L. Yaroslavsky ***Course 0510.7211 "Digital Image Processing: Applications"***

Lect. 4. Principles of signal and image coding.

General principles

General digitization. Epsilon-entropy (rate distortion function).
Coding-decoding quality evaluation: collective user vs expert user. "Lossless" and "Lossy" coding.
3 step coding: discretization-element-wise-quantization-"statistical" coding.

Discretization.

Variety of bases. Global and block-wise transforms.

- Shift bases. Decorrelation by prediction:

$$\varepsilon_k = a_k - \bar{a}_k;\ \ \bar{a}_k = \sum_{n=1}^{N} g_n a_{k-n}\ ;\ \{g_n\} = \arg\min\left[AV_{img}\left(|\varepsilon_k|^2\right)\right];\ \text{For } N=1:\ g_1 = \frac{AV_{img}(a_k \cdot a_{k-1})}{AV_{img}\left(a_{k-1}^2\right)}$$

DPCM, Delta-modulation. Coding/decoding artefacts.

- Orthogonal transform coding. Block coding. Blocking artefacts. Lapped transforms.
- Pyramid coding. Wavelet coding. Sub-band decomposition coding. Fractal coding.
- 2-D and 3-D Hybrid bases.

Element-wise quantization:

uniform and non-uniform;
homogeneous and inhomogeneous;
zonal;
adaptive.

Combined discretization-quantization procedures:

Vector quantization
Adaptive discretization
DPCM with feedback;
DPCM with feedback and adaptive quantization;

Adaptive coding methods:

adaptive DPCM, adaptive transform coding (adaptive block size, basis pursuit, adaptive bit allocation).

Statistical coding:

- Shannon-Fano-Huffman coding;
- Coding of coordinates of rare symbols. Run length coding.
- Coding with tracing contours.

Sensitivity of coding methods to channel noise

Coding of multi component, color and stereoscopic images.

Image coding standards

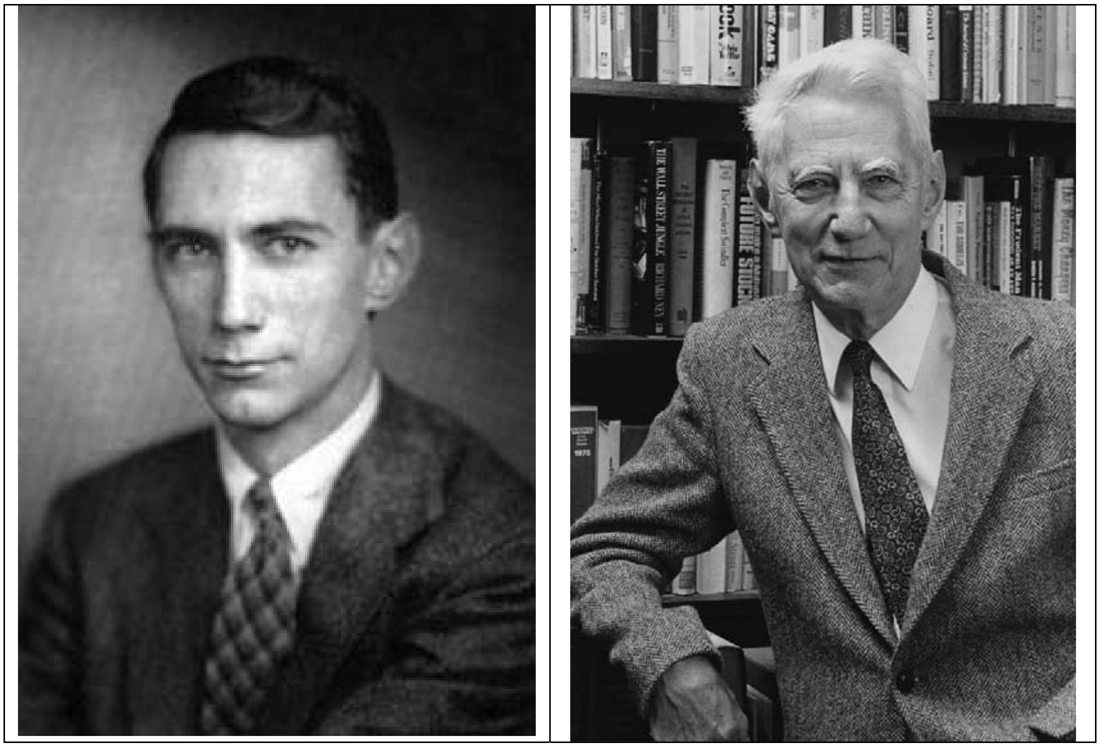
JPEG and JPEG2000 standards. Video coding. Motion compensation MPEG standards.

Questions for self-testing:

1. What are the basic principles of image compression? Compare compression for collective and expert users.
2. Characterize potential limits of data compression. What is "lossless" and "lossy" compression.
3. Describe DPCM without and with feedback, and methods for the predictor design.
4. Describe image block transform coding. Compare different transforms in terms of compression efficiency.
5. Describe quantization methods in image coding.
6. What is vector quantization and how it is related to general quantization?
7. Compare coding methods in terms their sensitivity to the channel noise.
8. Describe statistical coding methods and their implementations in image coding
9. How would you approach to multi component image coding?
10. Describe video coding with motion compensation.

Additional reading on image coding:

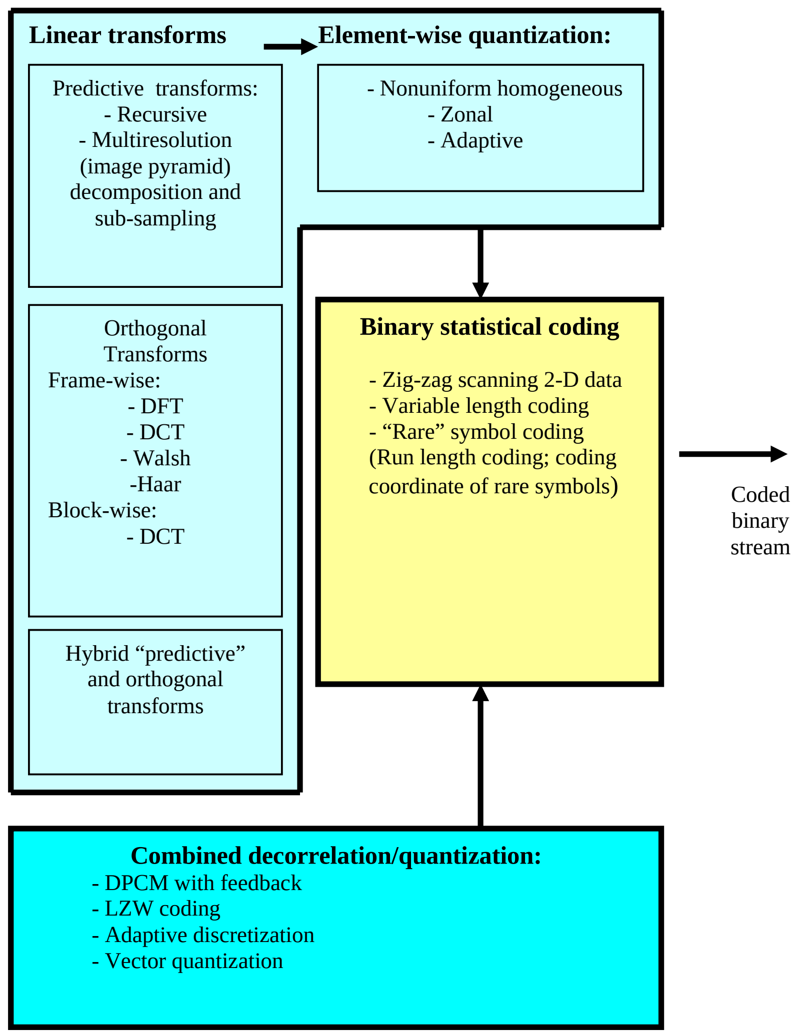
1. R.J. Clarke, Digital Compression of Still Images and Video, Academic Press, London, 1996
2. M. Vetterli, J. Kovacevic, Wavelets and Subband Coding, Prentice Hall PTR, Englewood Cliffs, New Jersey, 1995



Claude Shannon (1916 - 2001)

- **C. Shannon, A Symbolic Analysis of Relay and Switching Circuits, Trans. Of the American Institute of Electrical Engineers, v. 57 (1938) (based on his Magister Degree Thesis, MIT)**
- **C. Shannon, A Mathematical Theory of Communication, Bell System Technical Journal, 27 (1948), No. 3, pp. 379-423, No. 4, pp. 623-656**

CLASSIFICATION OF IMAGE COMPRESSION METHODS



Classification of digital image data compression methods

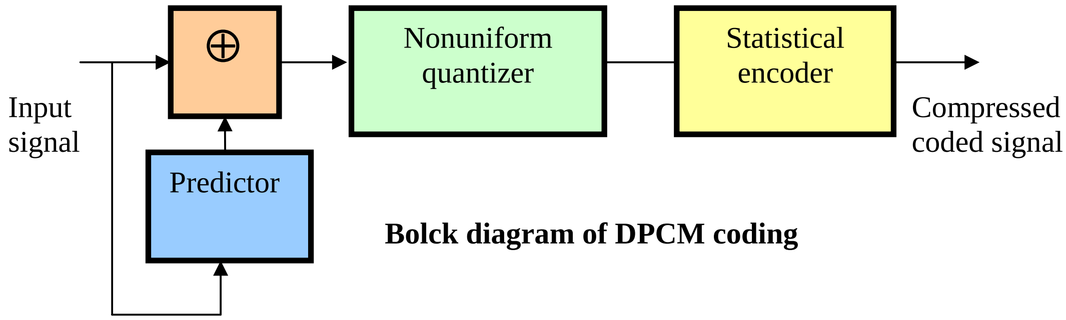
Variable length statistical coding

An example of Huffman coding of 8 symbols

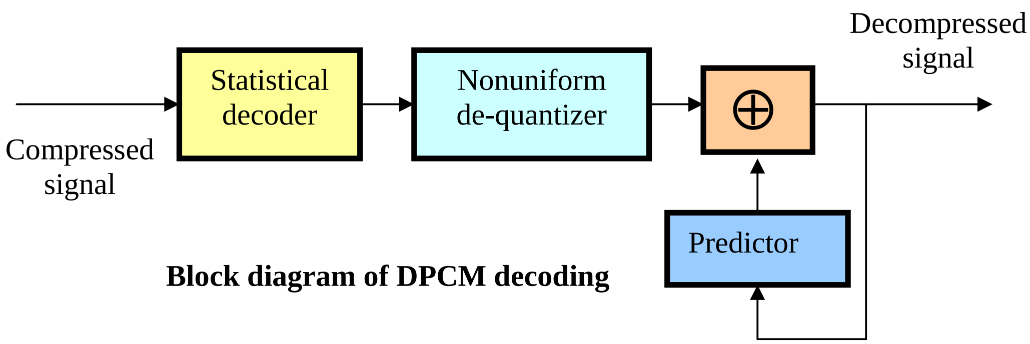
Iteration	A	B	C	D	E	F	G	H
	P(A)= 0.49	*P*(B)= 0.27	*P*(C)= 0.12	*P*(D)= 0.065	*P*(E)= 0.031	*P*(F)= 0.014	*P*(G)= 0.006	*P*(H)= 0.004
1-st	-	-	-	-	-	-	0	1
							P(GH)=0.01	
2-nd	-	-	-	-	-	0	1	
						P(FGH)=0.024		
3-d	-	-	-	-	0	1		
					P(EFGH)=0.055			
4-th	-	-	-	0	1			
				P(DEFGH)=0.12				
5-th	-	-	0	1				
			P(CDEFGH)=0.24					
6-th	-	0	1					
		P(BCDEFGH)=0.51						
7-th	0	1						
Binary code	0	10	110	1110	11110	111110	1111110	1111111
Entropy *H*=1.9554								
Average number of bits per symbol: 1.959								

Coding of rare symbols:

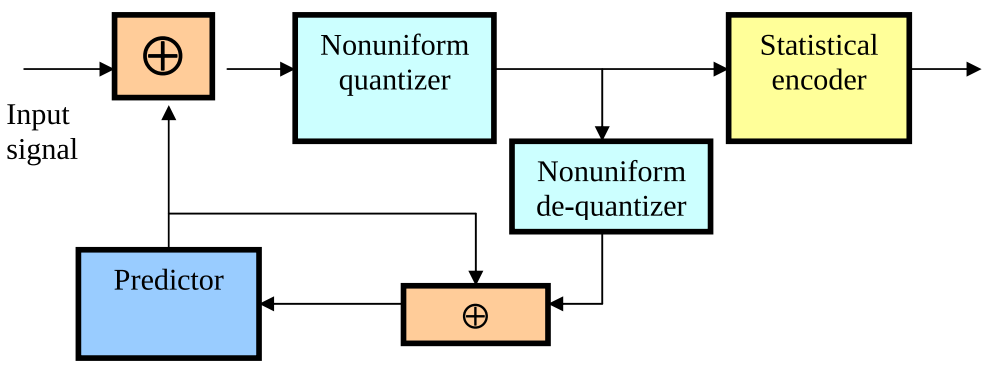
- **Run-length coding**
- **Coding of co-ordinates of rare symbols**
- **Coding by tracing connected components of patterns of rare symbols**



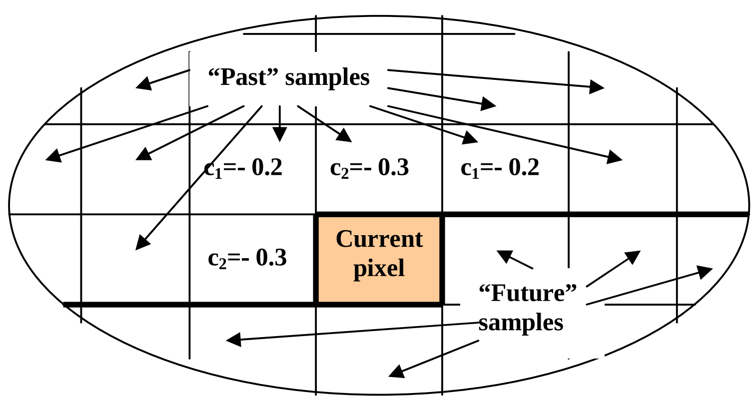
Bolck diagram of DPCM coding



Block diagram of DPCM decoding

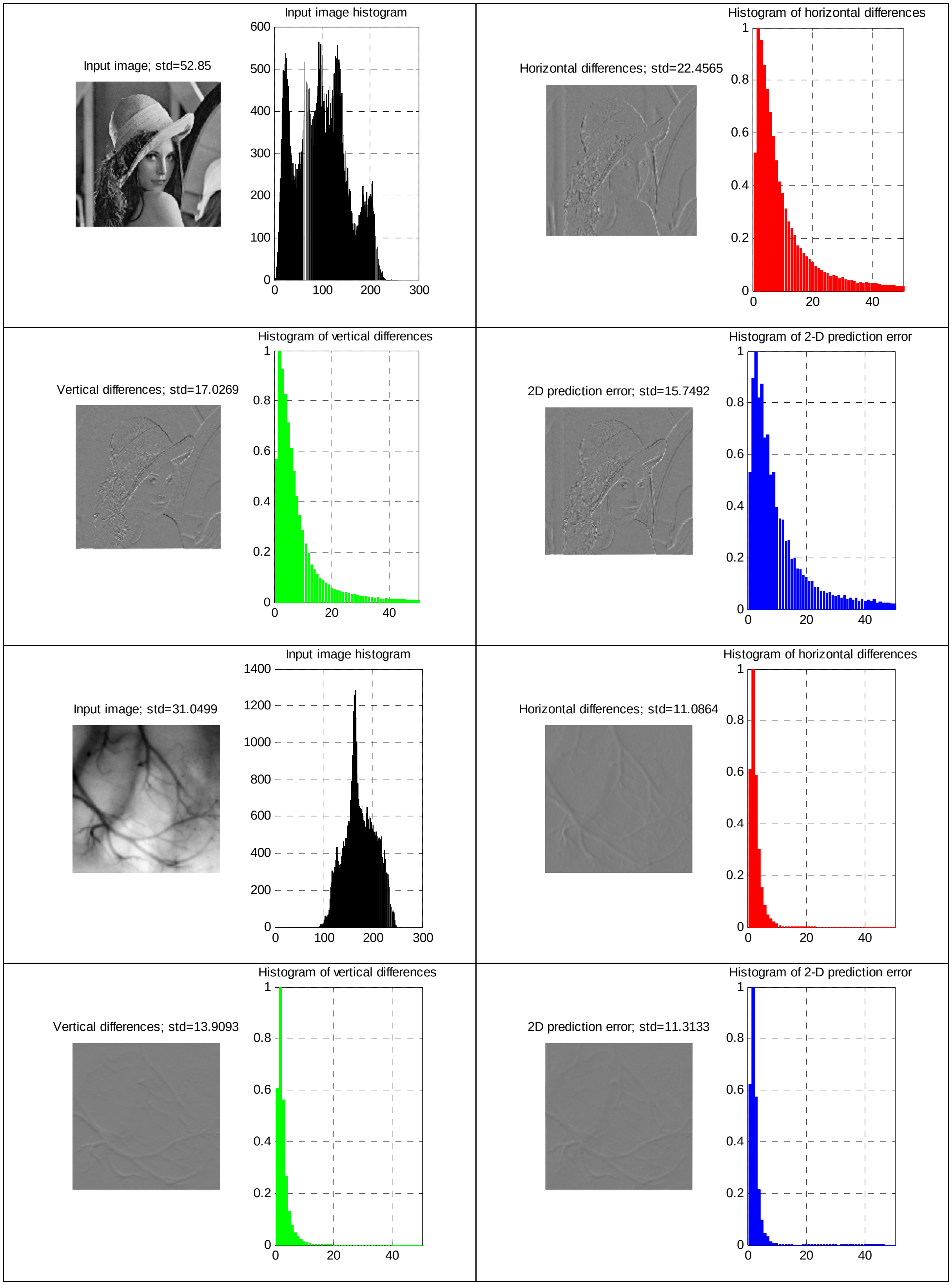


Block diagram of DPCM encoding with feedback



2-D prediction for row-column scanning method

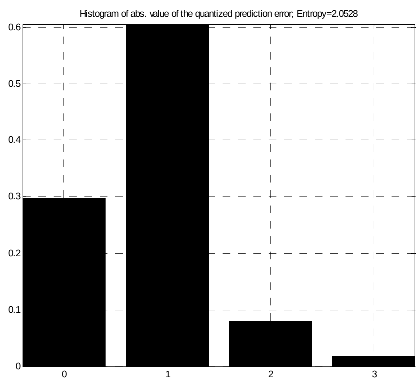
Prediction error statistics



Examples of DPCM image coding with *P*-th low of quantization of the prediction error

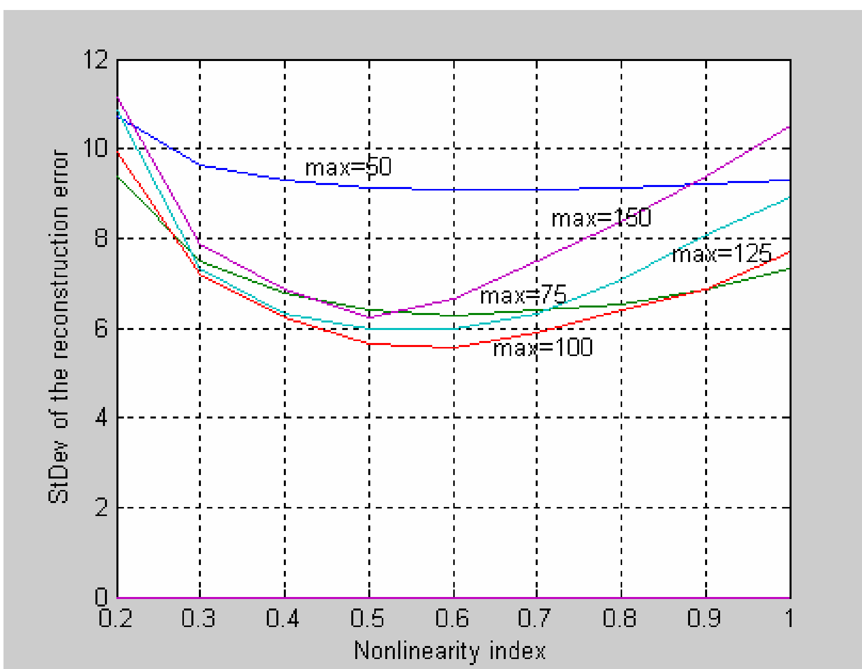
Initial image

DPCM_1D coded image; Q=7,mxm=100; P=0.6;
Std of the restoration error 7.35



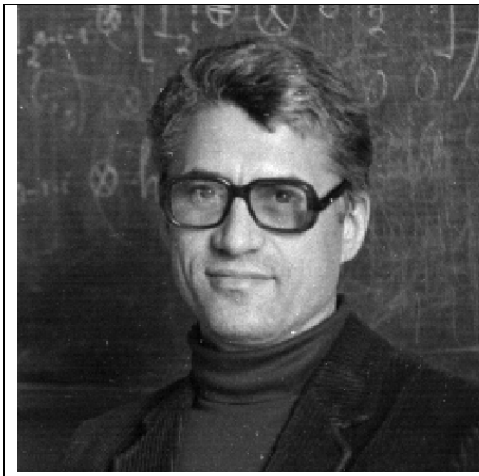
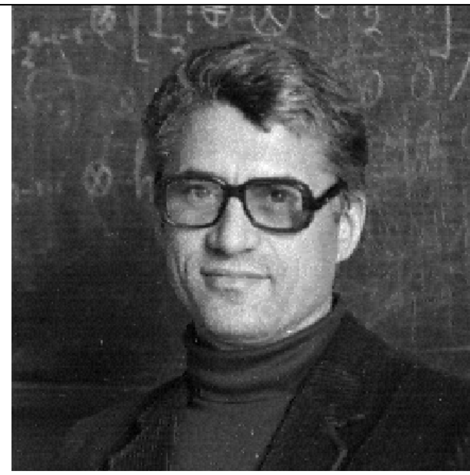
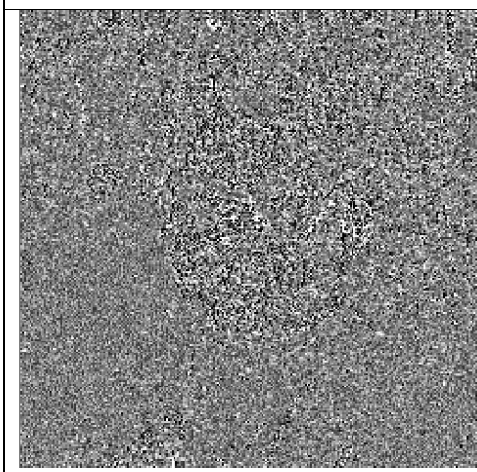
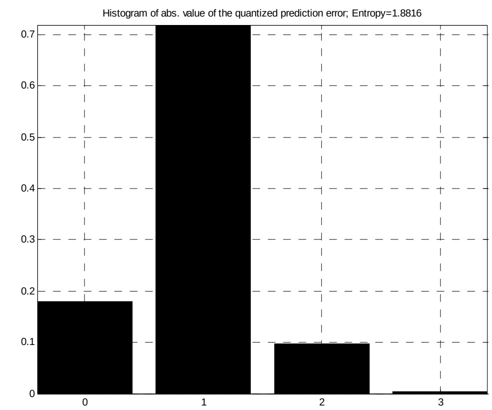
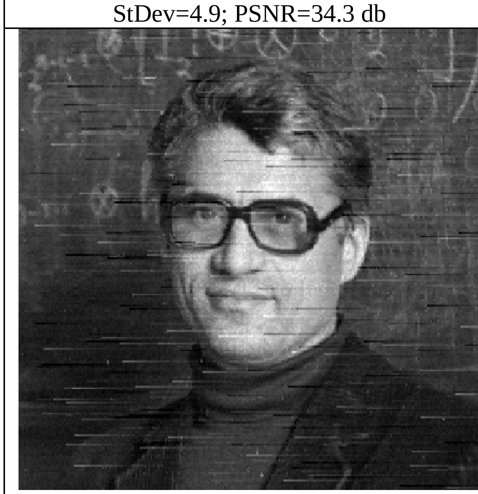
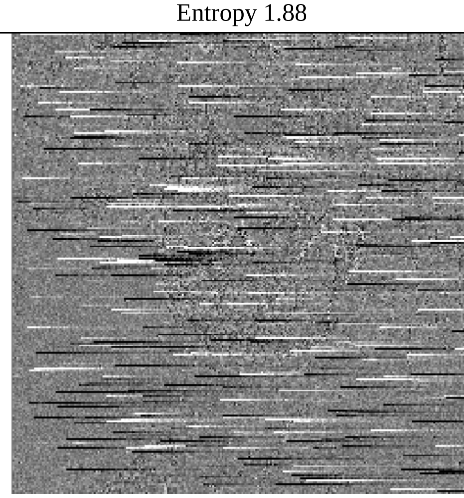
Histogram of abs. value of the quantized prediction error. Entropy =2.05

DPCM_1D coded image;
DPCM_1D coded image; Q=7,mxm=100; P=0.6;
Perr=0.005;Std of the restoration error 13.5

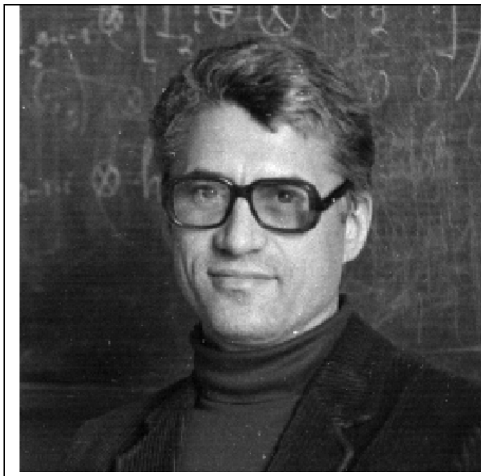
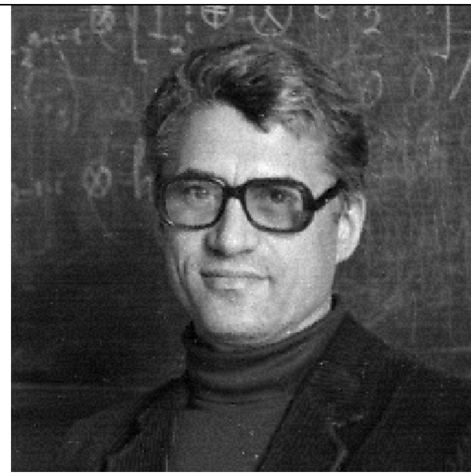
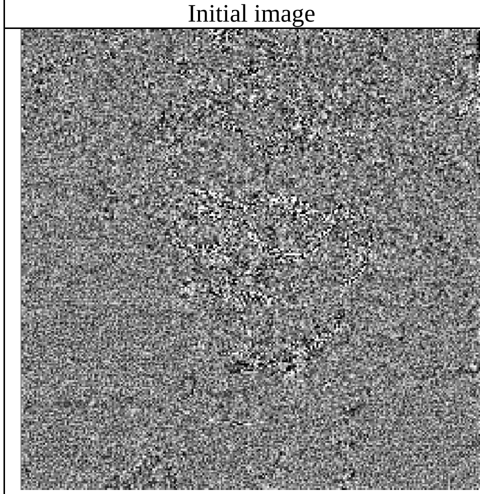
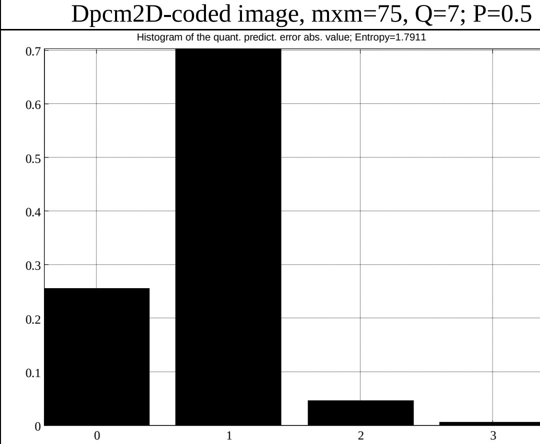
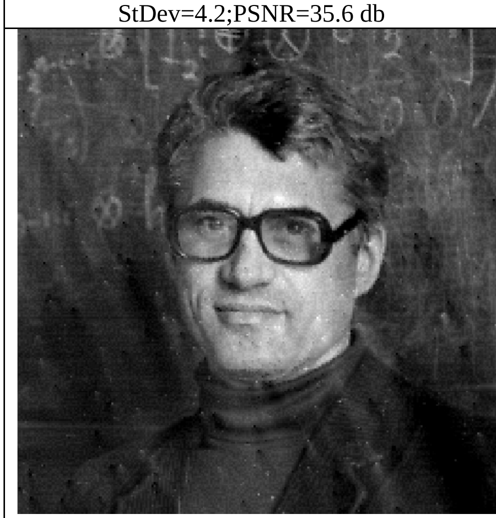
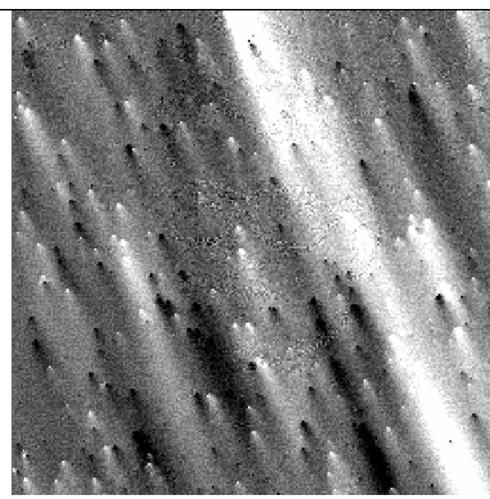


DPCM: optimisation of the quantization dynamic range and nonlinearity index ***P***

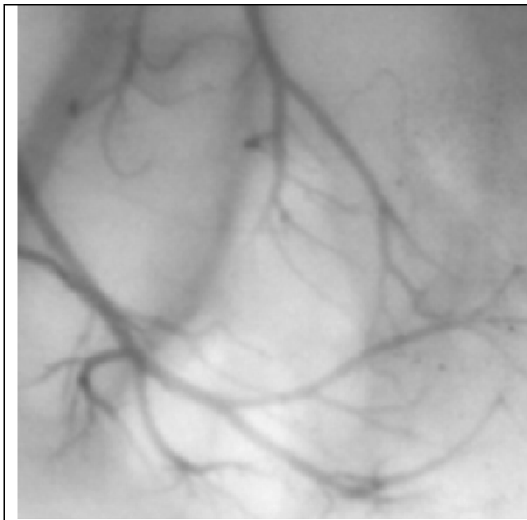
DPCM1D

	 Dpcm2D-coded image, mxm=75, Q=7; P=0.5
 Reconstruction error: StDev=4.9; PSNR=34.3 db	 Histogram of the prediction error abs. value, Entropy 1.88
 Dpcm2D-coded image, mxm=75, Q=7; P=0.5 Channel impulse noise Perr=0.075	 Impulse noise: Reconstruction error; StDev=10.75

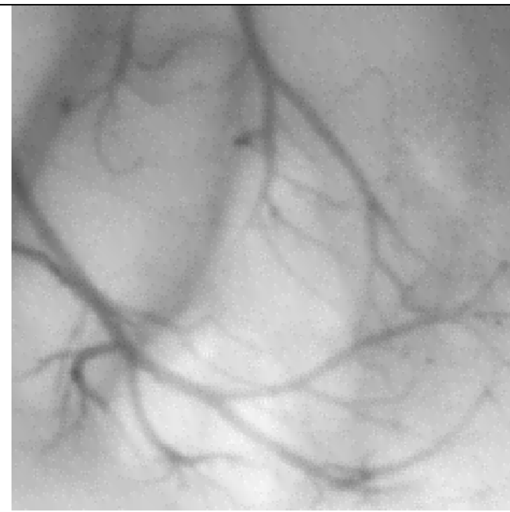
DPCM2D

 Initial image	 Dpcm2D-coded image, mxm=75, Q=7; P=0.5
 Reconstruction error: StDev=4.2;PSNR=35.6 db	 Histogram of the prediction error abs. value, Entropy 1.79
 Dpcm2D-coded image, mxm=75, Q=7; P=0.5 Channel impulse noise Perr=0.075	 Impulse noise: Reconstruction error; StDev=13.7

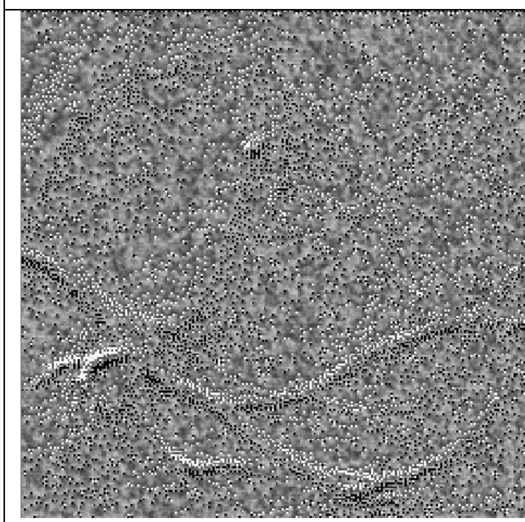
DPCM2D



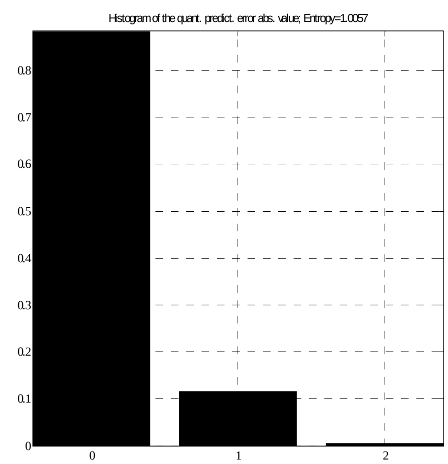
Initial image



Dpcm2D-reconstructed image, mxm=50;Q=5;
P=0.5;

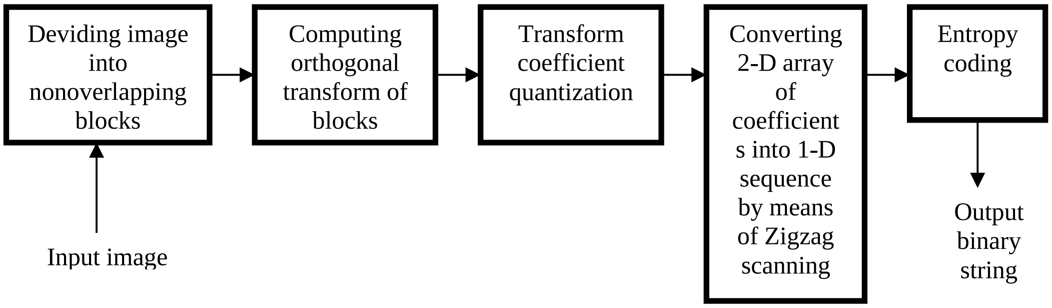


Reconstruction error; StDev=3.2



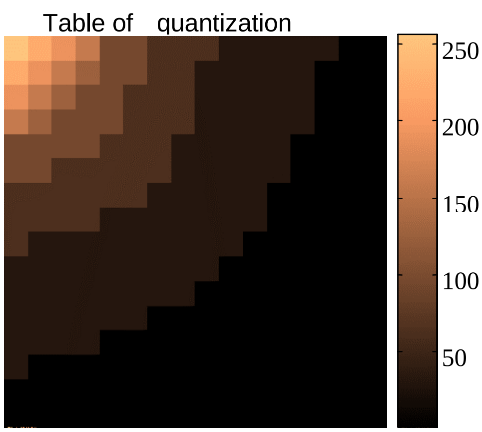
Histogram of abs. Value of the reconstruction error
Entropy 1 bpp

TRANSFORM BLOCK CODING



Principle of image transform coding

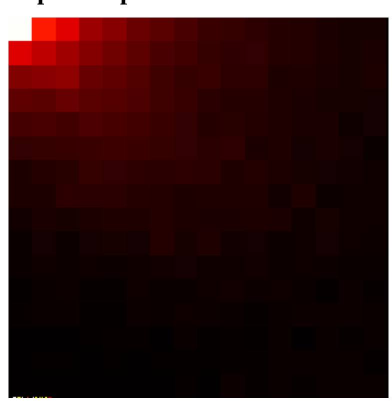
Bit allocation table for DCT coding and average DCT power spectra of images



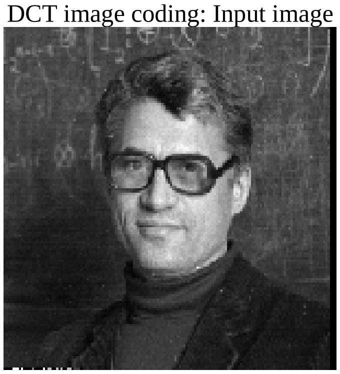
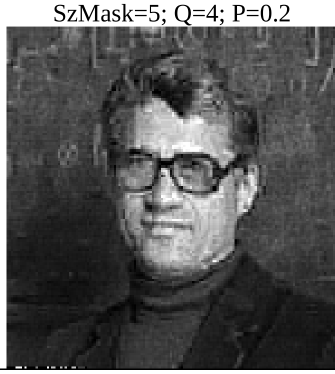
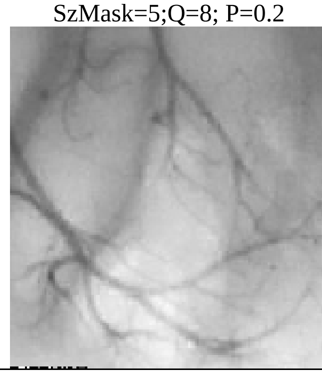
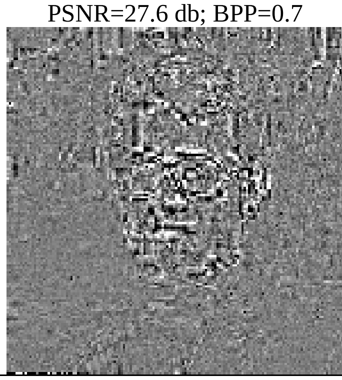
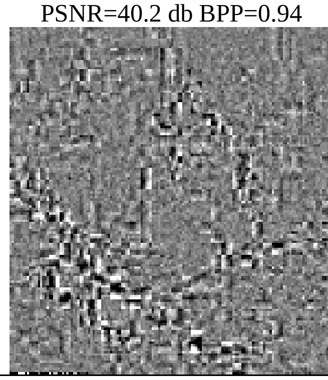
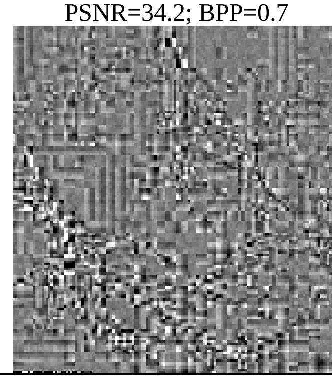
8	7	6	5	3	3	2	2	2	1	1	1	1	1	0	0
7	6	5	4	3	3	2	2	1	1	1	1	1	0	0	0
6	5	4	3	3	2	2	2	1	1	1	1	1	0	0	0
5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	0
3	3	3	3	2	2	2	1	1	1	1	1	0	0	0	0
3	3	2	2	2	2	2	1	1	1	1	1	0	0	0	0
2	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0
2	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bit allocation table for DCT 16x16 block coding

Lenna image and its average 16x16- DCT power spectrum



Examples of image DCT block coding with zonal quantization

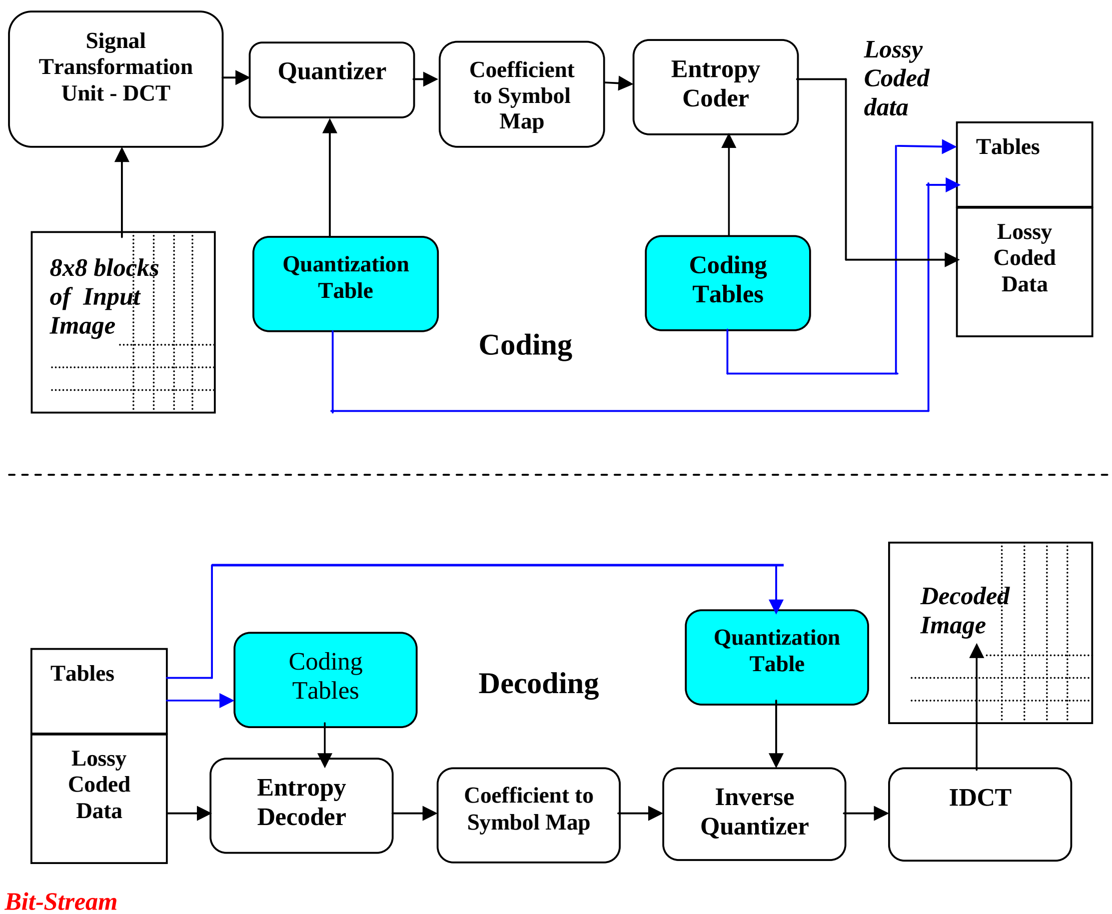
<table>
<tr><td>DCT image coding: Input image
</td><td colspan="2">DCT image coding: Input image
</td></tr>
<tr><td>Restored image, SzW=8; SzMask=5; Q=4; P=0.2
</td><td>Restored image, SzW=8; SzMask=5;Q=8; P=0.2
</td><td>Restored image, SzW=8; SzMask=5;Q=4; P=0.2
</td></tr>
<tr><td>Restoration error; Std=10.6; PSNR=27.6 db; BPP=0.7
</td><td>Restoration error; StdErr=2.5; PSNR=40.2 db BPP=0.94
</td><td>Restoration error; StdErr=5; PSNR=34.2; BPP=0.7
</td></tr>
</table>

JPEG CODING STANDARD

(after A.M. Tekalp, Digital Video Processing, Prentice Hall, Upper Saddle River, NJ, 1995):

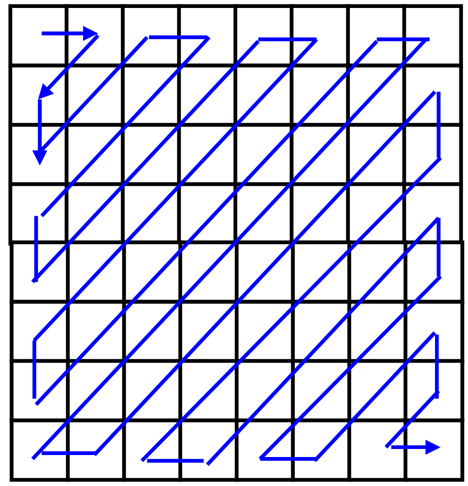
B/W images:

- **Image is subdivided into 8x8 blocks; DC component is subtracted.**
- **2-D DCT of each block is computed.**
- **The DCT coefficients are threshold coded using a quantization table and then reordered into 1-D sequence using zigzag scanning**
- **The nonzero AC quantized coefficients are Huffman coded; zero coefficients are run length coded.**
- **DC coefficient of each block is DPCM coded relative to the DCT coefficient of the previous block**



Block-diagrams of JPEG image coding and decoding

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



Intensity quantization table for 8x8 blocks and zig-zag scanning in JPEG coding

Quantization rule: $\hat{\alpha}_r = round(\alpha_r / \tilde{w}_r)$,

where $Q \leq 100$ is a quality factor $\tilde{w}_r = floor[(w_r ScFactor + 50)/100]$ and

$$ScFactor = \begin{cases} 1, & Q = 100 \\ 200 - 2 * Q, & 50 \leq Q \leq 99 \\ 5000 / Q, & 1 \leq Q \leq 50 \end{cases}$$

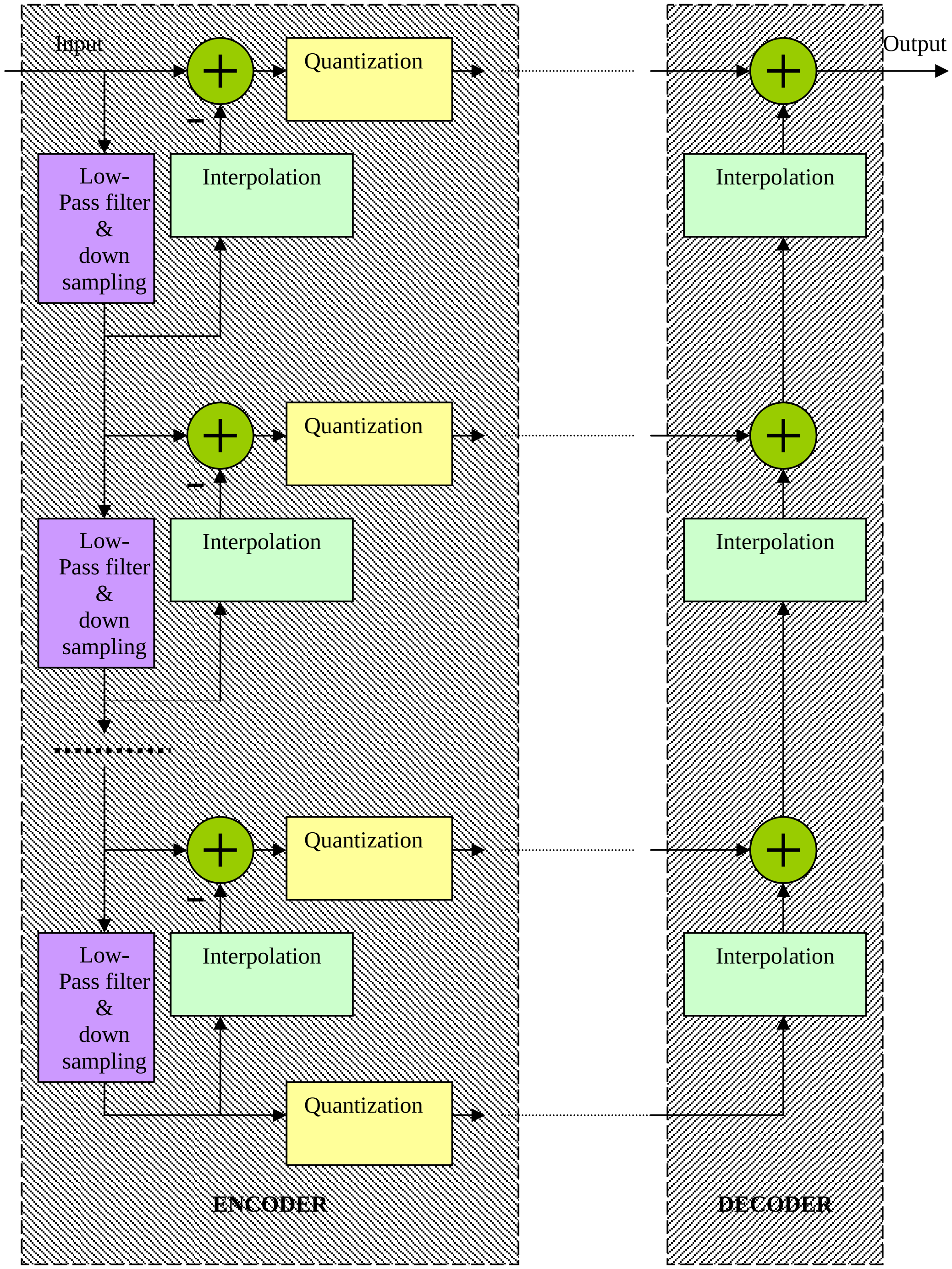
JPEG coding of colour images:

- **R-G-B components are transformed into Luminance-Chrominance space Y-Cr-Cb:**

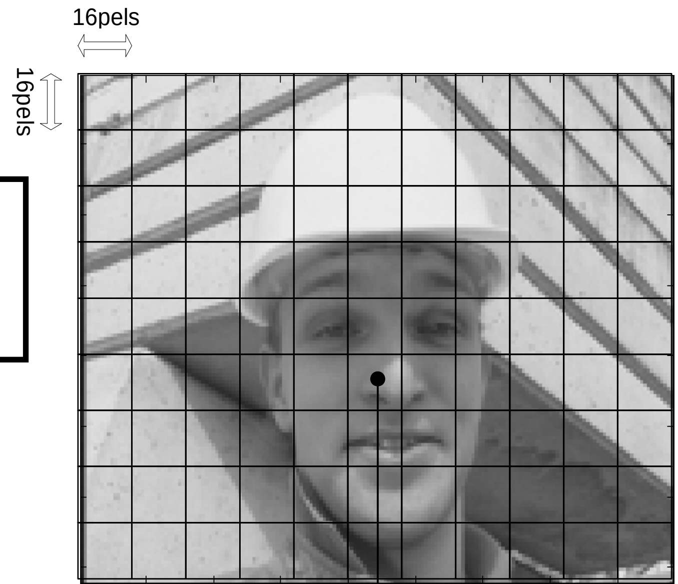
$$Y = 0.3R + 0.6G + 0.1B$$
$$Cr = (B - Y + 1)/2$$
$$Cb = (R - Y + 0.8)/1.6$$

- **Chrominance channels are subsampled by 2 in both directions.**
- **Obtained *Y, Cr* and *Cb* components are JPEG coded individually**

Multiresolution/pyramid/subband decomposition coding



VIDEO CODING with MOTION COMPENSATION

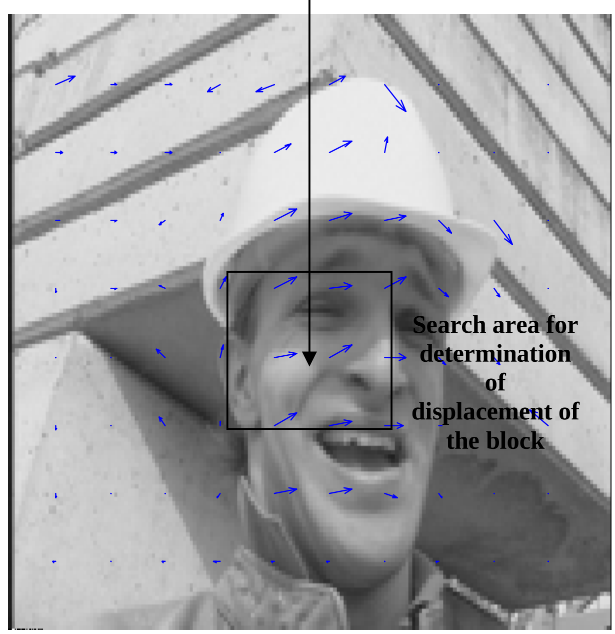


INTRAFRAME CODING:

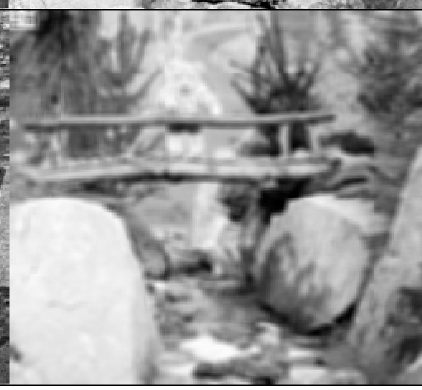
DCT block coding

INTERFAME CODING:

- Evaluation of block motion vector;
-Transmission of either motion vector or DCT coded block depending on the degree of the prediction mismatch



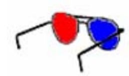
Redundancy of stereoscopic images

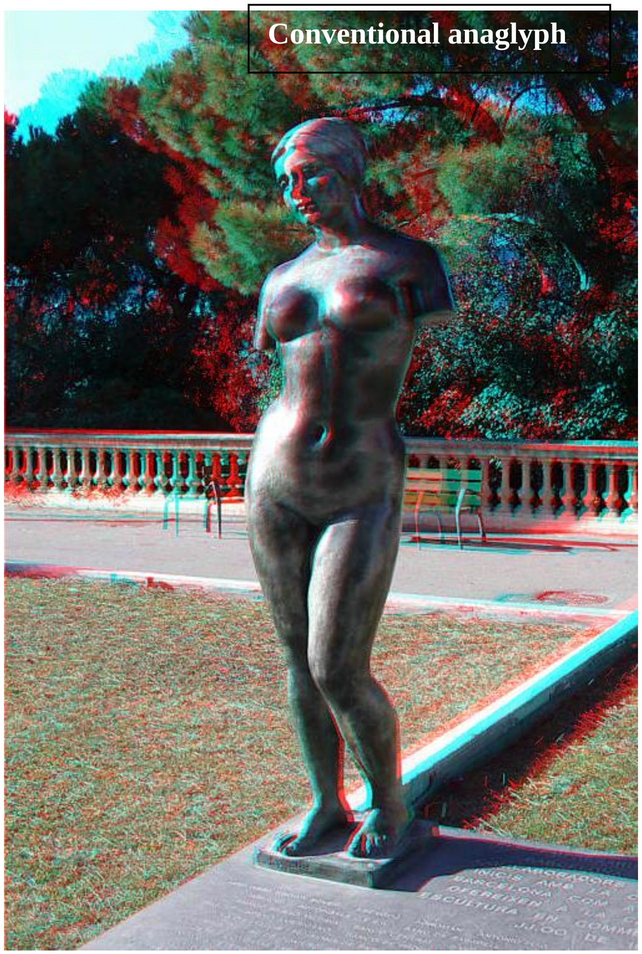
		**Original full resolution stereo pair**
		**Same stereo images, in which right image is 5x5 smoothed**

Color stereo pair in which left image is fully color and contrast saturated.

Anaglyph enhancement by means of blurring image red component





Anaglyph enhancement by means of blurring image red component