Thresholding and Quantization

- After FDCT, the 64 DCT coefficients are quantized.
- The goal is to achieve further compression by representing DCT coefficients with the right precision according to the image quality (specified by the user, such as quality 95).
- The is principal source of lossiness in DCT-based encoders.

\[\begin{align*}
T &= \text{deadzone threshold} \\
Q &= \text{quantizer step size}
\end{align*}\]
DC Coding and Zig-Zag Sequence

- The DC coefficient, $F(0,0)$, is a measure of the average value of 64 samples.
- Strong correlation between the DC coefficients of adjacent 8x8 blocks
- The quantized DC coefficient is encoded as the difference from the DC term of previous block in the encoding order.
- This special treatment is worthwhile since DC term contains important image information.
- The coefficients are encoded in Zig-Zag sequence with low-frequency go first
An 8x8 Block Coding Example

<table>
<thead>
<tr>
<th>128</th>
<th>-30</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Resulting 1-D sequence

- Run-length of zeros
- End-of-block
- DC component
- Nonzero amplitude

Symbol = (run, amp)

128, 30, -10, 0, 0, 0, 0, 0, -1, 0, 0, 0, 1, 0, 0, 0, 0, ...., 0

128, (0,30), (0,-10), (4,-1), (4,1), EOB
Entropy Coding

- Losslessly compress the quantized DCT coefficient sequence based on statistical characteristics.
- Usually, there are few nonzero and many zero-valued AC coefficients.
- Huffman coding and arithmetic coding are proposed.
- A two-step process:
  1. convert DCT coefficients into an intermediate sequence of symbol.
  2. assign variable-length codes to the symbols.
- Each nonzero AC coefficient is represented by two symbols:
  \((\text{Runlength, Size})(\text{Amplitude})\)
  symbol-1 symbol-2
  where Runlength is the number of consecutive zero-value preceding AC coef.
  it can be zero-runs of length 0 to 15.
  \((15, 0)\) represents extension, there can be 3 extensions.
  \((0, 0)\), EOB, is used to terminate the sequence.
  Size is the number of bits used to encode Amplitude, (1-10bits) for 8bit samples.
  Amplitude is the value of the nonzero AC coefficient. \([-2^{10}, 2^{10}-1]\)
Entropy coding

- DC coefficients are encoded using differential coding technique, because the strong correlation.
- The differential DC coefficients are encoded as
  
  \[
  \text{(Size) (Amplitude)} \cdot \text{symbol-1 symbol-2}
  \]
- Amplitude range=[\(-2^{11}, 2^{11}\) -1]
- symbol-1 is encoded using Huffman coding (VLC)
- symbol-2 is encoded using Variable-Length Integer (VLI) coding

<table>
<thead>
<tr>
<th>Baseline Huffman Coding Symbol-1 Structure</th>
<th>Baseline Entropy Coding Symbol-2 Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIZE</td>
<td>AMPLITUDE</td>
</tr>
<tr>
<td>0</td>
<td>EOB X X X X X X X X X</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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<tr>
<td>4</td>
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<td>5</td>
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<td>7</td>
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<td>8</td>
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<tr>
<td>9</td>
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</tbody>
</table>
Variable Length Integer (VLI) Coding

- It encodes a number by two values, (size, amplitude).
  - size = the number of bits used to encode the amplitude values.
  - amplitude encodes the number using a biased-number scheme.
- VLI coding table

<table>
<thead>
<tr>
<th>Size</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1,1</td>
</tr>
<tr>
<td>2</td>
<td>-3,-2,2,3</td>
</tr>
<tr>
<td>3</td>
<td>-7..-4,4..7</td>
</tr>
<tr>
<td>4</td>
<td>-15..-8,8..15</td>
</tr>
<tr>
<td>5</td>
<td>-31..-16,16..31</td>
</tr>
<tr>
<td>6</td>
<td>-63..-32,32..63</td>
</tr>
<tr>
<td>7</td>
<td>-127..-64,64..127</td>
</tr>
<tr>
<td>8</td>
<td>-255..-128,128..255</td>
</tr>
<tr>
<td>9</td>
<td>-511..-256,256..511</td>
</tr>
<tr>
<td>10</td>
<td>-1023..-512,512..1023</td>
</tr>
<tr>
<td>11</td>
<td>-2047..-1024,1024..2047</td>
</tr>
</tbody>
</table>

Examples:

- $1 \rightarrow (1, 1)$
- $-1 \rightarrow (1, -1+1) = (1, 0)$
- $-10 \rightarrow (4, -10+15) = (4, 5)$
- $30 \rightarrow (5, 30)$
- $128 \rightarrow (8, 128)$

Bias value
8x8 Block Coding Example

128, 30,-10,0,0,0,0,-1,0,0,0,0,1,0,0,...,0 will be encoded as

(8,128), ((0,5), 30), ((0,4), 5), ((4,1), 0), ((4,1), 1), (0, 0)

Note that for symbol 1=(15, 4) represents a coef. with 15 leading zeros and size 4. (15, 0)(0,5) represents a coef. with 16 leading zeros with size 5. (15,0)(15,0)(15,0)(14,3) represents a coef. with 62 leading zeros with size 3.
Progressive Mode Operation

Each image encoded in multiple scans (with increasing quality) can be transmitted quickly. Rough but recognizable scan can be transmitted quickly. Each image encoded in multiple scans (with increasing quality) require image-sized buffer memory at the output of quantizer.
Hierarchical Mode Operation

- Provide a “pyramidal” encoding at multiple resolutions.
- **Encoding Steps:**
  a. Filter and down-sample (by multiples of 2) the original image to the lowest resolution.
  b. Encode the reduced-size image using DCT.
  c. Decode the image and interpolate and up-sample by 2.
  d. Use this up-sampled image as a prediction of the original at this resolution and encode the difference image using DCT.
  e. Repeat steps c) and d) until full resolution of the image encoded.
- **Use when a high resolution image must be access by a lower-resolution device, which does not the buffer capacity to reconstruct the image at the full resolution and then scale it down.**
JPEG

- Joint Photographic Expert Group
- Formed in 1986, ISO-IEC/JTC1/SC29/WG10
- Proposal submission: June 1987
  12 proposed methods, 3 chosen for further refinement (DCT, ADPCM, GBTC)
- ADCT was selected Jan. 1988 for best quality over a range of bit rates.
- Committee Draft (CD) 1990
  International Standard (IS 10918): 1992
- Baseline process (required by all JPEG DCT-based codecs)
  DCT-based
  Input pixel accuracy = 8bits/pel/component
  sequential mode operation
  max # of Huffman tables = 2AC and 2DC tables
  max # of components = 4
  interleaved and non-leaved scan.
- xv command can view .jpg files, http://cs.uccs.edu/~cs525/jpeg/jpeg.FAQ
  includes info about the source. (Thanks Ed Hughes)