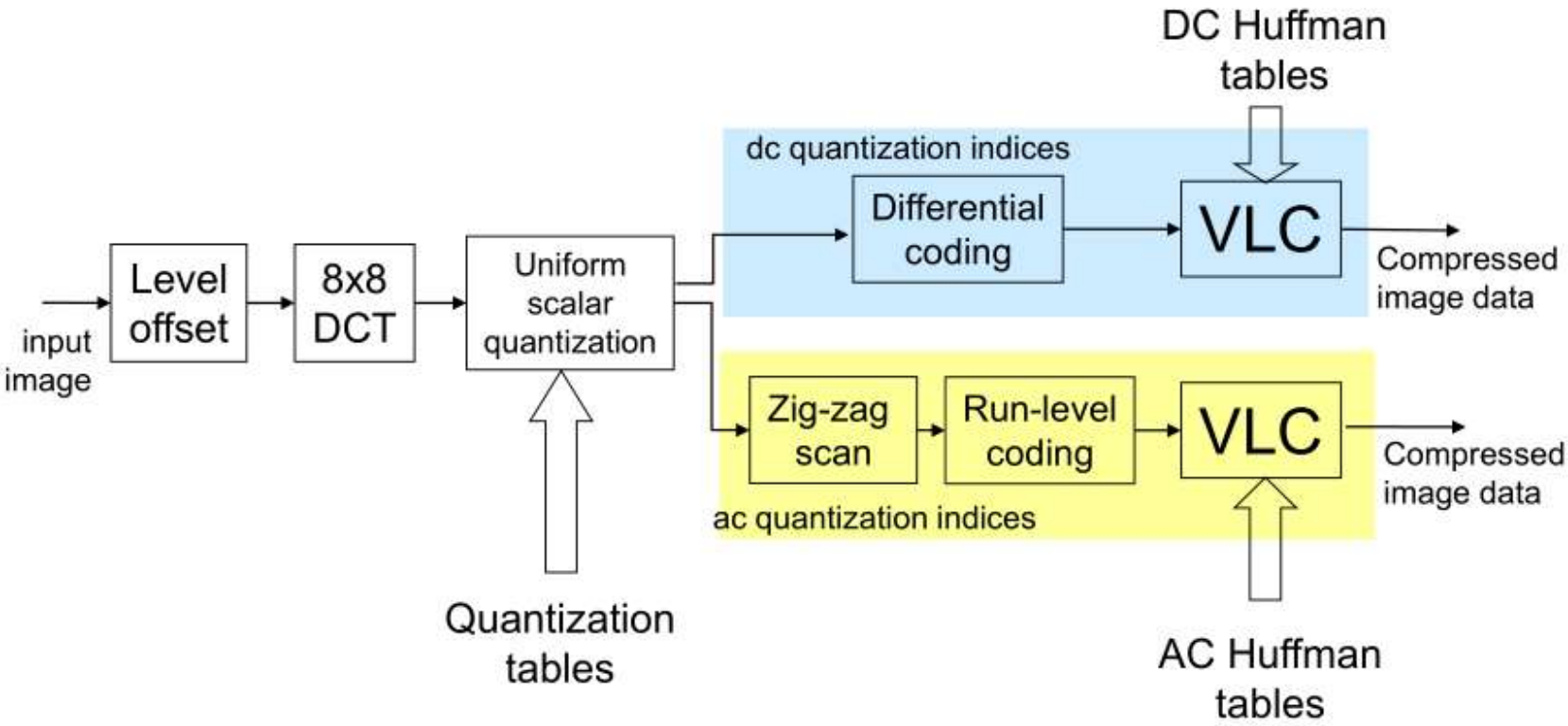
JPEG

- JPEG : Joint Photographic Experts Group
- Almost 80 percents of images on web are compressed by the JPEG standards
- JPEG is a lossy image compression method (decompression the EXACTimage does NOT possible)

JPEG

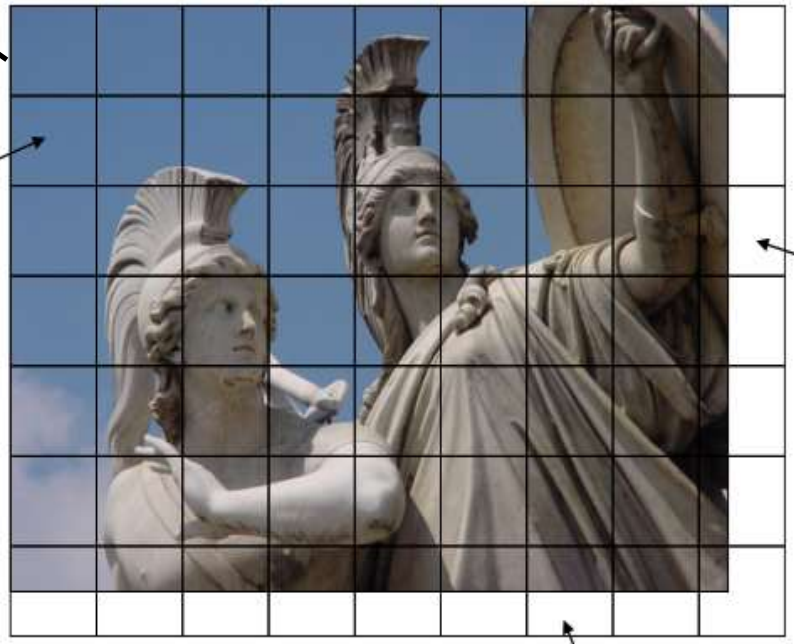
- We must convert rgb image into YCbCr
- JPEG apply on luma (Y)not chroma(CbCr)
- For croma we apply subsambling.

JPEG main steps



Dividision into 8*8 blocks

We apply the other steps on each 8*8



8x8 blocks

Padding of right boundary blocks

Padding of lower boundary blocks

Discrete Cosine Transform

- An image block is defined to have dimension M=N=8 :
- The definition of 2D DCT and its inverse IDCT are as follows:

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

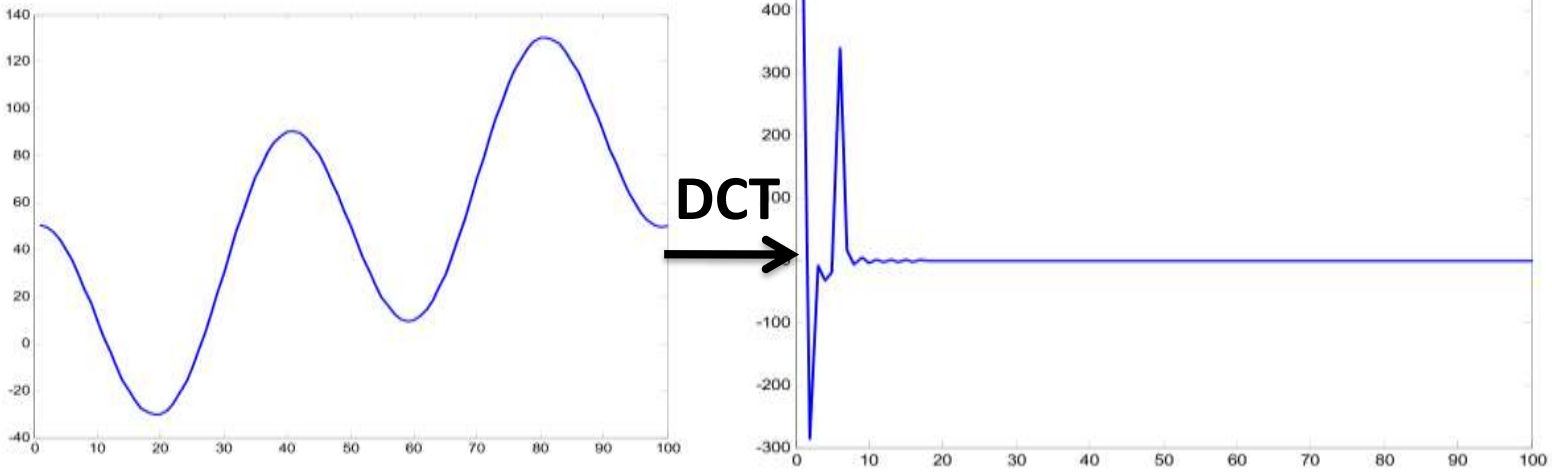
- 2D Inverse Discrete Cosine Transform(2D IDCT):

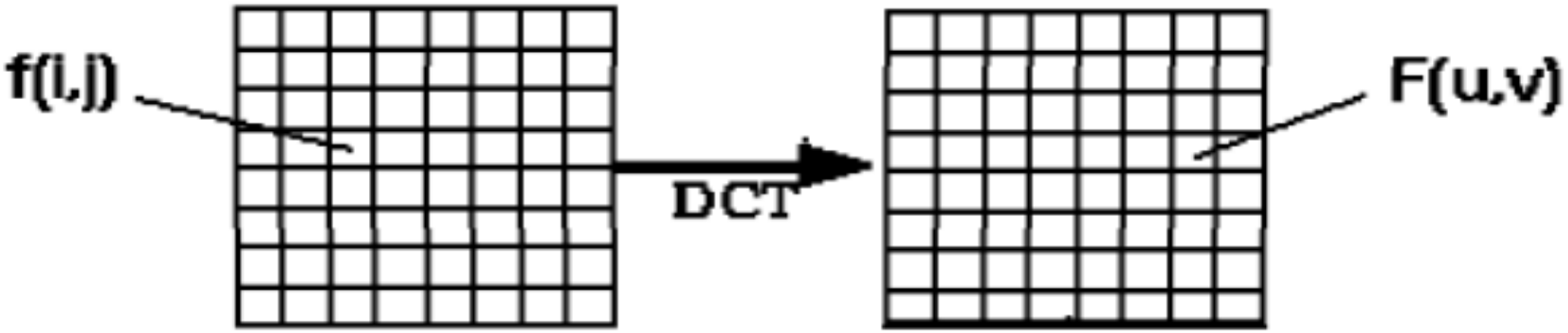
$$\tilde{f}(i,j) = \sum_{u=0}^{7}\sum_{v=0}^{7} \frac{C(u)C(v)}{4} \cos\frac{(2i+1)u\pi}{16} \cos\frac{(2j+1)v\pi}{16} F(u,v)$$

$$C(u) = \begin{cases} \frac{\sqrt{2}}{2} & if\ u=0 \\ 1 & else \end{cases}$$

Discrete Cosine Transform

x = (1:100) + 50*cos((1:100)*2*pi/40);





Discrete Cosine Transform

Suppose the output of appling DCT on (8*8)block is

20.0000	30.5458	-12.6501	1.4046	2.0000	-5.7644	-1.7957	0.0331
- 48.8409	-8.0914	10.0495	-1.3722	5.5094	0.0798	0.4861	2.7702
1.2833	-3.2701	-8.0355	4.7930	1.7917	-0.5632	-2.1464	-4.7514
5.2795	4.1426	-3.8016	-2.8859	0.6881	1.3372	2.4971	-2.5460
- 1.0000	1.5931	-1.8478	-0.2929	-0.5000	-1.7569	0.7654	3.6796
- 2.0945	-1.2395	-1.4372	3.4407	3.0840	3.1714	-2.0101	1.6248
2.4450	-0.0382	2.8536	-0.6242	-1.5539	1.2612	-0.9645	-1.7201
0.6589	1.3737	1.5349	0.9380	-3.1680	1.9134	3.0202	1.3059

Quantization

Table 9.1 The Luminance Quantization Table

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 9.2 The Chrominance 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

This step give jpeg The adjective(lossy algorithm)

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

Output of Quantization

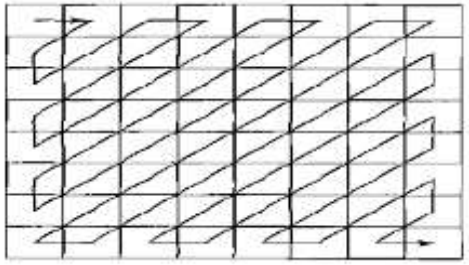
$$\hat{\mathcal{F}}(0,0) = \text{round}\frac{20}{16} = 1$$

1	3	-1	0	0	0	0	0
-4	-1	1	0	0	0	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	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Zigzag

– Turns the 8×8 matrix into a 64 vector

– Concatenates long runs of zeros



Output of Quantization →

1	3	-1	0	0	0	0	0
-4	-1	1	0	0	0	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	0	0	0	0	0	0
0	0	0	0	0	0	0	0

The out put of zigzag → 1 3 -4 0 -1 -1 0 1 0 0 0 0 -1 0 0 0 ….. 0 EOB

DPCM on DC Coefficients

$$d_i = DC_{i+1} - DC_i$$
$$d_0 = DC_0$$

for first DC **Coefficient**

Di = 1-0 = 1 = (1) 2

DC reprented in huffman coding ➔ 0111

Represent 1 in binary code

Dc code for category 1(#of bits to represent 1 in binary)

If dc=7➔
We write 7 in binary code 111
And we see 111 belongs which category in table ??==>3 because we use 3 bits to represent 7 in binary code ➔ so that representation of dc in this case is 00111

RLC(Run Length Coding)on ACs

- The 1 x 64 size vector contains long runs of zeros
- RLC (Run-length Coding):
  - (*skip, value*)
  - *skip: number of zeros, value: the next nonzero value*
  - (0,0): the end of a block **EOB** after the last nonzero AC coefficient is reached

1 3 -4 0 -1 -1 0 1 0 0 0 0 -1 0 0 0 ….. 0 EOB

ACs

Huffman Coding of AC Coefficient

- (0,6):
- (0/# bits of binary 6,binary of 6)=(0/3,110)
- From the AC table we find 0/3 → 100
- So coding for AC(0,6) is 100110
- The same manner we find:
- (0,-1)=000
- (0/3 , 011)=1 0 0 0 1 1
- **EOB=1010**

JPEG default AC code

Run/ Category	Base Code	Length	Run/ Category	Base Code	Length
0/0	**1010 (= EOB)**	**4**			
0/1	00	3	8/1	11111010	9
0/2	01	4	8/2	1111111111000000	17
0/3	100	6	8/3	1111111110110111	19
0/4	1011	8	8/4	1111111110111000	20
0/5	11010	10	8/5	1111111110111001	21
0/6	111000	12	8/6	1111111110111010	22
0/7	1111000	14	8/7	1111111110111011	23
0/8	1111110110	18	8/8	1111111110111100	24
0/9	1111111110000010	25	8/9	1111111110111101	25
0/A	1111111110000011	26	8/A	1111111110111110	26
1/1	1100	5	9/1	111111000	10
1/2	111001	8	9/2	1111111110111111	18
1/3	1111001	10	9/3	1111111111000000	19
1/4	111110110	13	9/4	1111111111000001	20
1/5	1111110110	16	9/5	1111111111000010	21
1/6	1111111110000100	22	9/6	1111111111000011	22
1/7	1111111110000101	23	9/7	1111111111000100	23
1/8	1111111110000110	24	9/8	1111111111000101	24
1/9	1111111110000111	25	9/9	1111111111000110	25
1/A	1111111110001000	26	9/A	1111111111000111	26
2/1	11011	6	A/1	111111001	10
2/2	1111000	10	A/2	1111111111001000	18
2/3	1111110111	13	A/3	1111111111001001	19
2/4	1111111110001001	20	A/4	1111111111001010	20
2/5	1111111110001010	21	A/5	1111111111001011	21
2/6	1111111110001011	22	A/6	1111111111001100	22
2/7	1111111110001100	23	A/7	1111111111001101	23

JPEG default DC code

Category	Base Code	Length	Category	Base Code	Length
0	010	3	6	1110	10
1	011	4	7	11110	12
2	100	5	8	111110	14
3	00	5	9	1111110	16
4	101	7	A	11111110	18
5	110	8	B	111111110	20

JPEG suggested AC code for luminance

Run/ Category	Base Code	Length	Run/ Category	Base Code	Length
0/0	**1010 (= EOB)**	**4**			
0/1	00	3	8/1	11111010	9
0/2	01	4	8/2	111111111000000	17
0/3	100	6	8/3	1111111110110111	19
0/4	1011	8	8/4	1111111110111000	20
0/5	11010	10	8/5	1111111110111001	21
0/6	111000	12	8/6	1111111110111010	22
0/7	1111000	14	8/7	1111111110111011	23
0/8	1111110110	18	8/8	1111111110111100	24
0/9	1111111110000010	25	8/9	1111111110111101	25
0/A	1111111110000011	26	8/A	1111111110111110	26
1/1	1100	5	9/1	111111000	10
1/2	111001	8	9/2	1111111110111111	18
1/3	1111001	10	9/3	1111111111000000	19
1/4	111110110	13	9/4	1111111111000001	20
1/5	11111110110	16	9/5	1111111111000010	21
1/6	1111111110000100	22	9/6	1111111111000011	22
1/7	1111111110000101	23	9/7	1111111111000100	23
1/8	1111111110000110	24	9/8	1111111111000101	24
1/9	1111111110000111	25	9/9	1111111111000110	25
1/A	1111111110001000	26	9/A	1111111111000111	26
2/1	11011	6	A/1	111111001	10
2/2	11111000	10	A/2	1111111111001000	18
2/3	1111110111	13	A/3	1111111111001001	19
2/4	1111111110001001	20	A/4	1111111111001010	20
2/5	1111111110001010	21	A/5	1111111111001011	21
2/6	1111111110001011	22	A/6	1111111111001100	22
2/7	1111111110001100	23	A/7	1111111111001101	23

JPEG default AC code (continued...)

2/8	1111111110001101	24	A/8	1111111111001110	24
2/9	1111111110001110	25	A/9	1111111111001111	25
2/A	1111111110001111	26	A/A	1111111111010000	26
3/1	111010	7	B/1	11111010	10
3/2	111110111	11	B/2	1111111111010001	18
3/3	11111110111	14	B/3	1111111111010010	19
3/4	1111111110010000	20	B/4	1111111111010011	20
3/5	1111111110010001	21	B/5	1111111111010100	21
3/6	1111111110010010	22	B/6	1111111111010101	22
3/7	1111111110010011	23	B/7	1111111111010110	23
3/8	1111111110010100	24	B/8	1111111111010111	24
3/9	1111111110010101	25	B/9	1111111111011000	25
3/A	1111111110010110	26	B/A	1111111111011001	26
4/1	111011	7	C/1	11111111010	11
4/2	1111111000	12	C/2	1111111111011010	18
4/3	1111111110010111	19	C/3	1111111111011011	19
4/4	1111111110011000	20	C/4	1111111111011100	20
4/5	1111111110011001	21	C/5	1111111111011101	21
4/6	1111111110011010	22	C/6	1111111111011110	22
4/7	1111111110011011	23	C/7	1111111111011111	23
4/8	1111111110011100	24	C/8	1111111111100000	24
4/9	1111111110011101	25	C/9	1111111111100001	25
4/A	1111111110011110	26	C/A	1111111111100010	26

JPEG default AC code (continued...)

5/1	1111010	8	D/1	1111111010	12
5/2	1111111001	12	D/2	1111111111000011	18
5/3	1111111110011111	19	D/3	1111111111000100	19
5/4	1111111110100000	20	D/4	1111111111000101	20
5/5	1111111110100001	21	D/5	1111111111000110	21
5/6	1111111110100010	22	D/6	1111111111000111	22
5/7	1111111110100011	23	D/7	1111111111001000	23
5/8	1111111110100100	24	D/8	1111111111001001	24
5/9	1111111110100101	25	D/9	1111111111001010	25
5/A	1111111110100110	26	D/A	1111111111001011	26
6/1	1111011	8	E/1	1111111110110	13
6/2	1111111000	13	E/2	1111111111101100	18
6/3	1111111110100111	19	E/3	1111111111101101	19
6/4	1111111110101000	20	E/4	1111111111101110	20
6/5	1111111110101001	21	E/5	1111111111101111	21
6/6	1111111110101010	22	E/6	1111111111110000	22
6/7	1111111110101011	23	E/7	1111111111110001	23
6/8	1111111110101100	24	E/8	1111111111110010	24
6/9	1111111110101101	25	E/9	1111111111110011	25
6/A	1111111110101110	26	E/A	1111111111110100	26
7/1	1111001	9	F/0	11111110111	12
7/2	1111111001	13	F/1	1111111111110101	17
7/3	1111111110101111	19	F/2	1111111111110110	18
7/4	1111111111000000	20	F/3	1111111111110111	19
7/5	1111111111000001	21	F/4	1111111111111000	20
7/6	1111111111000010	22	F/5	1111111111111001	21
7/7	1111111111000011	23	F/6	1111111111111010	22

JPEG default AC code (continued...)

5/1	1111010	8	D/1	1111111010	12
5/2	1111111001	12	D/2	1111111111000011	18
5/3	1111111110011111	19	D/3	1111111111000100	19
5/4	1111111110100000	20	D/4	1111111111000101	20
5/5	1111111110100001	21	D/5	1111111111000110	21
5/6	1111111110100010	22	D/6	1111111111000111	22
5/7	1111111110100011	23	D/7	1111111111001000	23
5/8	1111111110100100	24	D/8	1111111111001001	24
5/9	1111111110100101	25	D/9	1111111111001010	25
5/A	1111111110100110	26	D/A	1111111111001011	26
6/1	1111011	8	E/1	11111111010	13
6/2	11111111000	13	E/2	1111111111101100	18
6/3	1111111110100111	19	E/3	1111111111101101	19
6/4	1111111110101000	20	E/4	1111111111101110	20
6/5	1111111110101001	21	E/5	1111111111101111	21
6/6	1111111110101010	22	E/6	1111111111110000	22
6/7	1111111110101011	23	E/7	1111111111110001	23
6/8	1111111110101100	24	E/8	1111111111110010	24
6/9	1111111110101101	25	E/9	1111111111110011	25
6/A	1111111110101110	26	E/A	1111111111110100	26
7/1	1111000	9	F/0	111111110111	12
7/2	1111111001	13	F/1	1111111111110101	17
7/3	1111111110101111	19	F/2	1111111111110110	18
7/4	1111111111000000	20	F/3	1111111111110111	19
7/5	1111111111000001	21	F/4	1111111111111000	20
7/6	1111111111000010	22	F/5	1111111111111001	21
7/7	1111111111000011	23	F/6	1111111111111010	22

JPEG Example

Original Image Block

124	125	122	120	122	119	117	118
121	121	120	119	119	120	120	118
126	124	123	122	121	121	120	120
124	124	125	125	126	125	124	124
127	127	128	129	130	128	127	125
143	142	143	142	140	139	139	139
150	148	152	152	152	152	150	151
156	159	158	155	158	158	157	156

JPEG Example

Original Image Block → DCT

Large values

39.8750	6.5653	-2.2420	1.2203	-0.3750	-1.0874	0.7934	1.1347
-102.4388	4.5675	2.2637	1.1206	0.3581	-0.6336	-1.0530	-0.4802
37.7706	1.3144	1.7740	0.2583	-1.5095	-2.2182	-0.1010	0.2329
-5.6740	2.2421	-1.3260	-0.8132	1.4173	0.2212	-0.1393	0.1703
-3.3750	-0.7451	-1.7569	0.7764	-0.6250	-2.6597	-1.3018	0.7620
5.9894	-0.1399	-0.4595	-0.7788	1.9994	-0.2652	1.4643	0.0047
3.9733	5.5280	2.3990	-0.5588	-0.0512	-0.8476	-0.5240	-0.1301
-3.4331	0.5198	-1.0721	0.8711	0.9634	0.0903	0.3305	0.0109

Small values

DCT coefficients
After subtracting 128
From each pixel.

- (The *quantization table*)

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

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

$$round\left(\frac{39.88}{16}\right) = 2$$

DCT coefficients

39.88	6.56	−2.24	1.22	−0.37	−1.08	0.79	1.13
−102.43	4.56	2.26	1.12	0.35	−0.63	−1.05	−0.48
37.77	1.31	1.77	0.25	−1.50	−2.21	−0.10	0.23
−5.67	2.24	−1.32	−0.81	1.41	0.22	−0.13	0.17
−3.37	−0.74	−1.75	0.77	−0.62	−2.65	−1.30	0.76
5.98	−0.13	−0.45	−0.77	1.99	−0.26	1.46	0.00
3.97	5.52	2.39	−0.55	−0.051	−0.84	−0.52	−0.13
−3.43	0.51	−1.07	0.87	0.96	0.09	0.33	0.01

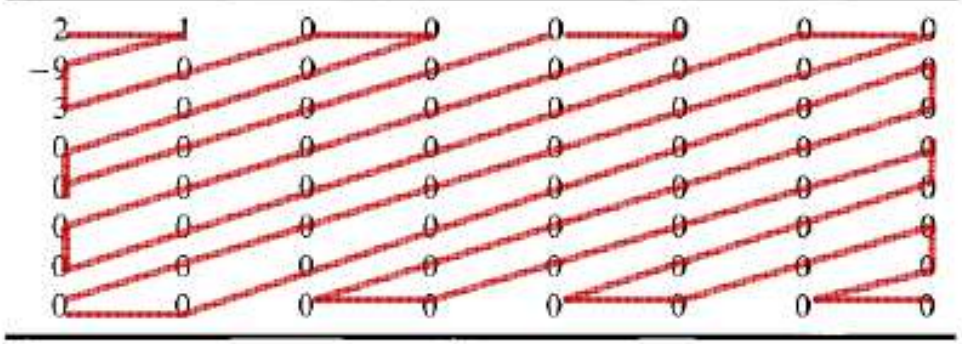
DCT coefficients

39.88	6.56	−2.24	1.22	−0.37	−1.08	0.79	1.13
−102.43	4.56	2.26	1.12	0.35	−0.63	−1.05	−0.48
37.77	1.31	1.77	0.25	−1.50	−2.21	−0.10	0.23
−5.67	2.24	−1.32	−0.81	1.41	0.22	−0.13	0.17
−3.37	−0.74	−1.75	0.77	−0.62	−2.65	−1.30	0.76
5.98	−0.13	−0.45	−0.77	1.99	−0.26	1.46	0.00
3.97	5.52	2.39	−0.55	−0.051	−0.84	−0.52	−0.13
−3.43	0.51	−1.07	0.87	0.96	0.09	0.33	0.01

Quantization table

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

Quantized DCT coefficients



Zigzag

DCPM ON DC

2	1	0	0	0	0	0	0
−9	0	0	0	0	0	0	0
3	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	0

DC = 2

Suppose the previous DC is -1, DIFF_DC = 2 – (-1) = 3

3 is in Category 2 (send 100), use 2 bits (11) to specify "3"

Send **10011 5 bits**

RLE ON ACs

Example (cont.)

2	1	0	0	0	0	0	0
−9	0	0	0	0	0	0	0
3	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	0

AC = (0,1), (0,-9), (0,3), EOB

1 is in Category 1, Z/C = 0/1 (send 00), use 1 bit to specify "1" (001) **3 bits**

-9 is in Category 4, Z/C = 0/4 (send 1011), use 4 bits to specify "-9" (1011 0110) **8 bits**

3 is in Category 2, Z/C = 0/2 (send 01), use 2 bit to specify "3" (0111) **4 bits**

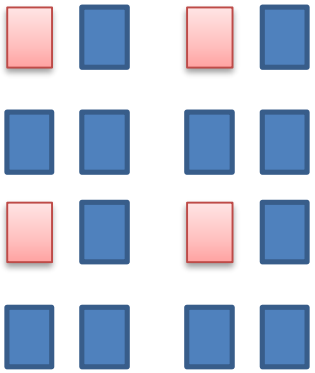
EOF (send 1010) **4 bits**

10011 001 1011 0110 0111 1010

Compression ratio=64*8/24=21.3 **Average length:24 / 64 = 0.375 bits per pixel**

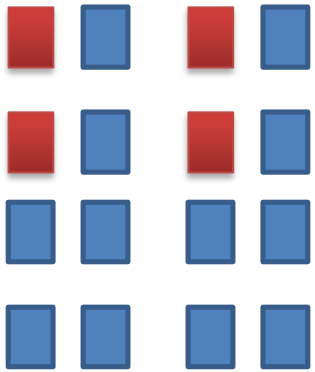
Chroma subsampling

4 : 2 : 0



From 4*4 we need 4 red pixels

4 : 2 : 2



Thanks for your attention