Image Compression Standards

Presented by

Jozsef Vass

Department of Computer Engineering and Computer Science

University of Missouri-Columbia

Columbia, MO 65211
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
All receivers shall implement the baseline mode

- Lossless mode
- Hierarchical mode
- Progressive DCT-based mode
- Sequential DCT-based mode (baseline)

JPEG modes

- Reference:
  - Joint Photographic Experts Group: ITU-T and ISO
JPEG Baseline Mode - DCT

JPEG baseline algorithm:

- Discrete cosine transform: Original image $\Rightarrow$ nonoverlapping $8 \times 8$ 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
  
  $F(0,0) = \frac{2}{n^2} \sum_{j,k=0}^{n-1} f(j,k)$
JPEGEarlier 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

\[
\begin{aligned}
&\left| \left( \frac{(a', n) \hat{D}}{(a', n) \hat{D}} \right) + (a', n) \hat{H} \right| \\ &\approx \left( \frac{(a', n) \hat{D}}{(a', n) \hat{H}} \right)_{\text{Nearest integer}} = (a', n)_{\text{quantization}}
\end{aligned}
\]
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 is used as a guide: weighting each coefficient according to its perceptual importance.

Example normalization array $O(n, \nu)$:
JPEGBaseline Mode - DC Coefficient Coding

DC coefficient is the most important, it represents the average brightness. The quantized DC coefficient is encoded with a 1-D predictor that pulse code modulation (PCM) 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.

JPEGBaseline Mo de/-DCCo e/#0FcientCo ding

DC co e/#0Fcientisenco ded withlosslessdi/#0Beren/-

DC co e/#0Fcient is the most important, it represents the average brightness.
All the coefficients but the top left: AC coefficients

JPGE Baseline Mode - AC Coefficient Coding
The values in category $k$ are in the range $\left(2^{k-1}, 2^k - 1\right)$ or $\left(-2^k + 1, -2^k - 1\right)$.

- Define a category for the coefficient magnitude.

- Each nonzero AC coefficient described by a composite 8-bit value.

- Runlength encoding: RLE

- Increasing order of their spatial frequencies.

- Decreasing order of their average energy.

- Zig-zag scan: Creating large runs of zero values.

JPEG Baseline Mode - AC Coefficient Coding
coefficient from the previous nonzero coefficient to the previous nonzero coefficient, i.e., the runlength of zero gives the position of the current coefficient relative to the category. The category specifies the sign and the magnitude of the coefficients within this position. It is necessary to send an additional A bits.

\[
\begin{array}{|c|c|}
\hline
\text{AC Category} & \text{Absolute Value} \\
\hline
\text{A} & 31.72 \times 10^{23} \\
\ldots & \ldots \\
4 & 8.12 \\
3 & 4.2 \\
2 & 3.2 \\
1 & 1 \\
\hline
\end{array}
\]
The output symbols for each block are then Huffman coded.

Huffman coding:

- A special symbol is used to code the end of block
- Symbols = 162 symbols
- Total number of symbols: 10 categories \times 16 runs + 2 special symbols

JPEG Baseline Mode - Huffman Coding
Suppose after zig-zag scan: 79 0 -2 1 -1 0 0 -1 EOB

35 bits/64 pixels = 0.55 bit/pixel

8 bits for DC difference Huffman codeword

Bitstream: DC difference Huffman codeword/110010/000/000/000/000/000/000/110110/1010

### JPEG Baseline Mode - AC Coding Example

<table>
<thead>
<tr>
<th>Run</th>
<th>Category</th>
<th>Magnitude Bits</th>
<th>Huffman Code</th>
<th>NA</th>
<th>EOB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>00 00 00</td>
<td>NA</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>00 00 00</td>
<td>NA</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1110</td>
<td>0</td>
<td>00 00 00</td>
<td>NA</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>00 00 00</td>
<td>NA</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1110</td>
<td>0</td>
<td>00 00 00</td>
<td>NA</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Note:** The table above shows the run, category, and magnitude bits for the Huffman code. The bitstream is represented as DC difference Huffman codeword/110010/000/000/000/000/000/000/110110/1010.
Similar to baseline JPEG mode:

- 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.
- Two modes:
  - Similar to baseline JPEG mode
  - Transmission of images over low bit rate channels
JPEG Hierarchical Mode

1. The residual image is coded and transmitted as the next layer. 
2. Resulted image is upsampled and subtracted from the next level.
3. Resulted image in multiples of two in each dimensions.
5. Modulating different types of displays.
6. Image can be transmitted in several spatial resolution accommodation.
JPEG Lossless Mode

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

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No prediction</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>A + B − C</td>
</tr>
<tr>
<td>5</td>
<td>A + (C − B)/2</td>
</tr>
<tr>
<td>6</td>
<td>C + (A − B)/2</td>
</tr>
<tr>
<td>7</td>
<td>(A + C)/2</td>
</tr>
</tbody>
</table>

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

Subjective performance:

<table>
<thead>
<tr>
<th>Compression Ratio</th>
<th>Quality</th>
<th>Rate [bpp]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:1</td>
<td>Indistinguishable</td>
<td>&gt; 2</td>
</tr>
<tr>
<td>10:1</td>
<td>Excellent</td>
<td>1.5</td>
</tr>
<tr>
<td>21:1</td>
<td>Very Good</td>
<td>0.75</td>
</tr>
<tr>
<td>32:1</td>
<td>Good</td>
<td>0.5</td>
</tr>
<tr>
<td>64:1</td>
<td>Fair</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Objective performance:

\[
\text{PSNR (dB)} = 20 \log_{10} \frac{\text{RMSE}}{255}
\]

\(\text{RMSE}:\) the root mean-squared error between the original and reconstructed images.

\(\text{PSNR:}\) measured by peak signal-to-noise ratio (PSNR).
<table>
<thead>
<tr>
<th>Compression Ratio</th>
<th>JPEG</th>
<th>SLCCA</th>
<th>Compression Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:1</td>
<td>40.44</td>
<td>37.94</td>
<td>37.94</td>
</tr>
<tr>
<td>16:1</td>
<td>34.84</td>
<td>31.42</td>
<td>31.42</td>
</tr>
<tr>
<td>32:1</td>
<td>16.1</td>
<td>27.79</td>
<td>27.79</td>
</tr>
<tr>
<td>64:1</td>
<td>8:1</td>
<td>3.16</td>
<td>3.33</td>
</tr>
<tr>
<td>128:1</td>
<td>3.74</td>
<td>3.42</td>
<td>3.42</td>
</tr>
<tr>
<td>256:1</td>
<td>3.74</td>
<td>3.42</td>
<td>3.42</td>
</tr>
</tbody>
</table>

Performance comparison (PSNR [dB] on "Lena" Image)
Provide good quality at both low bit rate and high bit rate

JPEG-2000
High performance low bit rate compression, especially under 0.25 bpp

Capabilities

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

Functionality

- JP2C-2000
Several functionalities have been implemented in MPEG-4.

Potential algorithms:

- Pyramid coding as in JPEG
- Wavelet or subband coding
- Algorithms
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