Chapter 7 Still Image Coding Standard – JPEG

- Since the mid-1980s, the ITU and ISO had been working together to develop a joint international standard for the compression of still images.
- JPEG became an international standard in 1992.
 Officially, JPEG is the ISO/IEC international standard 10918-1: digital compression and coding of *continuous-tone* still images, or the ITU-T Recommendation T.81.

- JPEG includes two classes of encoding and decoding processes:
 - Lossy process
 - DCT-based
 - sufficient for many applications
 - Lossless process
 - Prediction-based

JPEG includes four modes of operation

- Sequential DCT-based mode
- Progressive DCT-based mode
- Lossless mode
- Hierarchical mode.

Sequential DCT-based mode

- an image first partitioned into blocks of 8x8 pixels
- then the blocks processed from left to right, top to bottom.
- 8x8 2-D forward DCT is applied to each block
- 8x8 DCT coefficients then quantized
- quantized DCT coefficients entropy encoded and output

Progressive DCT-based mode

- Similar to sequential DCT-based mode
 - Block partition + DCT + quantization
- Quantized DCT coefficients, however, first stored in buffer.
- All DCT coefficients in buffer then encoded by a multiple scanning process
- In each scan, quantized DCT coefficients partially encoded either by spectral selection or successive approximation.
 - In spectral selection, quantized DCT coefficients divided into multiple spectral bands according to the zig-zag order. In each scan, a specified band is encoded.
 - In successive approximation, a specified number of most significant bits of quantized coefficients first encoded. In subsequent scans, less significant bits are encoded.







(a) Sequential coding: part-by-part







(b) Progressive coding: quality-by-quality

Figure 7.1 Difference <u>between</u> sequential coding and progressive coding

Lossless coding mode

DPCM coding in the spatial domain

Hierarchical mode

- An image first spatially down-sampled to a multiple layered pyramid
- This sequence of frames encoded by predictive coding. Except for the first frame, the encoding process is applied to the differential frames.
- Hierarchical coding mode provides a progressive presentation similar to progressive DCT-based mode but is useful in applications that have multi-resolution requirements.
- Hierarchical mode also provides the capability of progressive coding to a final lossless stage.



Figure 7.2 Hierarchical multi-resolution encoding

- Baseline algorithm (heart) of JPEG coding standard.
- Block diagram of encoding process



9



Figure 7.4 Partitioning to 8x8 blocks

Quantization

 Each of 64 DCT coefficients is quantized by a uniform quantizer such as:

 $S_{quv} = round\left(\frac{S_{uv}}{Q_{uv}}\right)$

 S_{quv} : quantized value of the DCT coefficient, S_{uv} , Q_{uv} : quantization step obtained from the quantization table.

- Four quantization tables, which may be used by encoder
- No default quantization tables specified in the specification.

• Some typical quantization tables are as follows:

16	11	10	16	24	40	51	61	17	18	24	47	99	99	99	99	
12	12	14	19	26	58	60	55	18	21	26	66	99	99	99	99	
14	13	16	24	40	57	69	56	24	26	56	99	99	99	99	99	
14	17	22	29	51	87	80	62	47	66	99	99	99	99	99	99	
18	22	37	56	68	109	103	77	99	99	99	99	99	99	99	99	
24	35	55	64	81	104	113	92	99	99	99	99	99	99	99	99	
49	64	78	87	103	121	120	101	99	99	99	99	99	99	99	99	
72	92	95	98	112	100	103	99	99	99	99	99	99	99	99	99	

Luminance quantization table

Chrominance quantization table

• At the decoder, the dequantization is performed as follows: $R_{quv} = S_{quv} \times Q_{uv}$ (7.3) R_{quv} : the value of the dequantized DCT coefficient. CS 4670/7670 Digital Image Compression

- The DC coefficient, S_{q00} , treated separately from other 63 AC coefficients.
 - DC coefficients: coded by predictive coding.
 - The value encoded is the difference (*DIFF*) *DIFF* = S_{q00} - *PRED* S_{q00}: DC coeff. at the present block *PRED*: DC coeff. of the previous block
 - *Diff* is coded by Huffman coding.

(7.4)

Quantized AC coefficients

Arranged in a zig-zag order:



Figure 7.5 Zig-zag scanning order of DCT coefficients

 $ZZ(0)=S_{q00}, ZZ(1)=S_{q01}, ZZ(2)=S_{q10}, \dots, ZZ(63)=S_{q77}.$ (7.5)

- RLC and Huffman coding
 - Each non-zero AC coeff. is represented by an 8-bit composite codeword 'RRRRSSSS'
 - 4 most significant bits 'RRRR': the <u>run-length of zeros</u> from the previous nonzero coeff.
 - 4 <u>least</u> significant bits 'SSSS': category for <u>the non-zero</u> <u>coefficient value</u> which ends the zero-run (10 categories).
 - Category k: ($2^{k-1}, 2^k 1$) or (- $2^k + 1, -2^{k-1}$)
 - 'RRRRSSSS'=11110000: a run-length of 16 zero coefficients
 - Run-length exceeding 16 needs multiple symbols. 'RRRRSSSS' = '00000000': the end-of-block (EOB) [remaining coefficients in the block are zero].



Figure 7.6 Two-dimensional value array for Huffman coding

Table: AC coefficient grouping (Table 10.1 from Rabbani)

- A total number of 162 codewords: (16 run-length 10 categories+ 2 special)
- The composite value, RRRRSSSS, is then Huffman coded.
- Each Huffman code is followed by additional bits, which specify the sign and exact amplitude of the coefficients.
- Huffman code tables developed from the average statistics of a large set of images with 8-bit precision.
- An adaptive arithmetic coding procedure can also be used for entropy coding.

- Example [Rabbani'91]
 - An 8×8 block of Lena image. f(j,k)
 - DCT transformed block F(u,v)
 - Quantization table
 - Quantized DCT coefficient F*(u,v)
 - Zigzag scanned quantized coeff. sequence: 79, 0, -2, -1, -1, -1, 0, 0, -1, EOB

- Bit stream (cascaded codewrods): DC difference Huffman codeword, 11100101, 000, 000, 000, 110110, 1010
- Resulting bit rate: 35 bits/64 pixel= 0.55 bit/pixel
- Huffman decoding, denormalized DCT coefficients:

 $\hat{F}(u,v) = F^*(u,v)Q(u,v)$

- IDCT f^(j,k)
- Reconstruction error e(j,k)
 - RMSE RMSE= 2.26

Progressive DCT-based encoding algorithm

- Blockwise 2-D 8x8 DCT
- Quantized DCT-coefficients: encoded with multiple scans.
 - At <u>each scan</u>, <u>a portion</u> of the DCT coefficient data is encoded.
 - This <u>partial encoded data</u> can be reconstructed to obtain <u>a full size image with lower picture quality</u>.
 - The coded data of each additional scan will enhance the reconstructed image quality until the full quality has been achieved at the completion of all scans.
 - Two methods:
 - Spectral selection
- Successive approximation
 CS 4670/7670 Digital Image Compression

Progressive DCT-based encoding algorithm

Spectral selection

- DCT coefficients re-ordered as zig-zag sequence
- Divided into several bands
- <u>A frequency band</u>: specifying the <u>starting and ending</u> indices
- The band containing DC coefficient is encoded at the first scan.

Successive approximation

- <u>Significant bits</u> of DCT coefficient encoded in the <u>first</u> scan
- Each succeeding scan improves the precision of the coefficients by one bit, until full precision is reached.

Progressive DCT-based encoding algorithm

 Figure 7.6
 Progressive coding with spectral selection and successive approximation



Lossless coding mode

- In lossless coding mode, coding method is spatial domain based instead of DCT-based.
- The coding method is extended from the method for coding the DC coefficients in the sequential DCT-based coding mode.
- Predictive coding. The predicted value is obtained from one of three 1-D or one of four 2-D predictors.

Lossless coding mode



Figure 7.7 Spatial relation between the pixel to be coded and three decoded neighbors

- x is the pixel to be coded
- a, b, and c are three **decoded** neighbors.
- The predictive value of x, P_x , is obtained from a, b and c via one of seven ways as listed in the following table. CS 4670/7670 Digital Image Compression

Lossless coding mode

Table 7.3 Predictors for lossless coding

Selection-value	Prediction						
0	No prediction (Hierarchical mode)						
1	Px = a						
2	Px = b						
3	Px = c						
4	Px = a+b-c						
5	$Px = a + ((b-c)/2)^*$						
6	$Px = b + ((a-c)/2)^*$						
7	Px = (a+b)/2						

* Shift right arithmetic operation

Hierarchical coding mode

- An input image frame first decomposed to a sequence of frames such as a pyramid.
- First frame encoded as non-differential frame.
- Following frames encoded as differential frames, which are encoded by using the previous coded frame as reference.
- Non-differential frame can be encoded by methods of sequential DCT-based coding, spectral selection method of progressive coding, or lossless coding with either Huffman code or arithmetic code.

Hierarchical coding mode



Figure 7.8 Coding of differential frame in hierarchical coding

<u>Up-sampling filter</u> increases spatial resolution by a factor of two in both horizontal and vertical directions by using bi-linear interpolation of two neighboring pixels.
 <u>Up-sampling with bi-linear interpolation is consistent with the down-sampling filter</u> which is used for the generation of down-sampled frames.