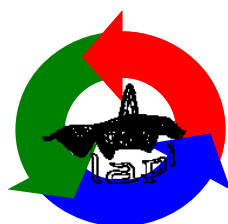
TEHNICI DE COMPRESIE A IMAGINILOR

C. VERTAN

LABORATORUL DE ANALIZA ŞI PRELUCRAREA IMAGINILOR



Compresie = reducerea cantitatii de date necesare pentru reprezentarea unei imagini

Compresia trebuie sa fie reversibila (functie inversabila).

Compresie

fara pierderi (eficienta sursei de informatie, Th. 1 Shannon)

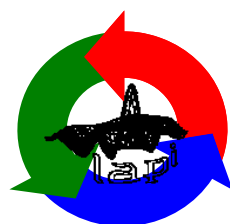
cu pierderi

Compresie

in domeniul valorilor (cuantizare, reducere numar de culori)

instante ale algoritmilor de clustering

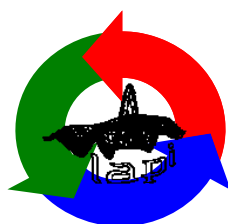
in domeniul spatial si al valorilor



Cerinte contradictorii :

Raport de compresie :: Calitatea imaginii reconstruite

(cantitate de date SNR, PSNR, MSE)



TEHNICI DE COMPRESIE A IMAGINILOR (continuare)

Compresia cu transformate

C. VERTAN

LABORATORUL DE ANALIZA ŞI PRELUCRAREA IMAGINILOR

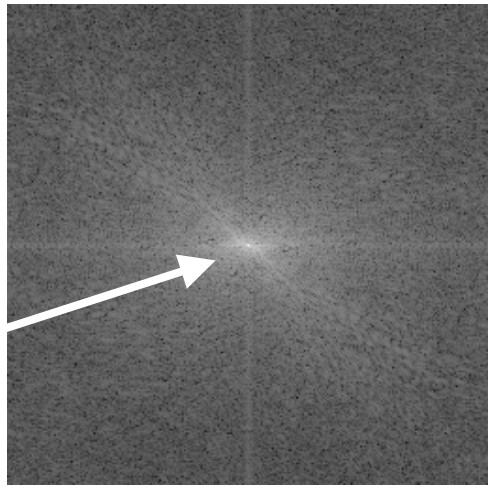
Compresia cu transformate a imaginilor (codarea in domeniul transformat)

Trecerea informatiei vizuale din imagine din domeniul spatial initial intr-un domeniu transformat (cu o transformare unitara); caracteristicile specifice ale transformarii (decorelare, concentrarea energiei) permit pastrarea unui numar mic de coeficienti ce vor aproxima imaginea.

Codarea efectiva este “clasica” (sir de simboluri), in sensul teoremei Shannon 1 (codare pentru canale fara perturbatii).

Care transformata ? Cum se aplica ? Care coeficienti se pastreaza ? Cum se transforma culorile ? Cum se codeaza ?

Fourier discret 2D

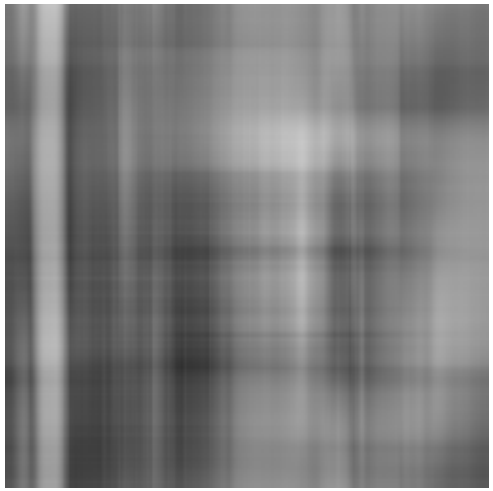


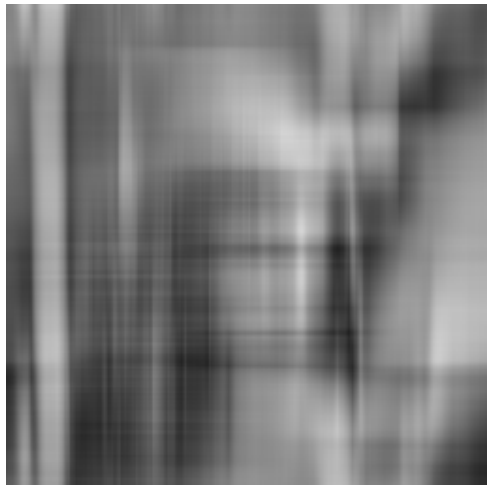
energia concentrata pe componentele de joasa frecventa

Compresia : se pastreaza doar frecventele joase, se anuleaza frecventele inalte (echivalentul unei filtrari de tip trece-jos). Imaginea se reconstruieste din spectru prin transformata inversa.

Factor de compresie mare : pastrez putine componente
Calitate buna a compresiei : pastrez multe componente

Fourier





Reconstructii din variantele comprimate prin pastrarea a:

2 / 256 4 / 256
14 / 256 22 / 256

componente spectrale.

Compresia cu transformate este legata de proprietatea de concentrare a energiei in valorile din domeniul transformat (si, suplimentar, de proprietatea de decorelare statistica a respectivelor valori).

Din aceste puncte de vedere, transformata Fourier nu este insa o transformata foarte buna.

Ideal ar trebui utilizata transformata Karhunen-Loeve, dar aceasta trebuei calculata pentru fiecare imagine in parte (deci este o transformare adaptiva si nu fixa).

Transformata fixa cea mai apropiata de tranformata KL in conditiile utilizarii pentru valori ale pixelilor din imagini este transformata COS discreta (folosita in compresia JPEG clasica).

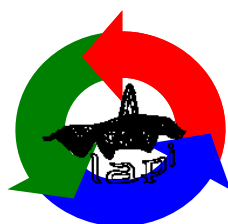
JPEG

Joint Photographic [Picture] Experts Group

varianta 1992 (JPEG “clasic”)
varianta 2000 (JPEG2000)

“Joint” = grup de experti provenind din mai multe organizatii de standardizare

ISO - International Standards Organization
IEC - International Electrotechnical Comission
ITU - International Telecommunications Union



Procesul de standardizare

JPEG clasic

ISO/ IEC 10928-1
ITU-T Recommendation T-81

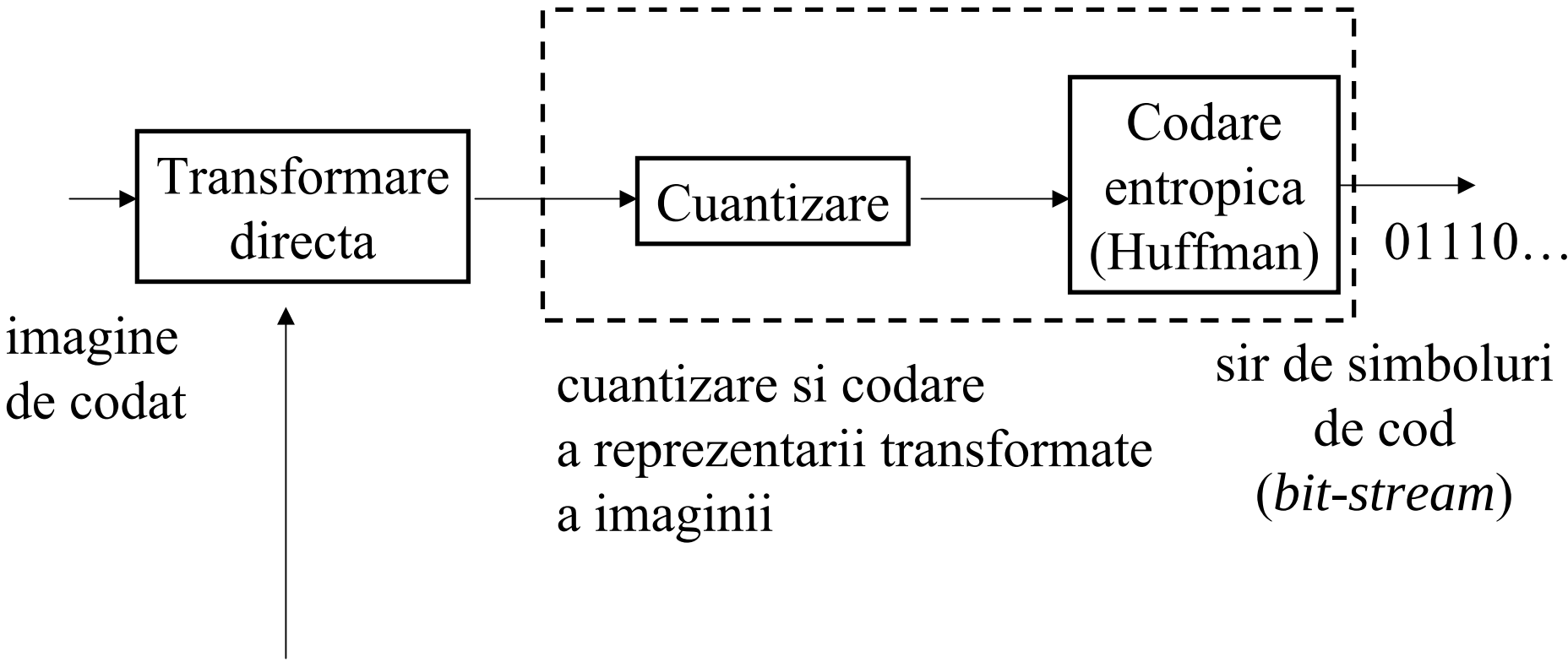
draft standard	1991
international standard	1992

JPEG 2000

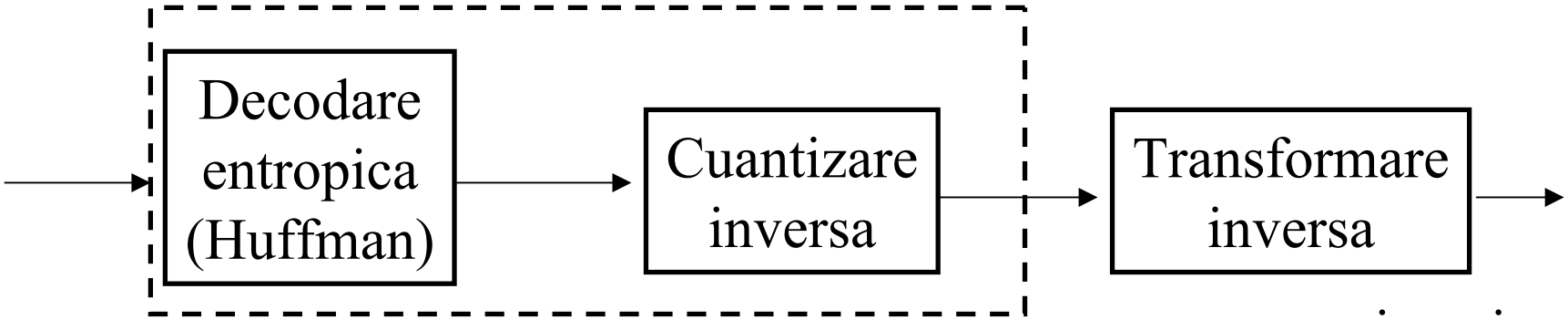
ISO/ IEC 15444-1
ITU-T Recommendation T-800

draft standard	2000
international standard	Dec. 2000 (partea 1)

Schema bloc de codare



Schema bloc de decodare



Fluxul de decodare este reflexia perfecta a fluxului de codare.

JPEG clasic

Transformarea directa :

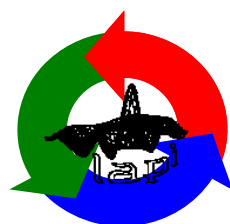
pre-procesare

procesare fundamentala (*core processing*) : DCT

Cuantizare

Codare entropica

Realizarea fluxului binar de cod



Transformarea directa

Pre-procesare (1) :

transformarea culorilor (RGB - YC_rC_b);

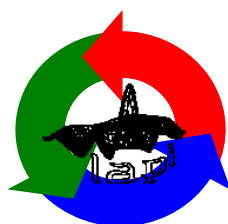
subesantionare crominante

$$\begin{pmatrix} Y \\ C_r \\ C_b \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.5 \\ 0.5 & -0.419 & -0.081 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

schimbarea nivelului de referinta (*DC level shifting*)

asigura trecerea de la o reprezentare cu intregi fara semn (uchar) pe P biti la o reprezentare cu semn in complement fata de 2, prin scaderea valorii centrale.

$$val' = val - 2^{P-1}$$

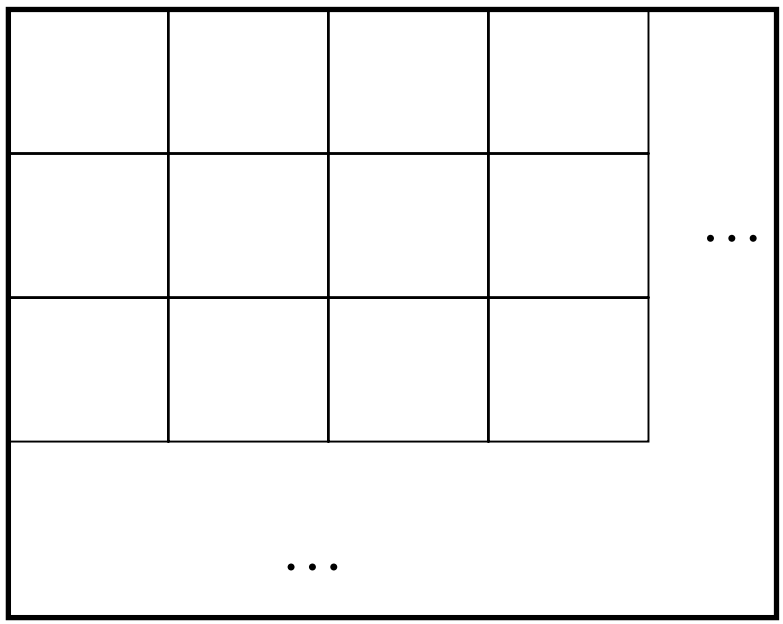


Transformarea directa

Pre-procesare (2) :

Decuparea suportului spatial al imaginii (*tiling*)

imaginea este impartita in blocuri ne-suprapuse de 8 x 8 pixeli.



Procesarea fundamentala

JPEG clasic

Transformarea cosinus discreta 2D (DCT) se aplica fiecarui bloc decupat din imagine

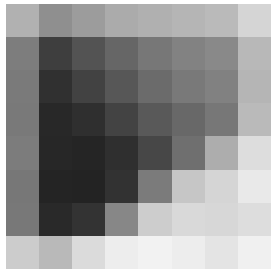
DCT 2D e o transformare separabila, se va aplica iterativ dupa fiecare dimensiune a setului de date (linii, coloane).

$$v(k)=\alpha(k)\frac{1}{N}\sum_{n=0}^{N-1}u(n)\cos\frac{(2n+1)\pi k}{2N},\ k=0,1,\ldots,N-1$$

$$\alpha(k)=\begin{cases}1, k=0\\ 2, k\neq 0\end{cases}$$

JPEG clasic

imagine originala
dimensiune 256 x 256,
256 nivele de gri

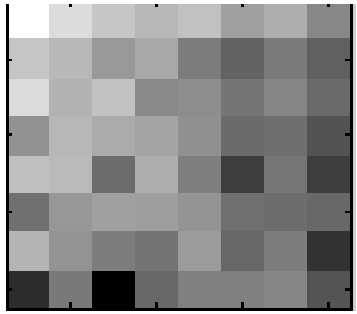


bloc 8 x 8 pixeli
(zoom)

DCT

177	143	156	171	176	181	186	213
125	62	83	102	119	130	137	184
122	48	66	87	107	121	129	181
121	40	47	67	89	104	119	186
124	39	37	47	71	111	173	221
119	36	35	50	123	198	213	233
120	41	51	135	205	217	215	221
204	185	219	237	242	237	228	240

JPEG clasic



spectrul COS al blocului din imagine (reprezentare prin cuantizare cu 256 nivele, uniform sau logaritmic)

1000 x

1.1007	-0.2843	0.1247	0.0725	0.1040	0.0285	0.0515	0.0116
-0.1222	0.0732	0.0227	-0.0406	0.0078	-0.0030	0.0074	-0.0027
0.2800	0.0600	-0.1086	-0.0129	-0.0147	-0.0059	-0.0109	-0.0039
-0.0179	-0.0727	0.0449	0.0346	-0.0167	0.0040	-0.0047	0.0016
0.0970	0.0773	0.0042	-0.0494	-0.0088	0.0007	-0.0061	-0.0007
-0.0050	-0.0215	-0.0303	0.0273	0.0189	-0.0050	-0.0044	-0.0036
0.0626	0.0183	0.0081	-0.0056	-0.0250	-0.0036	0.0081	-0.0005
-0.0004	-0.0069	0.0001	-0.0036	0.0090	0.0088	-0.0111	0.0017

JPEG clasic

Energia este concentrata in cativa coeficienti COS, grupati la “frecvente joase”

Compresia provine din folosirea unei reprezentari grosiere a coeficientilor de pondere mica ce corespund “frecventelor inalte” si a unei reprezentari mai precise pentru coeficientii de valoare semnificativa de la “frecvente joase”.

Coeficientii sunt separati in doua clase:

- coeficientul nivelului continuu (DC-level)
- coeficientii frecventelor ne-nule din imagine

Reprezentarea este data de cuantizarea coeficientilor.

Cuantizarea

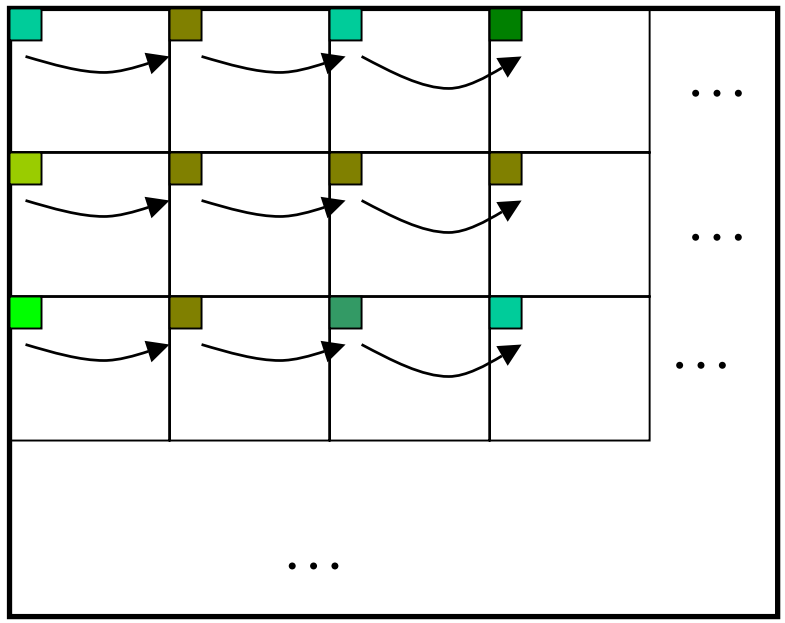
JPEG clasic

1. Codarea coeficientului nivelului continuu (DC)

codare DPCM pentru toti coeficientii DC ai blocurilor din imagine

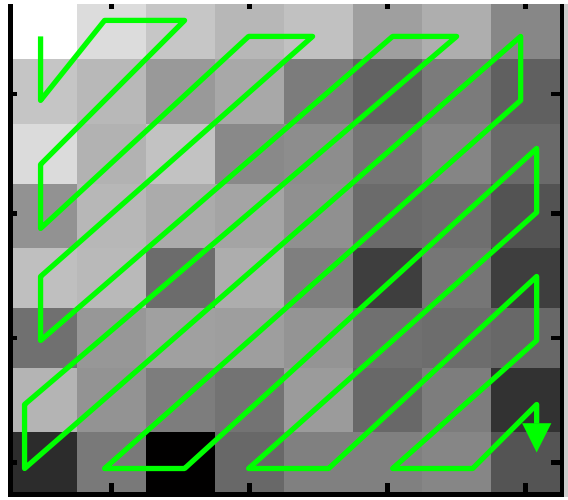
DPCM = Differential Pulse Code Modulation

se cuantizeaza diferentele dintre coeficientii DC ai blocurilor succesive din imagine

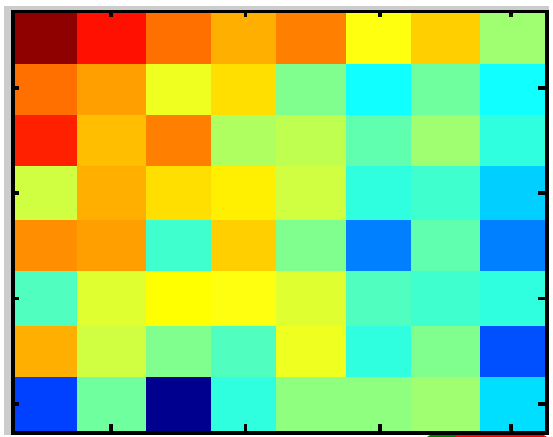


Cuantizarea

2. Codarea coeficientilor frecventelor nenule



parcurgerea spatiului de frecventa dupa un baleiaj in zig-zag, astfel incat coeficientii cei mai semnificativi se afla la inceputul secventei 1D astfel obtinute

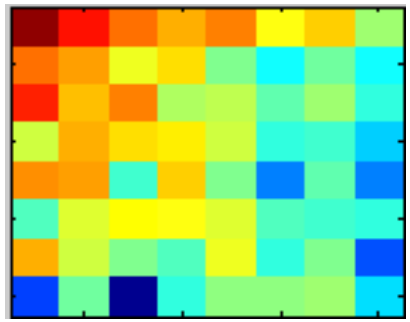


cuantizarea coeficientilor se realizeaza cu cuante crescatoare (deci o cuantizarea mai fina a coeficientilor mai semnificativi);

cuantele sunt scalate dupa un factor de "calitate a compresiei" stabilit de utilizator

JPEG clasic

Tabela de ponderi de cuantizare, luminanta:



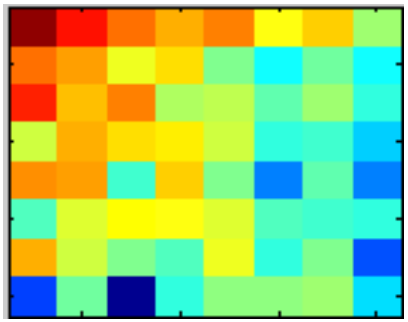
$Q \in [0,100]$

Q=1 - compresie minima, calitate maxima
Q=100 - maximum de compresie, calitate minima (cuantizarea cea mai grosiera)

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

JPEG clasic

Tabela de ponderi de cuantizare, crominante :



$Q \in [0,100]$

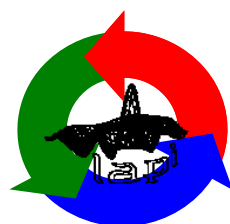
17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

Q=1 - compresie minima, calitate maxima
Q=100 - maximum de compresie, calitate minima (cuantizarea cea mai grosiera)

Codarea entropica

Algoritmul de codare Huffman este aplicat pe sirul de valori cuantizate ale coeficientilor COS ale blocurilor din intreaga imagine.

Rezulta un sir de cuvinte de cod (cu care se inlocuiesc valorile cuantizate ale coeficientilor COS) si un dictionar de codare ce memoreaza asocierea dintre cuvintele de cod si valorile cuantizate originale.



Fluxul JPEG

JPEG clasic

Imagine = parametri ce definesc particularitatile codarii

una (ne-ierarhic) sau mai multe (ierarhic) "*frame*"-uri

Frame = cate un "*scan*" pentru fiecare componenta a imaginii
(1 *scan* pentru imagini cu nivele de gri,
3 *scans* pentru imagini color)

Scan = una sau mai multe intervale de "*restart*" de lungime fixata, codate si respectiv decodate independent.

Fluxul JPEG

JPEG clasic

SOI (Start Of Image)

DQT (Define Quantization Table): length, values

DRI (Define Restart Interval): length, value

SOF (Start of Frame): length, frame params

DHT (Define Huffman Table): length, values

SOS (Start of Scan) : length, params

compressed data for restart interval RST_0

compressed data for restart interval RST_m

compressed data for final restart interval

DHT (Define Huffman Table): length, values

SOS (Start of Scan) : length, params

…

SOF (Start of Frame): length, frame params

…

EOI (End of Image)

Factor de calitate 4
(compresie minima - 5,
calitate maxima)

Factor de calitate 94
(compresie maxima - 50,
calitate minima)

JPEG clasic

compresia JPEG, Q=85

imagine originala

JPEG clasic

imagine originala

JPEG clasic

imagine originala

JPEG clasic

Principalele deficiente :

frontierele blocurilor decupate din imagine sunt vizibile (efect de "*blocking*")

variatia tonurilor de culoare pe zonele mari cu variatie lenta a culorii

nu ofera scalabilitate si nici multi-rezolutie

nu permite definirea de regiuni de interes

JPEG 2000

Transformarea directa :

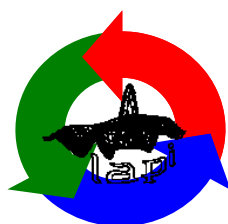
pre-procesare

procesare fundamentala (*core processing*) : ***wavelet***

Cuantizare

Codare entropica

Realizarea fluxului binar de cod



Transformarea directa

Pre-procesare (1) :

modificarea nivelului continuu (*DC level shifting*)

asigura trecerea de la o reprezentare cu intregi fara semn (uchar) pe *P* biti la o reprezentare cu semn in complement fata de 2, prin scaderea valorii centrale.

$$val' = val - 2^{P-1}$$

Transformarea directa

Pre-procesare (2) :

transformarea culorilor

(RGB - YC_rC_b)

$$\begin{pmatrix} Y \\ C_r \\ C_b \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.5 \\ 0.5 & -0.419 & -0.081 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

sau

(RGB - YCC reversibil)

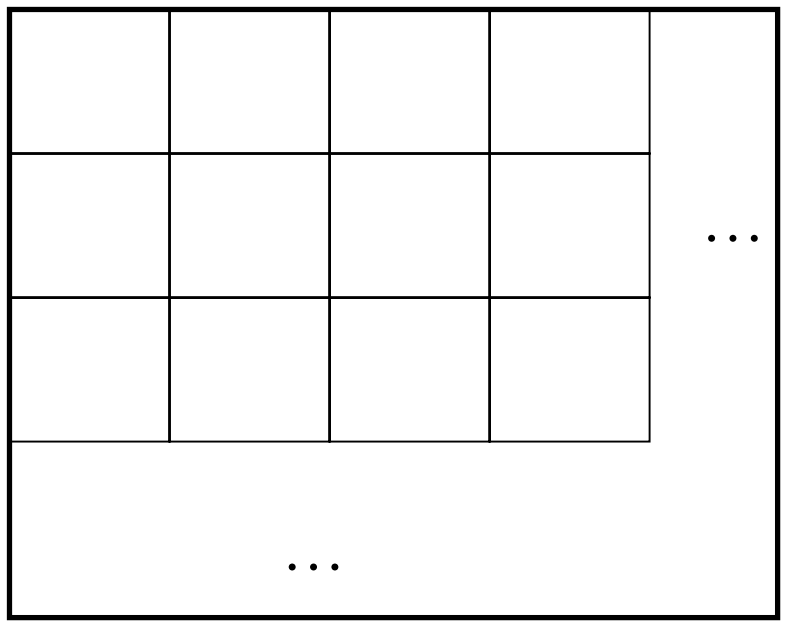
$$\begin{pmatrix} Y_{rev} \\ C_{rrev} \\ C_{brev} \end{pmatrix} = \begin{pmatrix} 0.25 & 0.5 & 0.25 \\ 1 & -1 & 0 \\ 0 & -1 & 1 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Transformarea directa

JPEG 2000

Pre-procesare (3) :

decuparea suportului spatial al imaginii (*tiling*)



Procesarea fundamentala

Transformarea wavelet discreta 2D (DWT) se aplica fiecarui bloc decupat din imagine

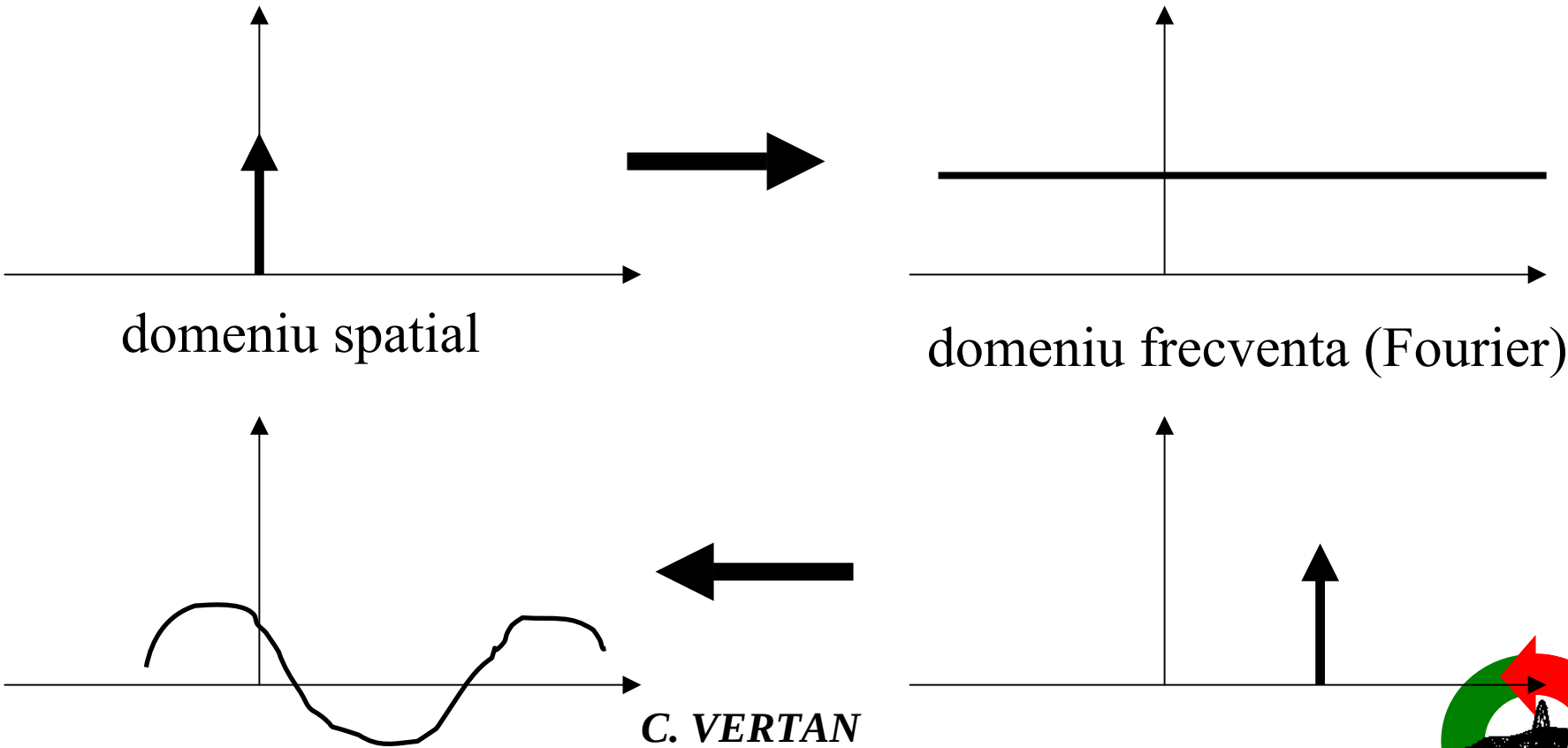
DWT 2D e o transformare separabila, se va aplica iterativ dupa fiecare dimensiune a setului de date (linii, coloane).

Ce este transformarea wavelet ?

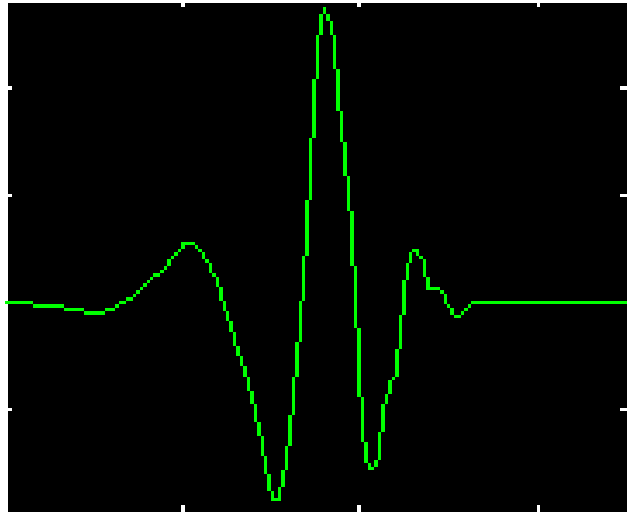
Transformata wavelet

Alte functii de baza decat exponentiale complexe (Fourier) sau cosinus (COS) care sa ofera proprietati de localizare mai buna.

Localizare ?



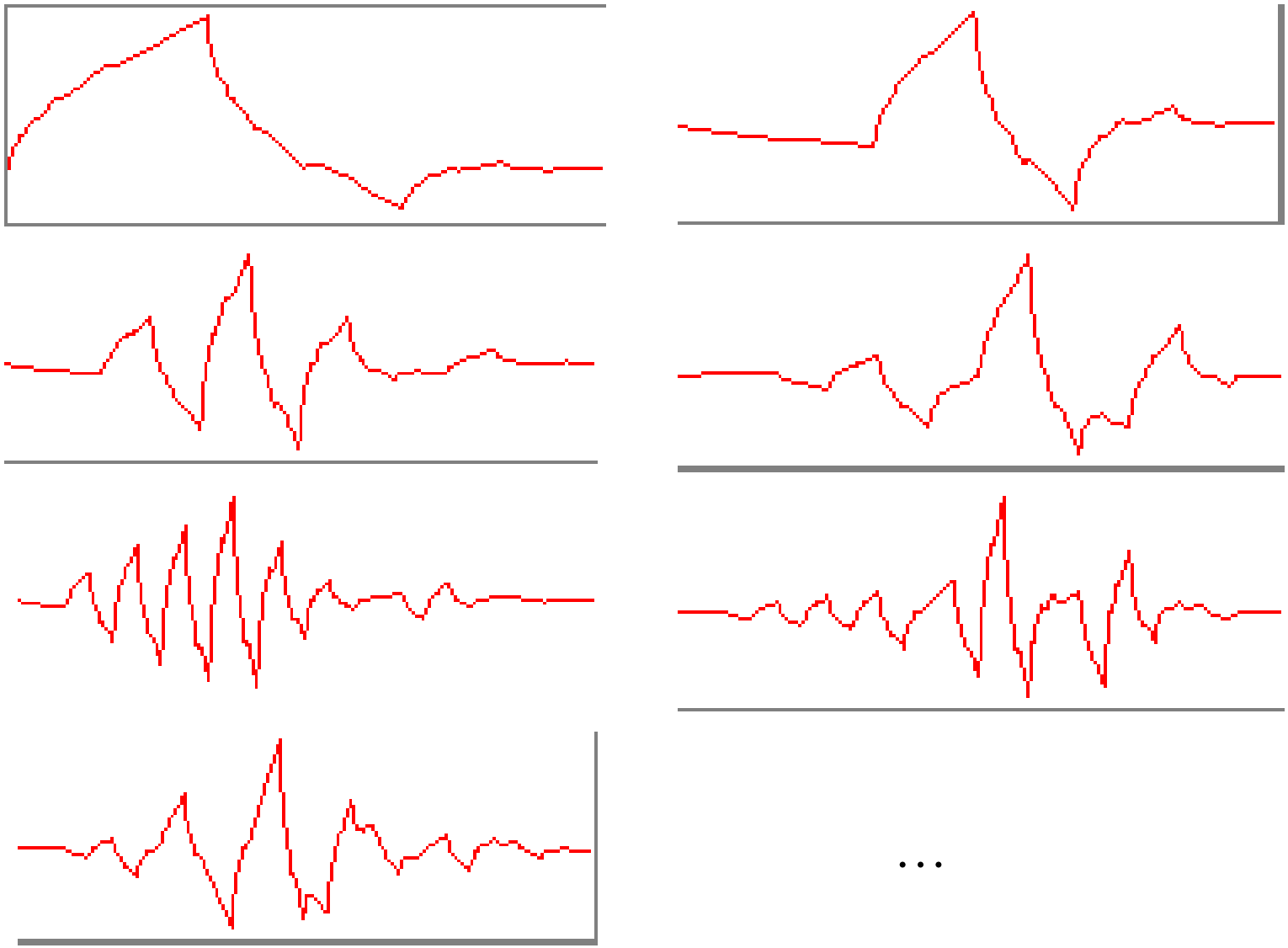
Exemplu de functie wavelet de baza :



Din particularizarea ecuatiei de baza de generare a bazelor wavelet se pot obtine mai multe familii (Haar, Daubechies, …)

Wavelet Daubechies

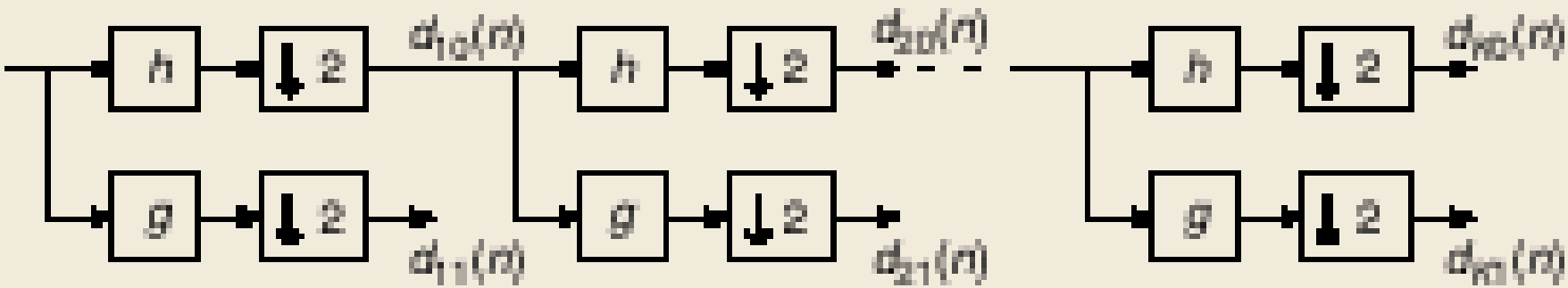
JPEG 2000



...

Descompunerea wavelet

Poate fi vazuta ca filtrarea cu un banc de filtre TJ (h) si TS (g) in cuadratura.



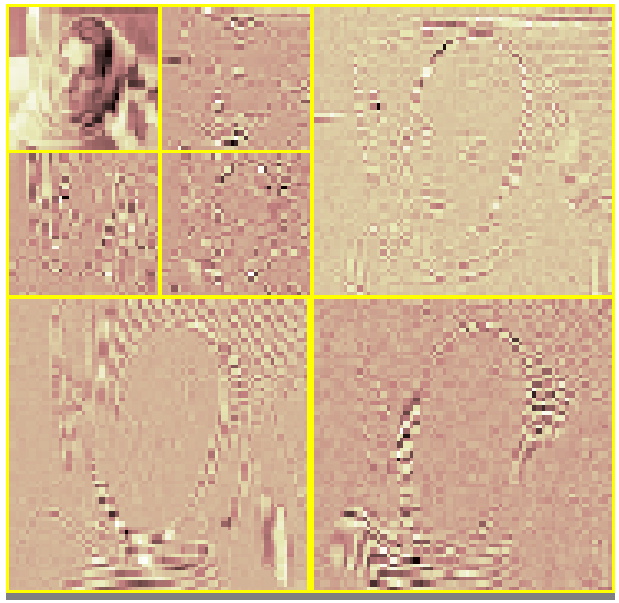
JPEG 2000

Descompunere la 1 scala de rezolutie

LL_1	HL_1
LH_1	HH_1

JPEG 2000

Descompunere la 2 scale de rezolutie



LL_2	HL_2	HL_1
LH_2	HH_2	
LH_1		HH_1

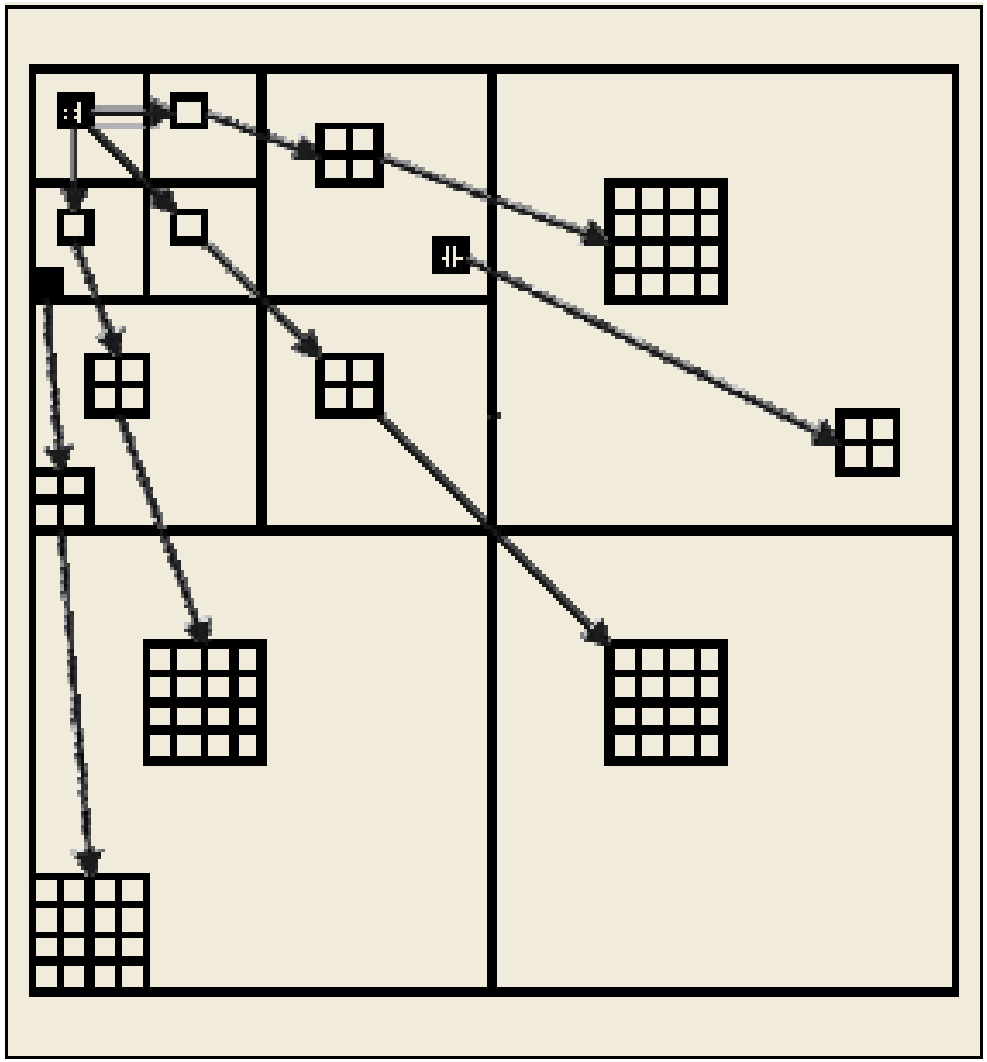
JPEG 2000

Compresia : anularea coeficientilor de valoare mica din benzile de detalii (HL, LH, HH) la diferite nivele de rezolutie si pastrarea coeficientilor din banda de “joasa frecventa”.

Spre deosebire de transformatele Fourier sau COS conteaza intreaga ierarhie de valori (deci nu pot anula coeficientii de la o anumiat scala fara a lua in considerare influenta lor asupra scalelor de rezolutie superioara).

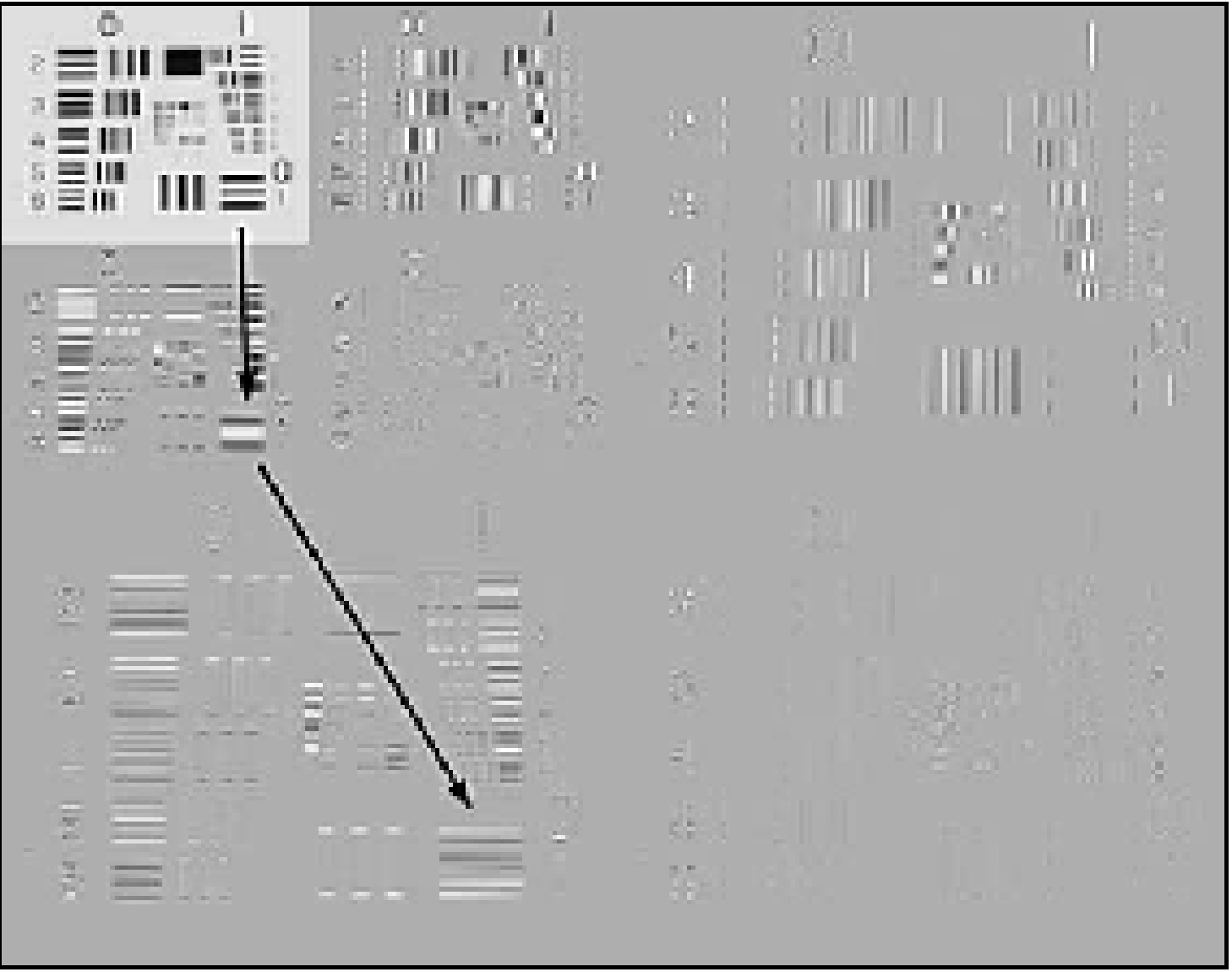
Algoritmul de codare este EZW

(*Embedded Zero-Tree Wavelet Coding*)

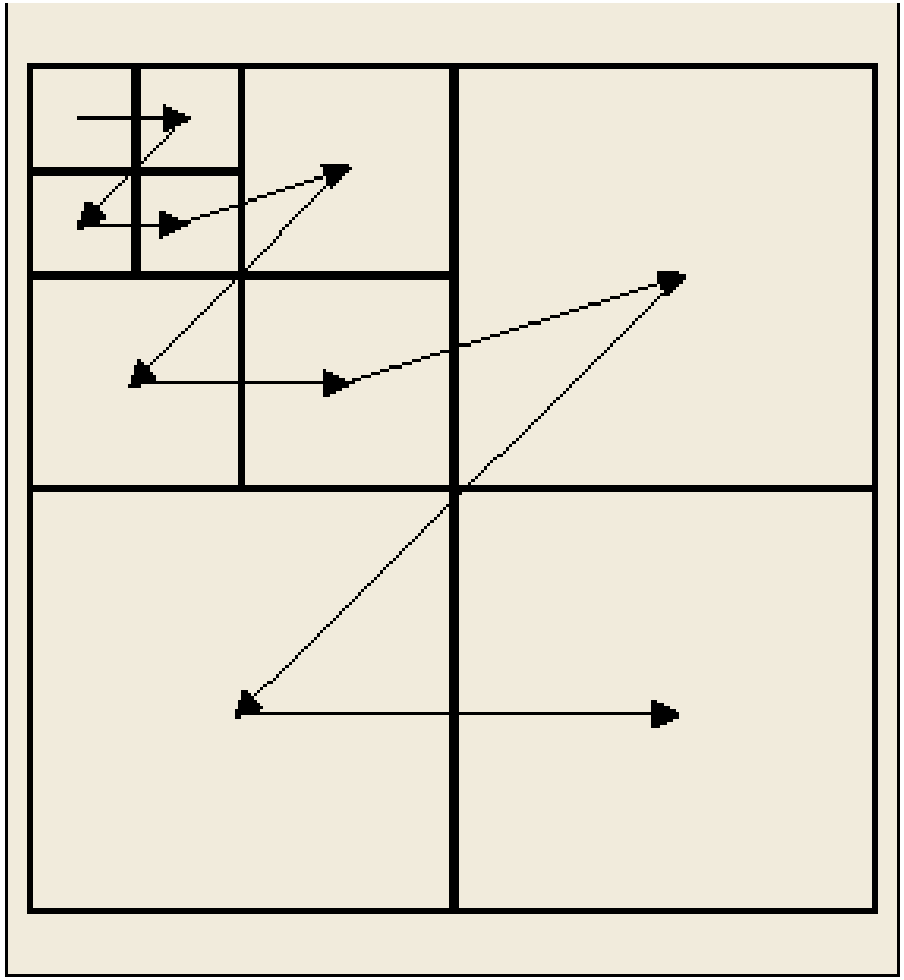


Arbore de influenta a coeficientilor wavelet

JPEG 2000



coeficientii dominanti apar in aceleasi pozitii spatiale in fiecare sub-banda de detalii cu orientare fixata



cautarea structurii arborescente de coeficienti wavelet ce se pot anula urmareste o ordine de scanare in zig-zag (astfel incat orice coeficient este scanat **inaintea** descendentilor sai).

coeficientii sunt declarati nesemnificativi daca au valoarea mai mica decat un prag (dependent de nivelul de rezolutie)

JPEG 2000

pentru codare cu pierderi :

transformare wavelet cu functii Daubechies 9/ 7

Analysis Filter Coefficients		
i	Low-Pass Filter $h_L(i)$	High-Pass Filter $h_H(i)$
0	0.6029490182363579	1.115087052456994
±1	0.2668641184428723	–0.5912717631142470
±2	–0.07822326652898785	–0.05754352622849957
±3	–0.01686411844287495	0.09127176311424948
±4	0.02674875741080976	

Synthesis Filter Coefficients		
i	Low-Pass Filter $g_L(i)$	High-Pass Filter $g_H(i)$
0	1.115087052456994	0.6029490182363579
±1	0.5912717631142470	–0.2668641184428723
±2	–0.05754352622849957	–0.07822326652898785
±3	–0.09127176311424948	0.01686411844287495
±4		0.02674875741080976

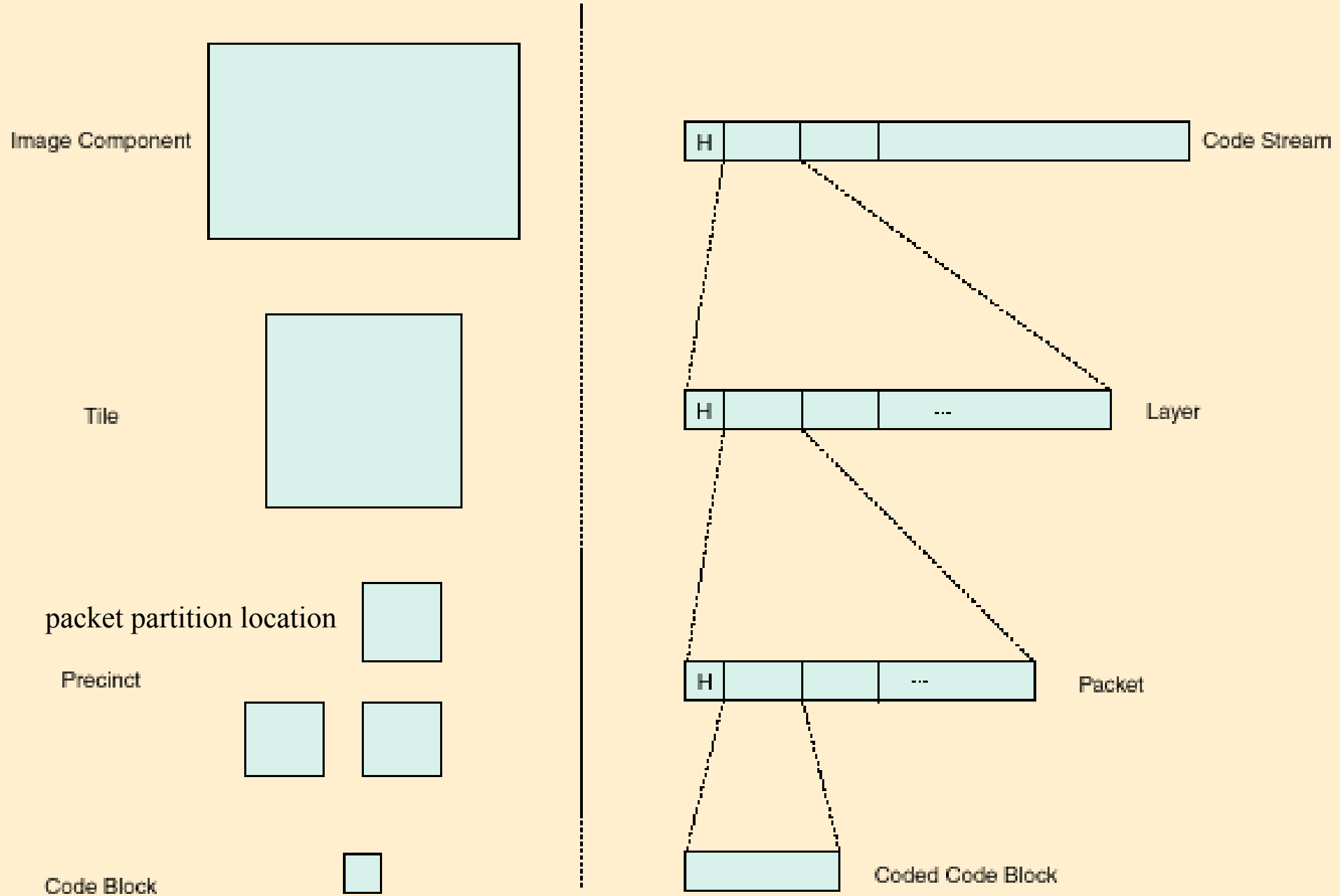
JPEG 2000

Table 4. Le Gall 5/3 Analysis and Synthesis Filter Coefficients.				
	Analysis Filter Coefficients		Synthesis Filter Coefficients	
i	Low-Pass Filter $h_L(i)$	High-Pass Filter $h_H(i)$	Low-Pass Filter $g_L(i)$	High-Pass Filter $g_H(i)$
0	6/8	1	1	6/8
±1	2/8	–1/2	1/2	–2/8
±2	–1/8			–1/8

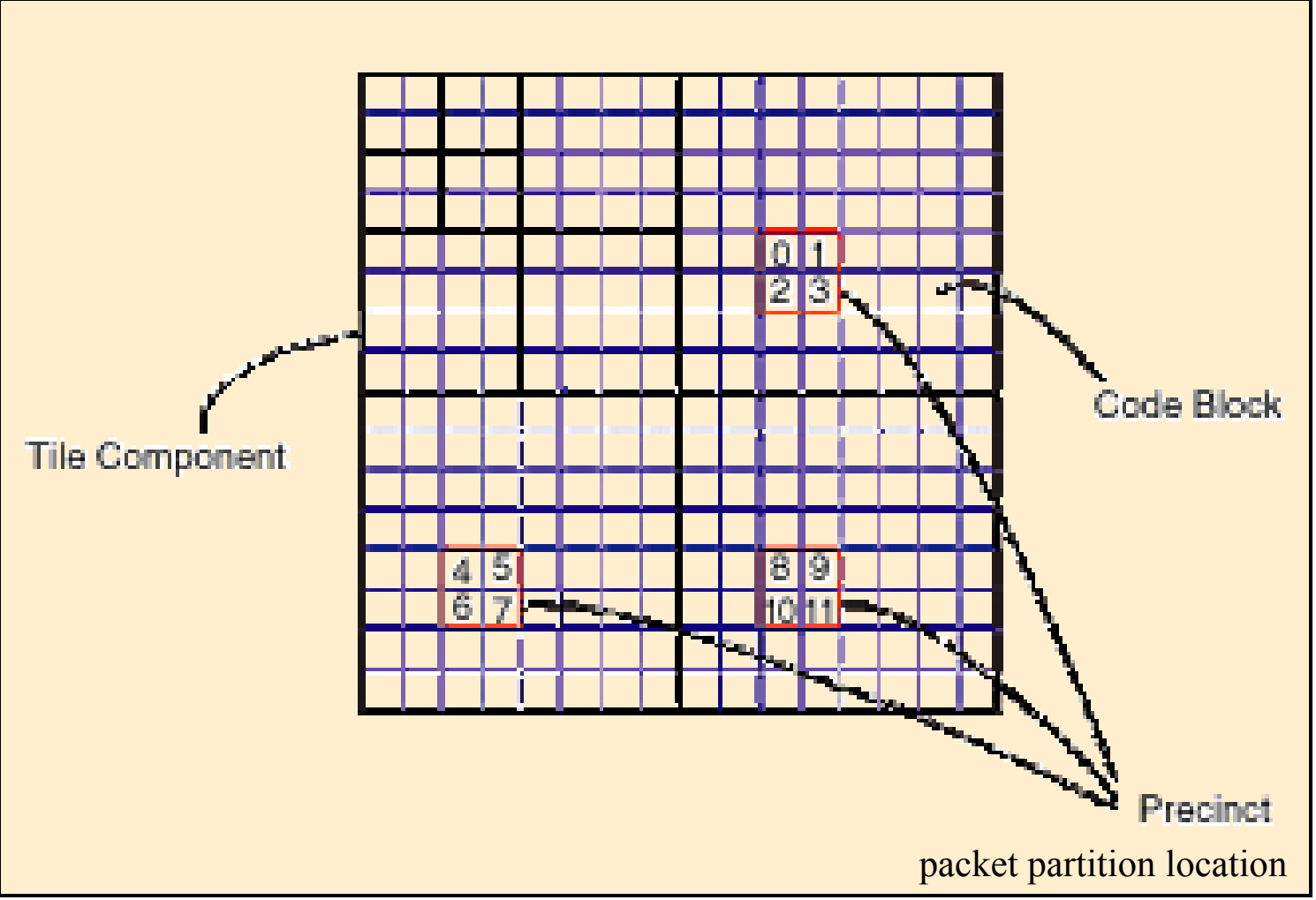
pentru codare fara pierderi :

transformare wavelet cu functii LeGall 5/ 3

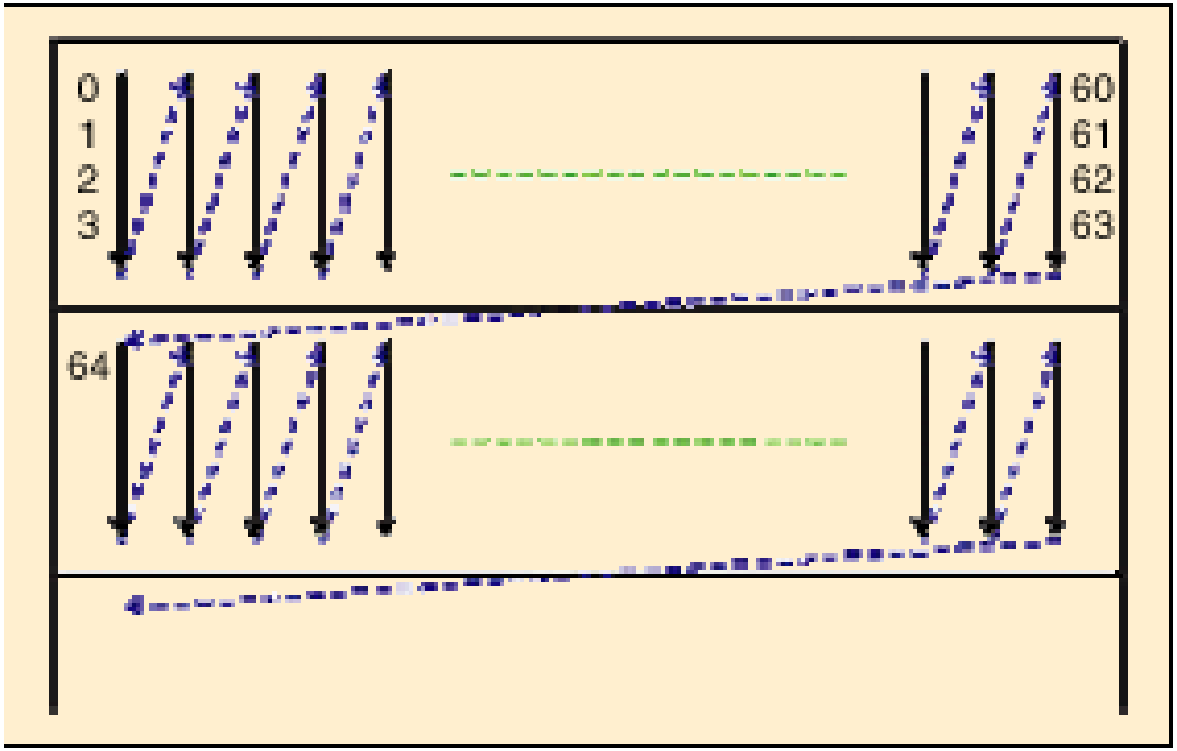
Fluxul JPEG 2000



JPEG 2000



Unitatea de baza a fluxului de biti este blocul de cod (64 x 64, 32 x 32)



Valorile din fiecare bloc de codare, dupa codarea entropica, sunt scanate dupa o ordine pe coloane (pe blocuri de 64 de valori) si codate pe plane de bit.

(a)

(b)

(c)

original JPEG JPEG 2000

Comparatia calitatii compresiei JPEG clasic/ 2000 :

rata de compresie 0.2 bpp

factor de compresie 40

(a)

(b)

JPEG

JPEG 2000

Comparatia calitatii compresiei JPEG clasic/ 2000 :

rata de compresie 0.25 bpp

factor de compresie 96

original

Imposed compression ration of 1:158

JPEG2000

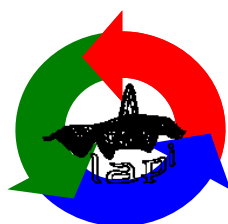
JPEG

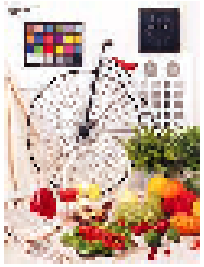
Elemente remarcabile ale standardului JPEG 2000 (1)

Transmisie progresiva bazata pe precizia pixelului si rezolutie (navigare web, arhive de imagini, …)

scalabilitate spatiala

scalabilitatea calitatii imaginii





scalabilitate spatiala :

decodare la rezolutii progresive.

C. VERTAN



scalabilitatea calitatii imaginii

reconstructii progresive la 0.125 bpp, 0.25 bpp, 0.5 bpp

Elemente remarcabile ale standardului JPEG 2000 (2)

Rezistenta la erorile de bit

Table 5. Tools for Error Resilience.	
Type of Tool	Name
Entropy coding level	—code blocks —termination of the arithmetic coder for each pass —reset of contexts after each coding pass —selective arithmetic coding bypass —segmentation symbols
Packet level	—short packet format —packet with resynchronization marker

Elemente remarcabile ale standardului JPEG 2000 (3)

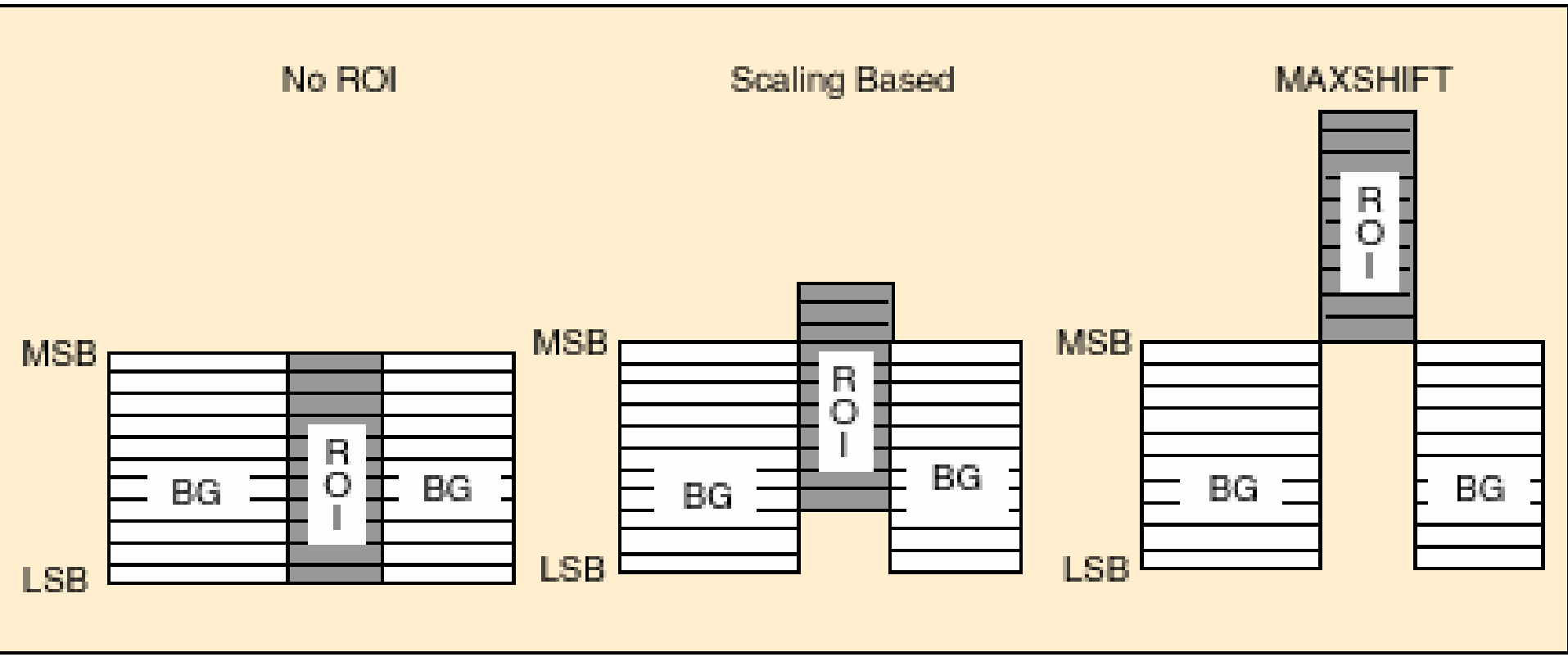
Codare la nivelul unei regiuni de interes (*ROI coding*)

Regiunea de interes (ROI) poate fi specificata de utilizator pentru fortarea unei codari mai precise in anumite zone ale imaginii.

Identificarea si codarea valorilor din ROI se bazeaza pe principiul general de codare prin scalarea valorilor : valorile ce corespund punctelor din ROI sunt scalate (reprezentarea binara este translatata) astfel ca bitii reprezentarii sa fie cuprinsi in plane de bit de ordin superior fata de planele de bit utilizate uzual pentru restul valorilor din imagine.

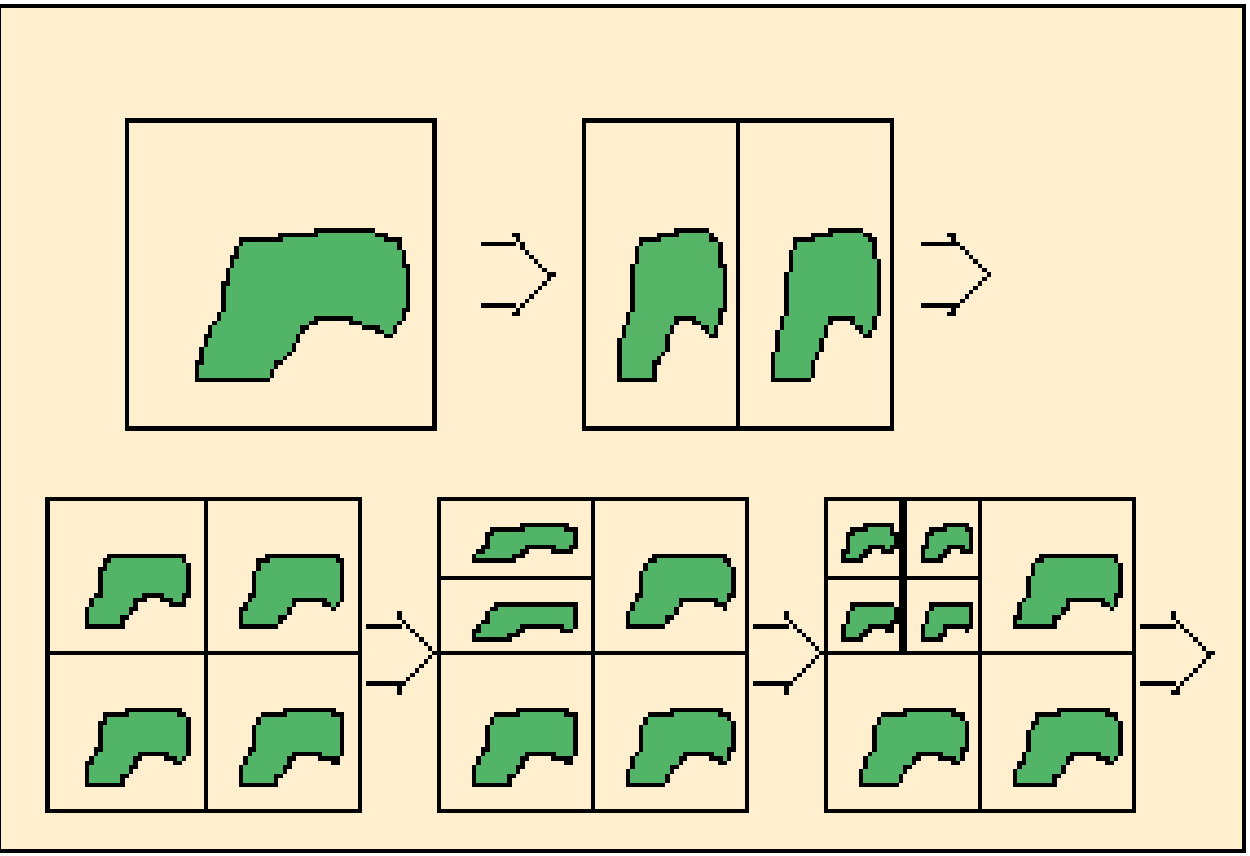
ROI coding

JPEG 2000



Varianta particulara de codare prin scalare utilizata : MAXSHIFT

ROI coding



Generarea mastii de definire a regiunii de interes (ROI) pentru diferitele domenii ale descompunerii wavelet.

Elemente remarcabile ale standardului JPEG 2000 (4)

Includerea de elemente de protectie a proprietatii

Arhitectura deschisa :

decodorul necesita doar prelucrarea standard de baza si parserul sirului de simboluri de cod - posibilitatea de adaptare a standardului pentru diferite aplicatii

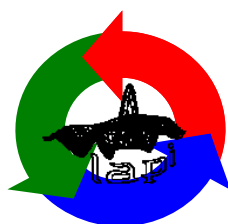


Table 6. Software Implementations.

Standard	Name of the Software	Source Code	Software Developers	Available at
JPEG 2000	Verification Model 8.6	C		http://www.jpeg.org (*)
JPEG 2000	JasPer	C	Image Power Univ. of British Columbia	http://www.ece.ubc.ca/mdadams/jasper http://spmg.ece.ubc.ca http://www.imagepower.com
JPEG 2000	JJ2000	JAVA	Cannon Research EPFL Ericsson	http://jj2000.epfl.ch
JPEG		C	Independent JPEG Group	http://www.ijg.org
JPEG-LS	SPMG	C	Univ. of British Columbia	http://spmg.ece.ubc.ca
Lossless JPEG		C	Cornell University	ftp://ftp.cs.cornell.edu/pub/multimed
PNG	PNG	C		ftp://ftp.uu.net/graphics.png

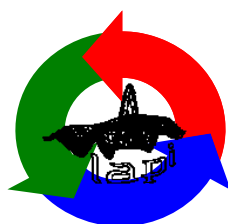
(*) Available to members only

Table 9. Functionality Evaluation Results.

	JPEG 2000	JPEG-LS	JPEG	MPEG-4 VTC
Lossless compression performance	•••	••••	•	
Lossy compression performance	•••••	•	•••	••••
Progressive bitstreams	••••		•	••
Region of Interest (ROI) coding	•••			•
Arbitrary shaped objects				••
Random access	••			
Low complexity	••	•••••	•••••	•
Error resilience	•••	•	•	•••
noniterative rate control	•••			•
Genericity	•••	•••	••	••

Table 10. Schedule of JPEG 2000 Parts.

Part	Title	Call for Papers	Working Draft	Committee Draft	Final Committee Draft	Final Draft International Standard	Internarional Standard
I	JPEG 2000 Image Coding System: Core Coding System	97/03	99/03	99/12	00/03	00/10	00/12
II	JPEG 2000 Image Coding System: Extensions	97/03	00/03	00/08	00/12	01/07	01/10
III	Motion JPEG 2000	99/12	00/07	00/12	01/03	01/07	01/10
IV	Conformance Testing	99/12	00/07	00/12	01/03	01/11	02/03
V	Reference Software	99/12	00/03	00/07	00/12	01/08	01/11
VI	Compound Image File Format	97/03	00/12	01/03	01/11	02/03	02/05



Inca in dezvoltare :

JPEG 3D

codare perceptuala si codare color

elemente de securitate (watermarking)

conformitate MPEG-7