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

Adaptive DCT Coefficient Quantization and JPEG Still Picture standard

Peter H.N. de With
(p.h.n.de.with@tue.nl)

slides version 1.0

5LSE0 - Mod 03 - A
Part 1.1

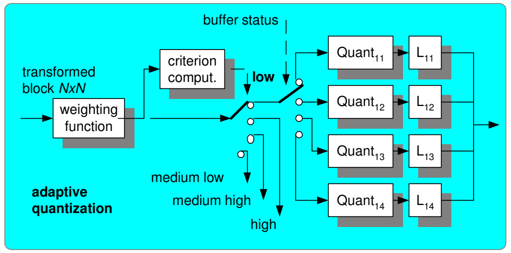
Introduction to Adaptive DCT Coefficient Quantization

Local Quant. / Quantization system

Transform Coder Quantization contains 3 elements:

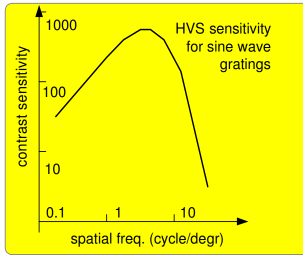
* **Weighting (frequency dependent)**
* **Criterion/metric computation (local adaptivity)**
* **Buffer status control (global activity)**

Adaptive quantization is required because of the variations of objects in images/video!



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**



Weighting matrix, N=8

8	8	8	8	8	7	6	5
8	8	8	7	6	5	4	4
8	8	7	7	6	5	4	4
8	7	7	6	5	4	4	4
8	6	6	5	5	4	4	4
7	5	5	5	4	4	4	4
6	4	4	4	4	4	4	4
5	4	4	4	4	4	4	4

normalize with 1/8

Quantization Weighting Matrix – (1)

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

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

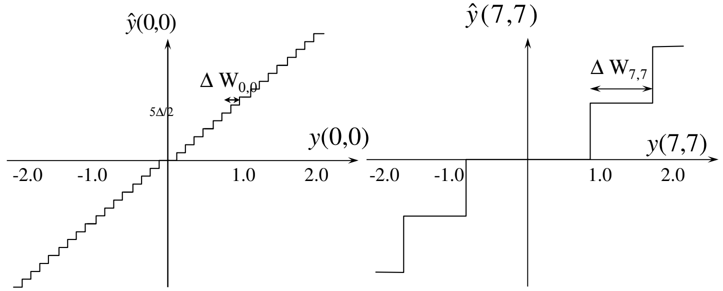
Note: in most standards like JPEG/MPEG, they divide by a weighting factor!

Quantizer equation:

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

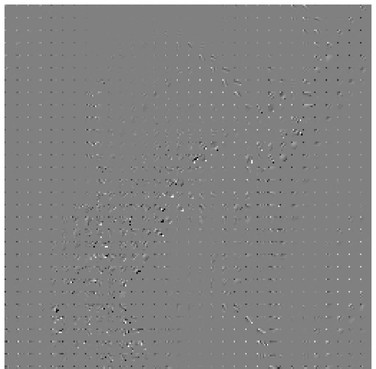
Quantization Weighting Matrix – (2)

- **Effect of weighting matrix:**

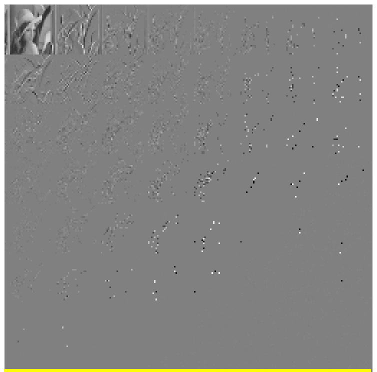


Weighting is fine for low "frequencies" and coarse for high freq!

Coeff. Weighting / Example of Result



Coded DCT blocks at spatial position



Collect DCT coefficients in "bands"

Local Quant. / Adaptivity criterion – (1)

Criteria / metrics for adaptive quantization

- **General measure**

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

- **AC energy**

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

- **Sum of absolute ac values**

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

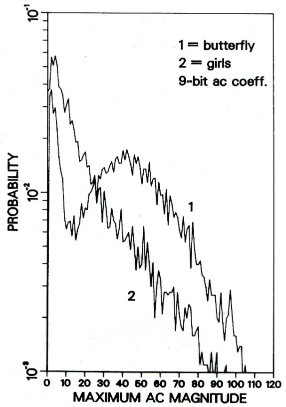
- **Maximum ac magnitude**

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

Local Quant. / Adaptivity criterion – (2)

Example for criterion:
  Maximum AC magnitude

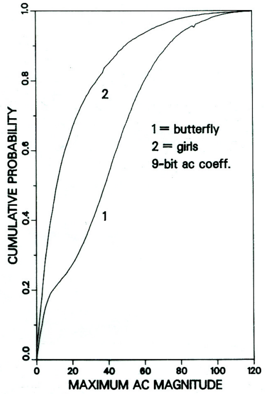
- Noisy characteristic
- Depends considerably on input picture
- Shows strong decay of maximum value occurrence



Local Quant. / Adaptivity criterion – (3)

Example for criterion:
  Maximum AC cumulative pdf

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



Local Quant. / Quantization classes

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

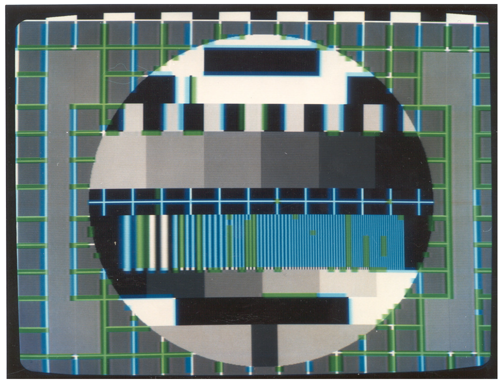
Example for crit.:
  max ac

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

Local Quant. / Quantization classes

Example metric:
  Max ac coeff.

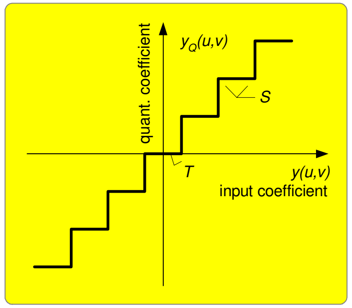
- **4 Classes**
  - Low: no colour
  - Med low: orange
  - Med high: green
  - High: blue
- **Adaptivity pays off (always)!**



Local Quant. / Block quantization

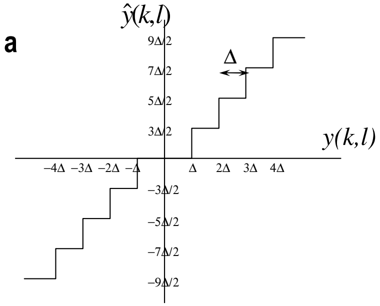
Block quantization

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



Local Approach: Quantizer Selection

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



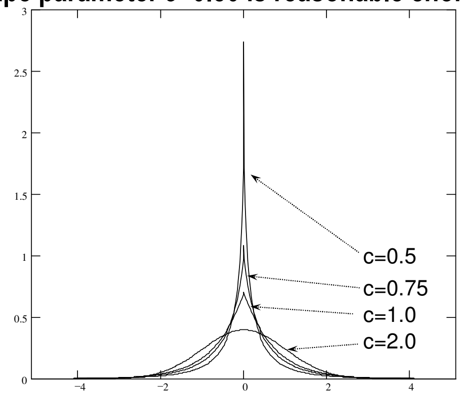
PCM Coding of DCT Coefficients – (1)

- **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)
- **Peaked pdf: prototype quantizers** can be designed using standard **Lloyd-Max** or **Unif. Threshold Q procedures**
- Mostly in practice: standard **uniform quantizer with deadzone** can be used
- Quantizer levels are then ***VLC encoded*** **(Huffman, modif. VLC,** arithmetic*)*

PCM Coding of DCT Coefficients – (2)

- Shape parameter c=0.50 is reasonable choice



5LSE0 - Mod 03 - A
Part 1.2

JPEG Still picture standard

Introduction to JPEG

- **Internat. standardization in 1988 - 1992 led to ISO and ITU-Telecommunicat's 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: strongly prescriptive standard, is only weakly programmable**

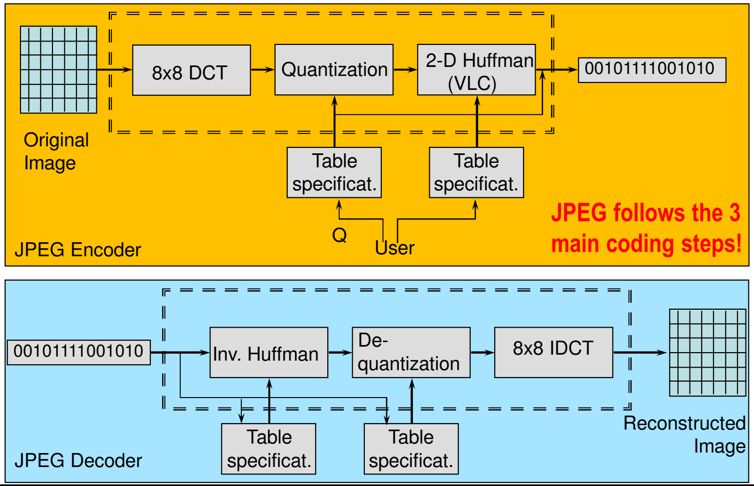
JPEG Requirements

- **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**

JPEG Coding System Architecture



JPEG DCT Weighting & Quantization

* **Quantization:**

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

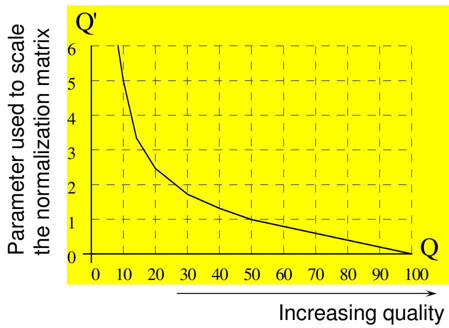
* **Recommended JPEG normalization matrix**

N(u,v)=W(u,v)

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

JPEG User Controllable Quality

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



JPEG 8x8 DCT Example – (1)

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

DCT transform is exactly defined in JPEG standard

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)

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

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

- **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)

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	1111001
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

Breakdown of coding

• signed amplitude =
category + offset + sign

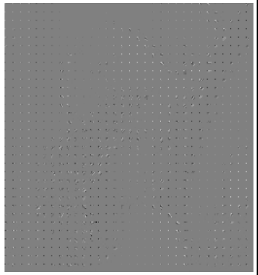
JPEG VLC Coding Example – (3)

- **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)

Coded at Q=10

Quantization errors



Coded DCT block

JPEG Customization & Flexibility

* **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) as add-on**
* **But: No possibility to vary Δ per DCT block (global Q)**
* **Suboptimal alternative: 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

* **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**