Image Compression Standards

Presented by

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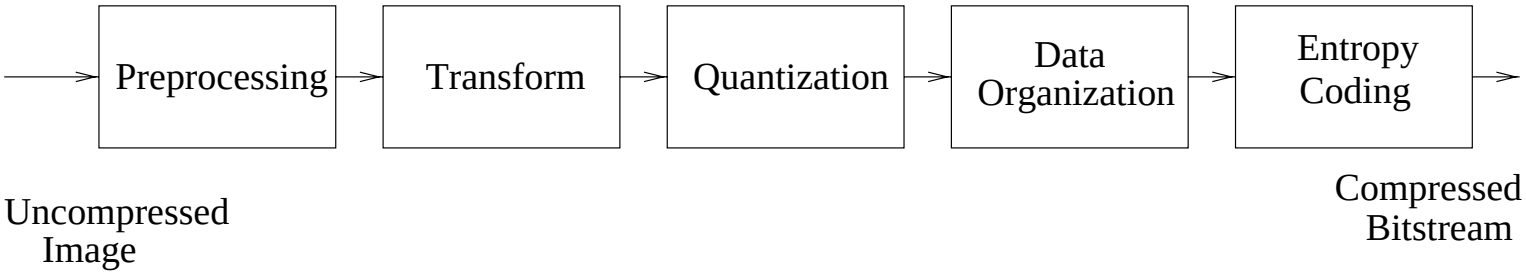
Overview

- Compression
- JPEG
- JPEG Baseline Mode
- JPEG Progressive Mode
- JPEG Hierarchical Mode
- JPEG Lossless Mode
- JPEG Performance
- JPEG-2000
- Conclusions

Compression



- Preprocessing: Downsampling
- Transformation: Different representation, reversible transformation (discrete cosine transform (DCT), wavelet, etc.), no compression
- Quantization: Irreversible
- Data organization: zig-zag scan order, zerotree
- Entropy coding (lossless coding): Runlength coding, Huffman coding, Arithmetic coding

JPEG

Joint Photographic Experts Group: ITU-T and ISO

Reference:

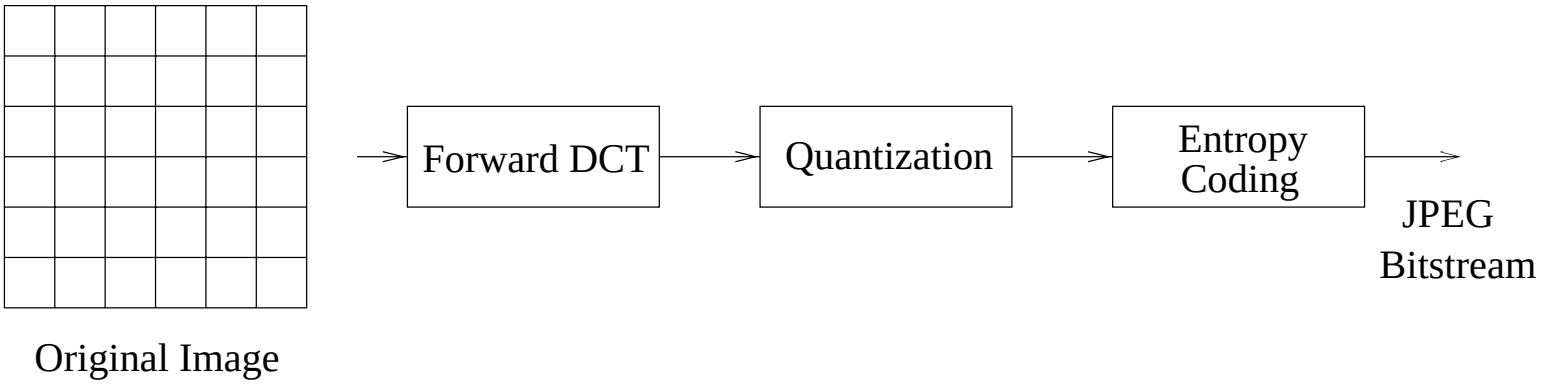
- W. Pennebaker, "JPEG Technical Specification, Revision 8," Working Document No. JTC1/SC2/WG10/JPEG-8-R8, Aug. 1990.
- G.K. Wallace, "The JPEG Still Picture Compression Standard," *Communications of the ACM,* vol. 34, no. 4, pp. 30–44, Apr. 1991.

JPEG modes

- Sequential DCT-based mode (baseline): Simple and efficient algorithm adequate for most image coding applications
- Progressive DCT-based mode
- Hierarchical mode
- Lossless mode

All receivers shall implemented the baseline mode

JPEG Baseline Mode - DCT



JPEG baseline algorithm:

- Discrete cosine transform: Original image $\Rightarrow$ nonoverlapping 8×8 image blocks
- Each block independently transformed by DCT:

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

- The top-left coefficient $F(0,0)$ in the 2-D DCT array: DC coefficient: Eight times the average brightness of the block

$$F(0,0) = \frac{2}{n^2} \sum_{j,k=0}^{n-1} f(j,k)$$

JPEG Baseline Mode - Quantization

- Perceptual quantization
- All transform coefficients normalized by applying a user-defined normalization array
- Normalized coefficients are uniformly quantized by rounding to the nearest integer

$$F^*(u,v) = \text{Nearest integer}\left(\frac{F(u,v)}{Q(u,v)}\right) \approx \left\lfloor \frac{F(u,v) + \left\lfloor \frac{Q(u,v)}{2} \right\rfloor}{Q(u,v)} \right\rfloor$$

JPEG Baseline Mode - Quantization

- Each component of the array is an 8-bit integer
- Up to four different normalization arrays can be specified:
  - one for gray scale
  - three for three color components
- The human visual system (HVS) contrast sensitivity function used as a guide: weighting each coefficient according to its perceptual importance
- Example normalization array $Q(u, v)$:

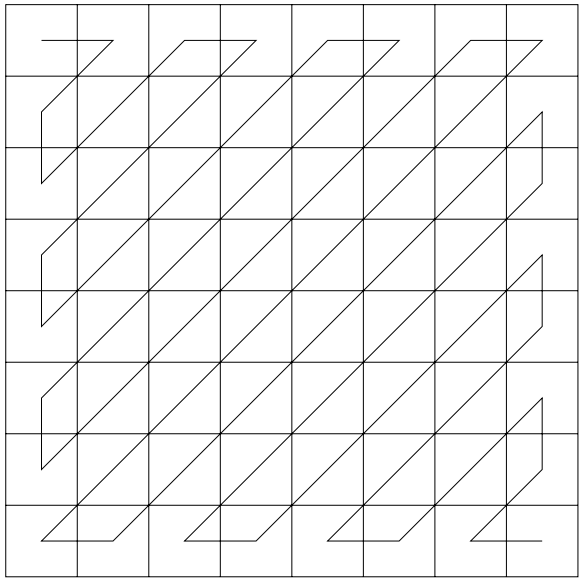
16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

JPEG Baseline Mode - DC Coefficient Coding

- DC coefficient is the most important, it represents the average brightness
- The quantized DC coefficient is encoded with lossless differential pulse code modulation (DPCM) scheme using the quantized DC coefficient from the previous block as a 1-D predictor
- For the baseline system, up to two separate Huffman tables for encoding the differential signal can be specified in the header information

JPEG Baseline Mode - AC Coefficient Coding

- All the coefficients but the top left: AC coefficients
- The quantization of AC coefficients produces many zeros, especially at higher frequencies
- Reorder the DCT coefficients into an 1-D vector: Zig-zag scan



JPEG Baseline Mode - AC Coefficient Coding

Zig-zag scan: Creating large runs of zero values

- Decreasing order of their average energy
- Increasing order of their spatial-frequencies

Coefficients encoding: Runlength coding combined with Huffman coding

- Each nonzero AC coefficient described by a composite 8-bit value $I = NNNNSSSS$
  - $SSSS$: 4 bits for category
  - $NNNN$: 4 bits for run
- Define a category for the coefficient magnitude
- The values in category k are in the range $(2^{k-1}, 2^k - 1)$ or $(-2^k + 1, -2^{k-1})$

JPEG Baseline Mode - AC Coefficient Coding

AC Coefficients Absolute Value	AC Category
1	1
2,3	2
[4,7]	3
[8,15]	4
...	...
[512,1023]	A

- For the category k, it is necessary to send an additional k bits to specify the sign and the magnitude of the coefficients within the category
- $NNNN$ gives the position of the current coefficient relative to the previous nonzero coefficient, i.e., the *runlength* of zero coefficients from the previous nonzero coefficient

JPEG Baseline Mode - Huffman Coding

Total number of symbols: 10 categories $\times$ 16 runs + 2 special symbols = 162 symbols

- A separate symbol, $I = 11110000$, represents the runlength of 16 zero coefficients
- A special symbol $I = 00000000$ is used to code the end of block (EOB), signaling all remaining coefficients in the block are zero

Huffman coding:

- The output symbols for each block are then Huffman coded, followed by additional bits for the sign and magnitude
- Up to two separate Huffman tables for AC coefficients in the baseline system

JPEG Baseline Mode - AC Coding Example

Suppose after zig-zag scan: 79 0 -2 -1 -1 -1 0 0 -1 EOB

Value	79	0	-2	-1	-1	-1	0	0	-1	EOB
Run	NA		1	0	0	0			2	0
Category	NA		2	1	1	1			1	0
Huffman Code	NA		111001	00	00	00			11011	1010
Magnitude Bits	NA		01	0	0	0			0	

- Bitstream: DC difference Huffman codeword/11100101/000/000/000/110110/1010
- 8 bits for DC difference Huffman codeword
- 35 bits/64 pixels = 0.55 bit/pixel

JPEG Progressive DCT Mode

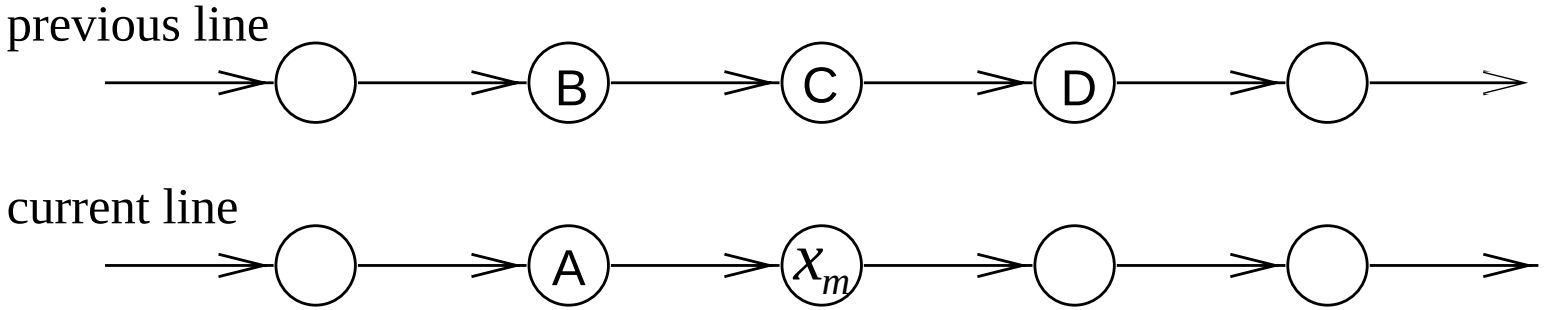
- Transmission of images over low bit rate channels
- Similar to baseline JPEG mode
- Two modes:
  - Spectral Selection: For each block, low frequency coefficients are sent first, followed by the higher frequency coefficients according to zig-zag scan order
  - Successive Approximation: Bit-plane transmission: Most significant bit-planes of all coefficients are sent in the first scan, followed by the next most significant coefficients, etc.

JPEG Hierarchical Mode

- Image can be transmitted in several spatial resolution accommodating different types of displays.
- Pyramidal image representation: Filtering and downsampling the image in multiples of two in each dimensions
- Resulted image is upsampled and subtracted from the next level
- The residual image is coded and transmitted as the next layer.

JPEG Lossless Mode

- Independent of the JPEG-Baseline mode
- Simple predictive coding is used



Predictor	Prediction
0	No prediction
1	A
2	C
3	B
4	$A + B - C$
5	$A + (C - B)/2$
6	$C + (A - B)/2$
7	$(A + C)/2$

- After prediction, entropy coding combined with run-length coding is applied

JPEG Performance

Subjective performance:

Rate [bpp]	Quality	Compression Ratio
≥ 2	Indistinguishable	8:1
1.5	Excellent	10.7:1
0.75	Very Good	21.1:1
0.50	Good	32:1
0.25	Fair	64:1

Objective performance:

- Measured by peak signal-to-noise ratio (PSNR)

$$\text{PSNR [dB]} = 20 \log_{10} \frac{255}{\text{RMSE}},$$

- RMSE: the root mean-squared error between the original and reconstructed images

JPEG Performance

Performance comparison (PSNR [dB]) on "Lena" image.

Compression Ratio	64:1	32:1	16:1	8:1
JPEG	27.79	31.42	34.84	37.94
SLCCA	**31.38**	**34.33**	**37.38**	**40.44**

JPEG Performance

SLCCA
CR=130:1

SLCCA
CR=80:1

JPEG
CR=130:1

JPEG
CR=80:1

JPEG-2000

Provide good quality at both low bit rate and high bit rate compression

- To be standardize by 2000 and incorporate latest research results
- Define flexible compression architectures and formats
- Integration of new algorithms by downloadable software components
- JPEG-2000 Applications: Document imaging, Facsimile, Internet, Remote sensing, Digital libraries, Medical imaging, Prepress, etc.

JPEG-2000

Functionalities

- High performance low bit rate compression, especially under 0.25 bpp
- Compress images larger than $64K \times 64K$
- Capable of compression both continuous-tone and bilevel images
- Lossless and lossy compression in a progressive manner
- Progressive transmission
- Robustness to transmission errors
- Open architecture enabling downloadable software tools specified by syntactic description language
- Content-based description to locate images in large databases
- Image security by watermarking
- Alpha channel information

JPEG-2000

Potential algorithms:

- Several functionalities have been implemented in MPEG-4
- Wavelet or subband coding
- Pyramidal coding as in JPEG

Conclusions

- Focus on still image compression standard JPEG
- Detailed discussion of JPEG baseline mode
- Review of other three JPEG modes
- JPEG performance evaluation and comparison with wavelets
- JPEG-2000