

Techniques for Video Compression and Analysis (5LSE0), Module 03 - A

Adaptive DCT Coefficient Quantization and JPEG Still Picture standard

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slides version 1.0

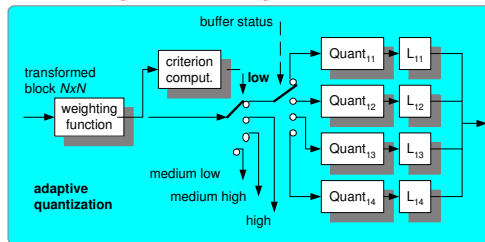
5LSE0 - Mod 03 - A Part 1.1

Introduction to Adaptive DCT Coefficient Quantization

Local Quant. / Quantization system

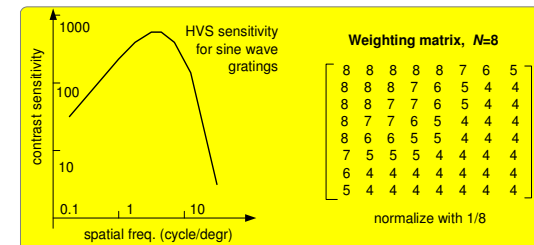
Transform Coder Quantization contains 3 elements:

- * Weighting (frequency dependent)
- * Criterion/metric computation (local adaptivity)
- * Buffer status control (global activity)



Local Quant. / Coefficient Weighting

- * Human Vis. Syst. has strong frequency dependence
- * Can be exploited for weighting of coefficients
- * weighting matrix $W(u,v)$ specifies individual weights



Quantization Weighting Matrix – (1)

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- * The coarseness of quantization of $y_{u,v}$ is controlled by
 - the value of $S=\Delta$ (for the DCT block under consideration)
 - the (inverse) weighting matrix $W(u,v)$

$$W(u,v) = \begin{bmatrix} 8 & 16 & 19 & 22 & 26 & 27 & 29 & 34 \\ 16 & 16 & 22 & 24 & 27 & 29 & 34 & 37 \\ 19 & 22 & 26 & 27 & 29 & 34 & 34 & 38 \\ 22 & 22 & 26 & 27 & 29 & 34 & 37 & 40 \\ 22 & 26 & 27 & 29 & 32 & 35 & 40 & 48 \\ 26 & 27 & 29 & 32 & 35 & 40 & 48 & 58 \\ 26 & 27 & 29 & 34 & 38 & 46 & 56 & 69 \\ 27 & 29 & 35 & 38 & 46 & 56 & 69 & 83 \end{bmatrix}$$

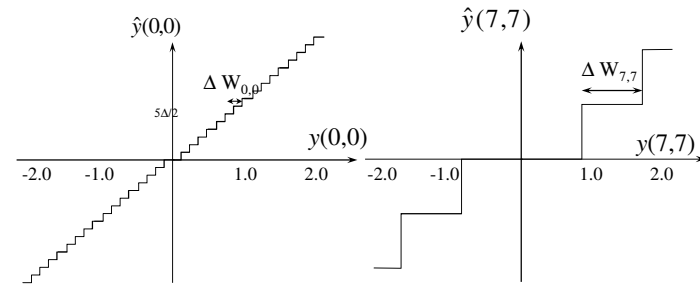
Quantizer equation:

$$\hat{y}(u,v) = \text{round} \left[\frac{y(u,v)}{\Delta \times W(u,v)} \right]$$

Quantization Weighting Matrix – (2)

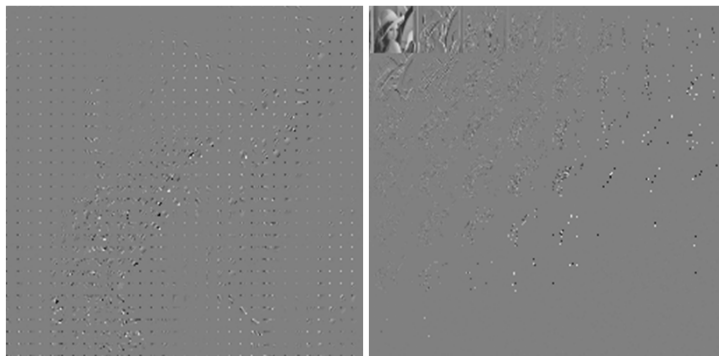
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- * Effect of weighting matrix:



Coeff. Weighting / Example of Result

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Coded DCT blocks at spatial position

Collect DCT coefficients in "bands"

Local Quant. / Adaptivity criterion – (1)

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Criteria / metrics for adaptive quantization

- * General measure

$$C = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} W_{u,v} |y(u,v)| \dots \dots (u,v) \neq (0,0)$$

- * AC energy

$$C = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} |y(u,v)|^2 \dots \dots (u,v) \neq (0,0)$$

- * Sum of absolute ac values

$$C = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} |y(u,v)| \dots \dots (u,v) \neq (0,0)$$

- * Maximum ac magnitude

$$C = \max \{ |y(u,v)|, (u,v) \neq (0,0) \}$$

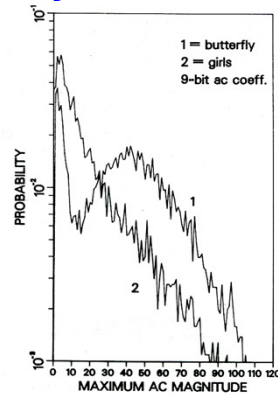
Local Quant. / Adaptivity criterion – (2)

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Example for criterion:

Maximum AC magnitude

- * Noisy characteristic
- * Depends considerably on input picture
- * Shows strong decay of maximum value occurrence



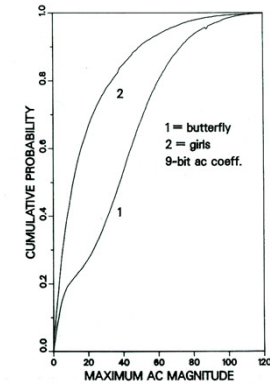
Local Quant. / Adaptivity criterion – (3)

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Example for criterion:

Maximum AC cumulative pdf

- * Smooth behaviour
- * Depends less on input picture, smooth curve
- * Normalized range



Local Quant. / Quantization classes

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In practice, we divide the amplitude range in intervals, hence classes

Example for crit.:
max ac

- * 4 Classes
 - Low: no colour
 - Med low: orange
 - Med high: green
 - High: blue

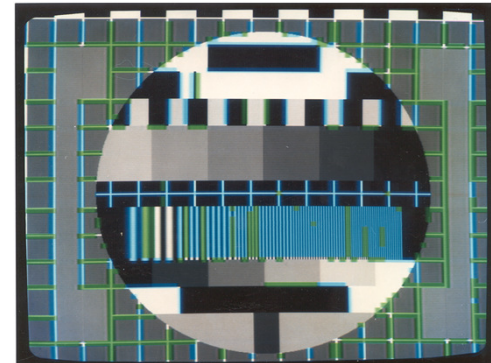


Local Quant. / Quantization classes

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Example metric:
Max ac coeff.

- * 4 Classes
 - Low: no colour
 - Med low: orange
 - Med high: green
 - High: blue
- * Adaptivity pays off (always)!

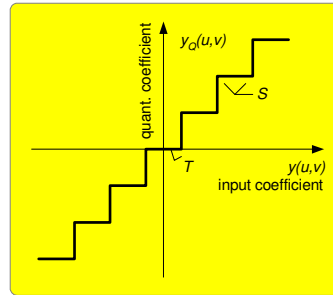


Local Quant. / Block quantization

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Block quantization

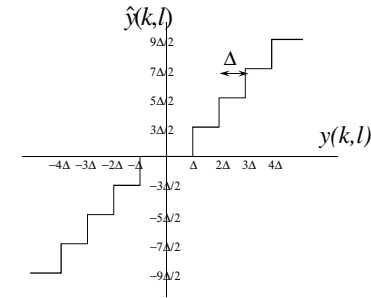
- * Performed after weighting and adaptivity control
- * **Uniform** quantization in most cases
- * Can be specified by **linear multiplication** with stepsize S or $1/S$
- * **Threshold T** for dead-zone control of small values



Local Approach: Quantizer Selection

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- * Each DCT coefficient in each block can have different step size $S=\Delta$ for a uniform quantizer
- * Different DCT coefficients are of unequal importance
 - Use different Δ per DCT coefficient: overhead



PCM Coding of DCT Coefficients – (1)

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- * All DCT coefficients (except #1) are PCM encoded
- * If a PDF-optimized quantizer is used, the following PDF typically applies:

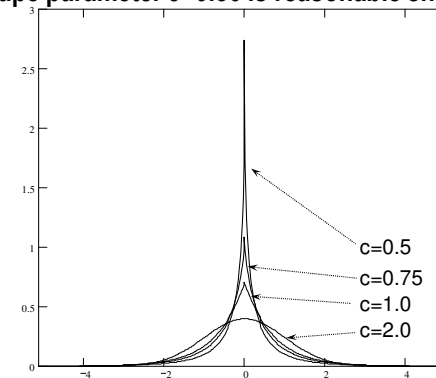
$$p(x) = a \exp(-|bx|^c)$$

(generalized Gaussian, shape parameter c)
- * **Prototype quantizers** can be designed using standard **Lloyd-Max** or **Unif. Threshold Q** procedures
- * Alternatively, standard **uniform quantizer with deadzone** can be used
- * Quantizer levels are **VLC encoded** (Huffman, modif. VLC, arithmetic)

PCM Coding of DCT Coefficients – (2)

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- * Shape parameter $c=0.50$ is reasonable choice



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JPEG Still picture standard

Introduction to JPEG

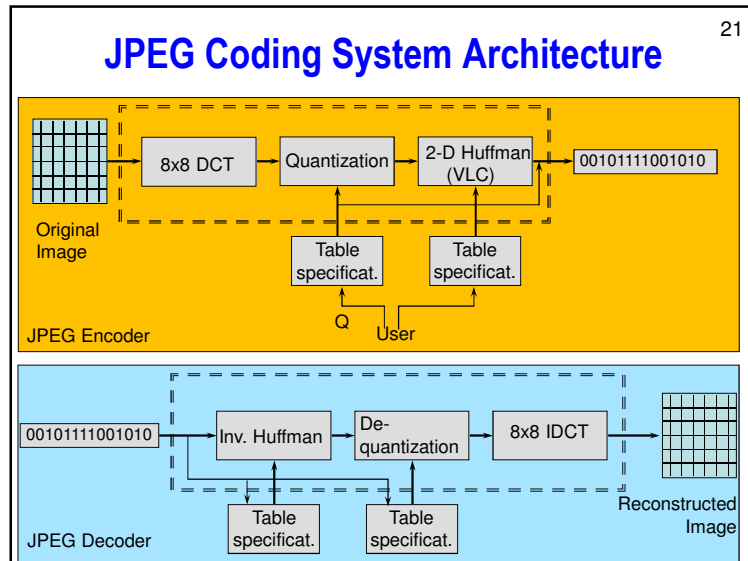
- * International standardization in 1988 - 1992 led to ISO and ITU-Telecommunications standard for still picture coding
 - Referred to as *ISO/IEC IS 10918*
- * JPEG: Joint Photographic Experts Group
- * Rationales
 - Comparable requirements for *many* applications
 - Possible exchange of compressed data
 - Hardware/software reduction (>10 years ago!)
 - DCT had become very popular
- * JPEG is a strongly prescriptive standard

JPEG Requirements

- * Usability:
 - Wide range of bit rates and qualities
 - Moderate complexity
 - Encoder/decoder of comparable complexity
 - Sequential image build up (top-left to bottom-right)
- * Quality guidelines:
 - 0.25-0.50 bit/color pixel: Moderate to good quality
 - 0.50-0.75 bit/color pixel: Good to very good quality
 - 0.75-1.50 bit/color pixel: Excellent quality
 - >1.50 bit/color pixel: Indistinguishable from original

JPEG Coding Modes

- * Baseline JPEG (“sequential mode”)
 - 8x8 DCT based compression
 - Quantization: normalization (=weight) matrix and rounding
 - DC coefficients are DPCM coded (lossless)
 - AC coefficients are {zero run, amplitude} Huffman coded
 - Up to 4 color components and 4 different normalization matrices
 - Bit stream can store normalization matrices and VLC table
 - No explicit bit rate control
- * Progressive mode (currently: *Internet pictures*)
- * Hierarchical mode
- * Lossless compression mode: JPEG-LS



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JPEG DCT Weighting & Quantization

* **Quantization:**

$$\hat{y}(u, v) = Q[y(u, v)] = \text{round} \left(\frac{y(u, v)}{Q W(u, v)} \right)$$

* **Recommended JPEG normalization matrix**

$$N(u, v) = W(u, v) = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

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JPEG User Controllable Quality

* User has control over a “quality parameter” that runs from 100 (“perfect”) to 0 (“extremely poor”)

The graph shows the relationship between the quality parameter Q (x-axis, increasing quality from 0 to 100) and the parameter used to scale the normalization matrix Q' (y-axis, ranging from 0 to 6). The curve shows that as quality increases, the scaling factor Q' decreases.

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JPEG 8x8 DCT Example – (1)

DCT transform is exactly defined in JPEG standard

$$x(k, l) = \begin{bmatrix} 139 & 144 & 149 & 153 & 155 & 155 & 155 & 155 \\ 144 & 151 & 153 & 156 & 159 & 156 & 156 & 156 \\ 150 & 155 & 160 & 163 & 158 & 156 & 156 & 156 \\ 159 & 161 & 162 & 160 & 160 & 159 & 159 & 159 \\ 159 & 160 & 161 & 162 & 162 & 155 & 155 & 155 \\ 161 & 161 & 161 & 161 & 160 & 157 & 157 & 157 \\ 162 & 162 & 161 & 163 & 162 & 157 & 157 & 157 \\ 162 & 162 & 161 & 161 & 163 & 158 & 158 & 158 \end{bmatrix}$$

average x 8

$$y(u, v) = \begin{bmatrix} 1260 & -1 & -12 & -5 & 2 & -2 & 3 & 1 \\ -23 & -17 & -6 & -3 & -3 & 0 & 0 & -1 \\ -11 & -9 & -2 & 2 & 0 & -1 & -1 & 0 \\ -7 & -2 & 0 & 1 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 2 & 0 & -1 & 1 & 1 \\ 2 & 0 & 2 & 0 & -1 & 1 & 1 & -1 \\ -1 & 0 & 0 & -1 & 0 & 2 & 1 & -1 \\ -3 & 2 & -4 & -2 & 2 & 1 & -1 & 0 \end{bmatrix}$$

JPEG 8x8 Block Coding, Example – (2) 25

$$\hat{y}(u,v) = \begin{bmatrix} 79 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ -2 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Quantization using $Q' = 1$

- * **DC:** Difference with quantized DC coefficient of previous block is Huffman encoded
- * **AC:** Zigzag scanning of coefficients, and convert to (zero run-length, amplitude) combinations:
 - Input : (79) 0 -2 -1 -1 -1 0 0 -1 0 0 0 ...
 - Output: Code(79) {1,-2} {0,-1} {0,-1} {0,-1} {2,-1} EOB

JPEG VLC Coding of AC Coefficients 26

- * 1. Amplitudes are classified in **categories**

Category	AC Coefficient Range
1	-1,1
2	-3,-2,2,3
3	-7,...,-4,4,...,7
4	-15,...,-8,8,...,15
5	-31,...,-16,16,...,31
6	-63,...,-32,32,...,63
7	-127,...,-64,64,...,127
8	-255,...,-128,128,...,255
9	-511,...,-256,256,...,511
10	-1023,...,-512,512,...,1023

- * 2. Events (zero run-length, categories) → Huffman coded
- * 3. Sign and amplitude offset within a category are FLC coded (required #bits = category number)

JPEG AC Coefficient Huffman Coding Table (run, category) 27

Breakdown of coding

- signed amplitude = category + offset + sign

Zero Run	Category	Code length	Codeword
0	1	2	00
0	2	2	01
0	3	3	100
0	4	4	1011
0	5	5	11010
0	6	6	111000
0	7	7	1111000
1	1	4	1100
1	2	6	111001
1	3	7	1111000
1	4	9	111110110
2	1	5	11011
2	2	8	11111000
3	1	6	111010
3	2	9	111110111
4	1	6	111011
5	1	7	1111010
6	1	7	1111011
7	1	8	11111001
8	1	8	11111010
9	1	9	111111000
10	1	9	111111001
11	1	9	111111010
EOB	4	1010	

JPEG VLC Coding Example – (3) 28

- * The event series

{1,-2} {0,-1} {0,-1} {0,-1} {2,-1} EOB

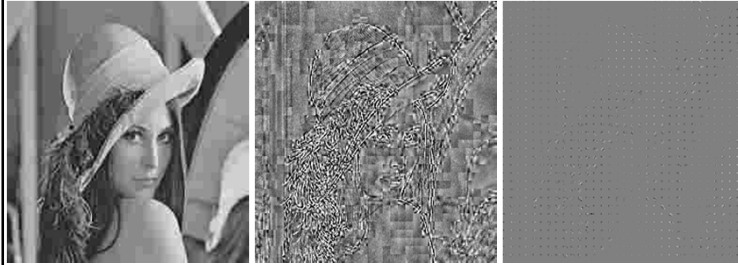
now becomes as bit string

111001 01 / 00 0 / 00 0 / 00 0 / 11011 0 / 1010

- * Bit rate for AC coefficients in this DCT block
27 bits/64 pixels = 0.42 bit/pixel

JPEG VLC Coding Example – (4)

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Coded at Q=10

Quantization errors

Coded DCT block

JPEG Customization

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- * **Design of the normalization matrix $N(u,v)=W(u,v)$**
- * **Design of the Huffman tables**
 - Usually done by quantization of all picture data,
 - Followed by a histogram analysis of the (zero run-length, amplitude) combinations
- * **Rate-control mechanism (trial and error)**
- * **No possibility to vary Δ over DCT blocks (global Q)**
- * **Suboptimal alternative is to locally discard non-zero quantized DCT coefficients if they “cost” too much**
 - Long zero run followed by small non-zero amplitude

JPEG follow-up: JPEG 2000

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- * **Recent update of existing standard**
- * **Advanced wavelet coding technique**
 - Wavelet analysis of picture with filter banks
 - Wavelet functions for suited for scalable video
- * **Special band-coding algorithms**
 - Parent-children coding technique of (non-)zeros
 - Special quantization and VLC
- * **Standard is accepted in digital Cinema, prof. imaging**