Multimedia Video Coding & Architectures (5LSE0), Module 07

Transform Coding

Quantization and VL Coding

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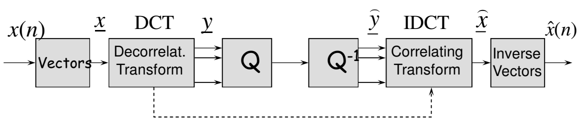
slides version 1.0

5LSE0 - Mod 07
Part 1

Block Characterization of DCT coefficients, Global & Local Quantization

DCT-based Coding System



* **Quantization of the DCT coefficients**
  - PCM versus DPCM
  - Global versus block-based local approach
* **VLC of quantized DCT coefficients**
  - Concentrate on active dimensions: non-zeros
  - Special ordering in coding

Prediction Gain per DCT Coefficient

* **DCT only decorrelates info within a block of *N* samples**
* **Are DCT coefficients y_k in neighboring blocks correlated?**
* **Prediction gain per DCT coefficient (Lena image, 8x8 DCT)**

2141.9	239.3	55.4	17.7	8.1	4.1
73.3	50.8	20.9	9.0	5.8	2.5
14.3	13.6	10.1	6.6	3.1	2.3
3.6	5.6	5.6	3.1	3.0	1.8
1.6	1.9	2.0	2.0	1.6	1.2

Variance of DCT coefficients

3.76	1.67	1.13	1.04	1.03	1.04
1.04	1.35	1.06	1.02	1.05	1.05
1.04	1.00	1.05	1.00	1.00	1.00
1.01	1.00	1.01	1.03	1.03	1.01
1.02	1.01	1.00	1.01	1.02	1.00

Prediction gain

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:

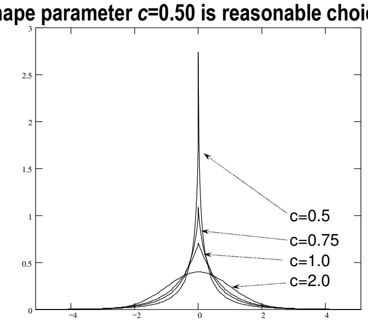
$$p(x) = a\exp(-|bx|^c)$$

(generalized Gaussian, shape parameter c)

* **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)

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



DPCM Coding DCT DC Coefficient – (1)

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- **First DCT coefficient still has a lot of correlation**
  - Basis function for this DCT coefficient shows that y_0 is the average value in a DCT block
- **Example for image**

y_{00}:

- **Use inter-block (standard) DPCM on y with c = 0.75**
  - In many cases y_0 is encoded at high bit rate (near-lossless)

Global versus Local Approach for Q

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For selecting a quantizer (& bit rate) per DCT ac coeffic.:

- ***Global approach***
  - **For the same y_u the *same* quantizer** is used in all image blocks
  - Bit allocation globally optimizes R-D behavior
  - ***Forward*** bit assignment
- ***Local (adaptive) approach***
  - Per block, ***different* quantizers for the same y_u** are used
  - For complexity reasons, **use uniform quantizer** with variable Δ per DCT block and per DCT coefficient
  - **Efficient VLC coding** per DCT coefficient needed
  - ***Feedback*** bit allocation

Global Q / Group DCT Coefficients – (1)

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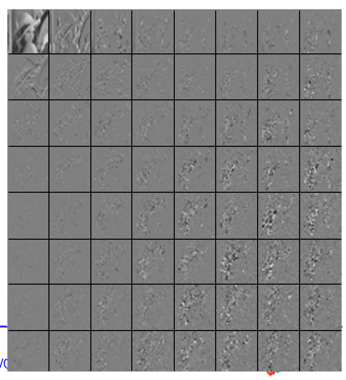
- **DCT coefficients** belonging to the **same basis vector** (basis image) are quantized with the same quantizer
- **The bit rate** for each of such set of DCT coefficients belonging to the **same basis vector is fixed**



Global Quantization Approach – (2)

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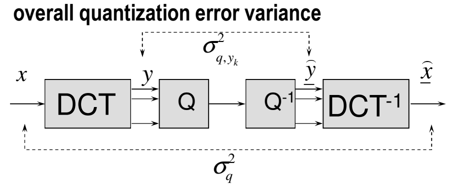
- **Given a certain average bit rate, we minimize the overall quantization error variance**



- **Easy to show because *DCT* is orthogonal:**

$$\sigma_q^2 = \frac{1}{N}\sum_{u=0}^{N-1}(y_u - \hat{y}_u)^2 = \frac{1}{N}\sum_{u=0}^{N-1}\sigma^2_{q,y_u}$$

Global Quantization Approach – (3)

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- **General formulation of the *bit allocation* problem:**

Minimize the overall coding distortion

$$D = \sigma_q^2 = \frac{1}{N}\sum_{u=0}^{N-1}\sigma^2_{q,y_u} = \frac{1}{N}\sum_{u=0}^{N-1}\sigma^2_{y_u}\sigma^2_{q,u,\text{proto}}$$

subject to the constraint of given bit rate:

$$R = \frac{1}{N}\sum_{u=0}^{N-1}R_u$$

depends on selected quantizer

- **Solution methods: Lagrange method, simulation, etc.**

Global Q Bit Allocation / Illustration – (4)

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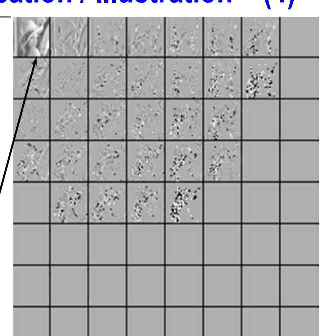
5.1 (128)	4.6 (128)	3.4 (32)	2.7 (15)	1.8 (7)	1.8 (7)
3.4 (32)	3.4 (32)	2.7 (15)	1.8 (7)	1.8 (7)	1.5 (5)
2.7 (15)	2.7 (15)	1.8 (7)	1.8 (7)	1.5 (5)	1.5 (5)
1.5 (5)	1.8 (7)	1.8 (7)	1.5 (5)	1.5 (5)	1.5 (5)
0	1.5 (5)	1.5 (5)	1.5 (5)	1.2 (3)	0

Pred. gain

\# output levels

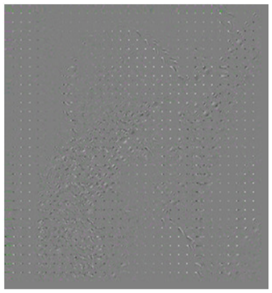
DC coeff. in DPCM

Coded at 1 bit/pixel



Global Q Bit Allocation / Illustration – (5)

Coded at 1 bit/pixel



Coded DCT blocks at spatial position

Local Quant. / Non-zero Coefficients

- **Each DCT block is quantized separately**
  - DCT coefficients belonging to the same basis vector are quantized with the different quantizer
  - Bit rate per block is variable
  - Require efficient way to represent
    - the quantized DCT coefficient
    - Selected DCT coefficients appear in a DCT block
- **Example:**

DCT coefficients

33	12	12	16	7	2	1	3
10	14	10	6	10	14	14	1
6	3	3	3	4	3	3	3
1	6	6	9	5	6	6	0
5	0	3	5	1	4	0	2
1	2	5	2	2	1	2	1
3	2	3	3	3	4	3	1
1	4	1	2	1	3	2	0

$$\hat{y}_{u,v} = Q[y_{u,v}]$$

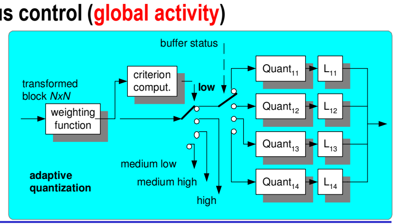
Quantized coefficient

7	3	1	0	0	0	0	0
5	2	0	0	0	0	0	0
0	0	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	2	0	0	1	0
0	0	0	0	0	0	0	0

Local Quant. / Quantization system

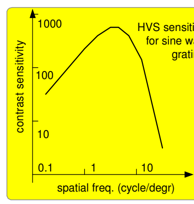
Transform Coder Quantization contains 3 elements:

- **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**



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 $W(u,v)$

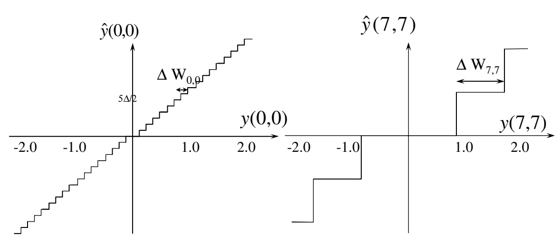
$$W(u,v) = \begin{bmatrix} 8 & 16 & 19 & 22 & 26 & 27 & 29 & 34 \\ 16 & 16 & 22 & 24 & 27 & 29 & 34 & 37 \\ 19 & 22 & 26 & 27 & 29 & 34 & 34 & 38 \\ 22 & 22 & 26 & 27 & 29 & 34 & 37 & 40 \\ 22 & 26 & 27 & 29 & 32 & 35 & 40 & 48 \\ 26 & 27 & 29 & 32 & 35 & 40 & 48 & 58 \\ 26 & 27 & 29 & 34 & 38 & 46 &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

Quantizer equation:

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

Quantization Weighting Matrix – (2)

- **Effect of weighting matrix:**



Coeff. Weighting / Example of Result

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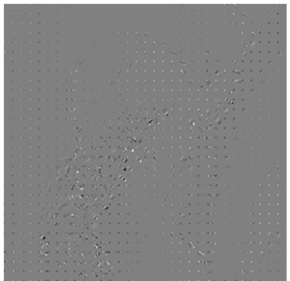
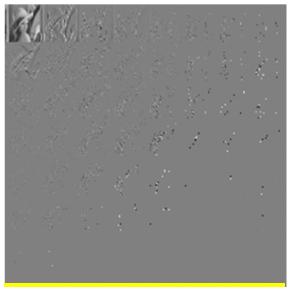


Coded DCT blocks at spatial position



Collect DCT coefficients in "bands"

Local Quant. / Adaptivity criterion – (1)

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Criteria / metrics for adaptive quantization

* **General measure**

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

* **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)

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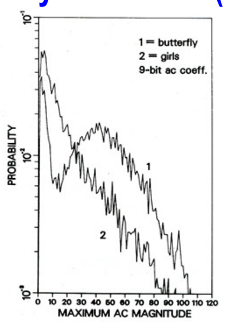
Example for criterion:
Maximum AC magnitude

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



Local Quant. / Adaptivity criterion – (3)

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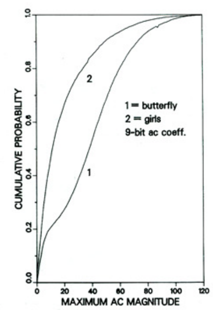
Example for criterion:
Maximum AC cumulative pdf

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



Local Quant. / Quantization classes

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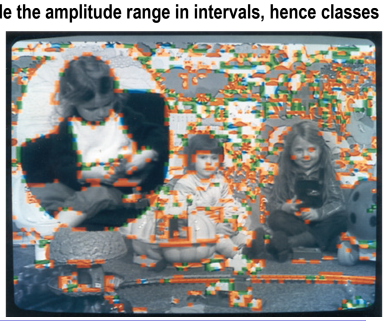
In practice, we divide the amplitude range in intervals, hence classes

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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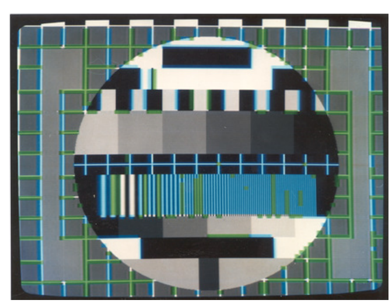
Example metric: **Max ac coeff.**

* **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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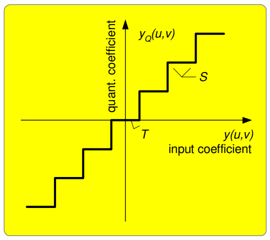
Block quantization

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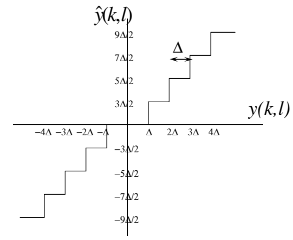
- Each DCT coefficient in each block can have different step size $S=\Delta$ for a uniform quantizer
- Different DCT coefficients are of unequal importance
  - Use different Δ per DCT coefficient: *overhead*



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5LSE0 - Mod 07 Part 2

Variable Length Coding algorithms for DCT-based compression

Coding of DCT Coefficients (Zonal)

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- **In general:**
  - Many zeros and only few non-zeros
  - Amount of non-zeros varies per DCT block
- **Efficient ways to encode this pattern?**
- ***Zonal coefficient selection***

Zone: Always send only these coefficients

7	3	1	0	0	0	0	0
5	2	0	0	0	0	0	0
0	0	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	2	0	0	1	0
0	0	0	0	0	0	0	0

VL-Coding DCT Coefficients - Improved

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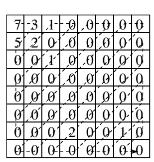
- *1. Threshold coefficient selection*
- *2. Zig-zag scanning and 2-D Huffman coding (!!)*

1.

7	3	1	0	0	0	0	0
5	2	0	0	0	0	0	0
0	0	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	2	0	0	1	0
0	0	0	0	0	0	0	0

Send only DCT coefficients >1 (example), including their positions

2.



Send combinations of length of zero-runs and non-zero DCT amplitude:
2-D Huffman coding

VL-Coding DCT Coefficients - Start

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Starting point for coding, example: a typical block

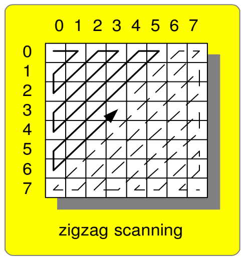
- **Concentration towards low-freq. coefficients**
  - weighting
  - energy concentration
- **Amplitude characteristics**
  - many small values
  - few large ones
- **Focus on non-zero values!**

8x8 DCT transform result

281	9	6	20	1	3	4	1
-1	0	-5	6	-3	0	0	0
3	-11	-1	0	0	0	0	0
0	2	0	0	0	0	0	0
-7	-2	0	0	0	0	0	0
4	-1	0	0	0	0	0	0
2	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Coding DCT Coefficients - Scanning

- **Zigzag scanning (or diagonal)**
  - Prepares for non-zero coefficient coding
  - Converts 2-D to 1-D stream of numbers
  - Starts with most relevant coefficients
  - Clusters zeros at the end



VL-Coding Coefficients - Main principles

Principles for good coding algorithms

- **Consider on transmission of non-zero coefficients only!**
  - one-third or less of coefficients is relevant
  - omit zonal coding
- **If non-zero values are only used: some form of address information is needed**
  - skip zero values and code length of skip, or
  - indicate the address of a coefficient (direct or indirect)

VL-Coding Coeff. / Runlength Coding – (1)

Example of Runlength Coding

- **Two coding tables**
  - Amplitudes (magn.+sign)
  - Runlengths
- **Prefix code to switch from amplitude to runlength**
- **After runlength, always ampl. code**
- **EOB code terminates each block**

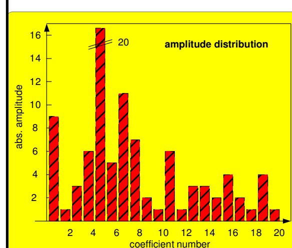
$$\begin{bmatrix} 287 & 11 & 0 & 0 \\ 16 & -4 & -3 & 0 \\ 0 & 3 & 0 & 0 \\ 2 & -2 & 0 & 0 \end{bmatrix}$$ **matrix, *N*=4**

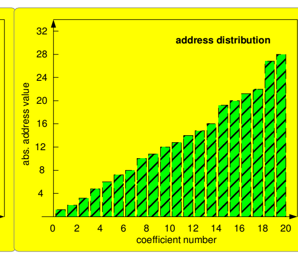
287	9 bits	100011111
11	8+1	000000010
16	11+1	000001011110
prefix	3	010
runl(1)	2	11
-4	5+1	000011
prefix	3	010
runl(2)	3	101
-3	4+1	01111
3	4+1	01110
2	3+1	0010
-2	3+1	0011
EOB	4	0001
Total	69 bits	

VL-Coding coeff. / Runlength Coding – (2)

Example of Runlength Coding

- **Observation: Coefficients are coded serially (address)**

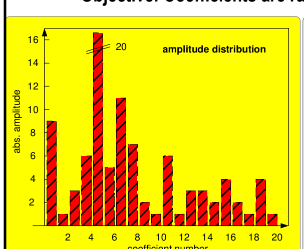


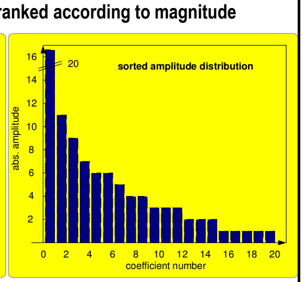


VL-Coding / Diff. Decr. Ampl. Coding – (1)

Alternative for Runlength Coding

- **Objective: Coefficients are ranked according to magnitude**





VL-Coding / Diff. Decr. Ampl. Coding – (2)

Example of **Differential Decreasing Amplitude Coding (DDAC)**

- **Two coding tables**
  - Differential amplitudes (magn.+sign)
  - Addres (direct and relative)
- **No switch prefix code (always alternating...)**
- **EOB code terminates block**

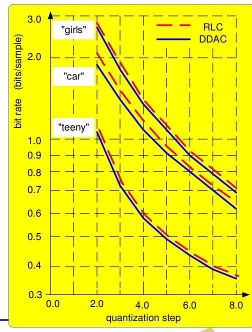
$$\begin{bmatrix} 287 & 11 & 0 & 0 \\ 16 & -4 & -3 & 0 \\ 0 & 3 & 0 & 0 \\ 2 & -2 & 0 & 0 \end{bmatrix}$$ **matrix, *N*=4**

287	9 bits	100011111
16	5+1	011110
adr(2)	3	101
5	5+1	011010
adr(1)	2	11
-7	7+1	00000011
adr(2)	3	101
-1	3+1	0101
adr(4)	4	0101
0	1+1	10
adr(1)	2	11
1	3+1	0100
....	....	....
EOB	4	0001
Total	65 bits	

VL-Coding / Diff. Decr. Ampl. Coding – (3)

Efficiency Comparison
Runlength Coding vs/ Diff. Decr. Ampl. Coding

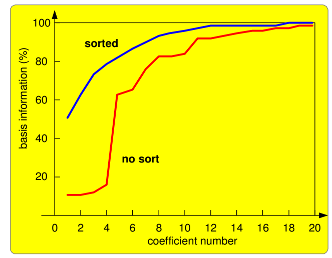
* **Slightly better in efficiency**
  – Extra: differential aspect
* **DDAC more complex due to sorting**
* **Relevance is elsewhere ...**
  – Use the concept of visual summaries hidden at the start!



VL-Coding / Diff. Decr. Ampl. Coding – (4)

Comparison of **Cumulative Basis Information** (e.g. energy)

* **Compare build up of received information**
* **DDAC is optimal, but more complex**
* **RLC result depends on location of largest components**



VL-Coding / Diff. Decr. Ampl. Coding – (5)

Visual result of DDAC using **largest ac coefficient** only

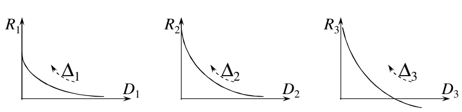
* **Optimal build up of information**
* **Postfiltering would improve visual result**

Bit-rate control / Selection of $S=\Delta$

* **We have *M* different DCT blocks. How to choose Δ_i?**
  – Fixed Δ_i for all DCT blocks
    • Easy, but ignores image variations
    • No ***minimal*** quantization error variance at a certain bit rate
  – **Use fixed Δ_i but vary slightly as function of "image features" (edges, texture, variance, ...)**
    • Heuristic, experimental, codec simulation
  – **Two-pass coding strategy**:
    • First fixed Δ_i, analyse resulting R and σ_q^2
    • Change Δ_i depending on the (R,σ_q^2) per block
  – Minimize σ_q^2 for given R

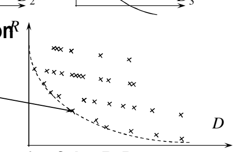
Rate control / Rate-Distortion Behavior

* **Example rate-distortion function for 3 DCT blocks**



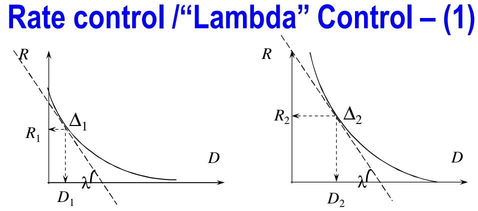
* **Overall rate-distortion function**

Which (Δ_1, Δ_2, Δ_3) to use?



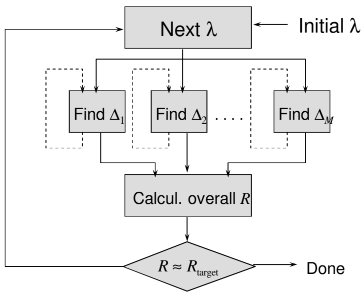
* ***Overall optimal points*: gradient λ of the R-D curve is same in all blocks**

Rate control /"Lambda" Control – (1)



* **For given $\lambda=\delta R/\delta D$, the appropriate Δ_i can be (iteratively) determined in *each* DCT block *independently***
  – Quantization carried out ***independently*** in each DCT block
  – Take into account 2-D Huffman coding in R calculation
  – Optimal, but *a priori* unknown R and D: ***Feedback*** technique

Rate control / "Lambda" Control – (2)



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