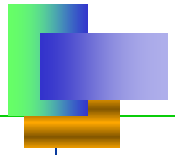

Wavelet Image Compression - JPEG2000

Progressive Coding /Embedded

Progressive image compression
EZW and SPIHT

IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 41, NO. 12, DECEMBER 1993 3445

Embedded Image Coding Using Zerotrees of Wavelet Coefficients

Jerome M. Shapiro

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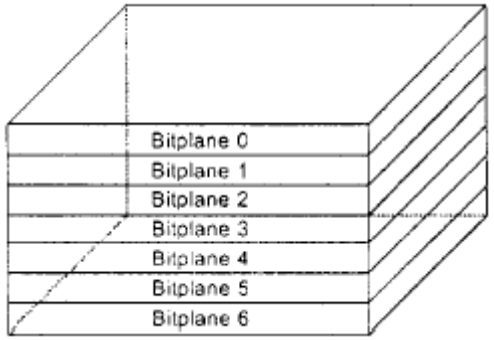
IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, VOL. 6, NO. 3, JUNE 1996 243

A New, Fast, and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees

Amir Said, *Member, IEEE,* and William A. Pearlman, *Senior Member, IEEE*

Bit-plane coding

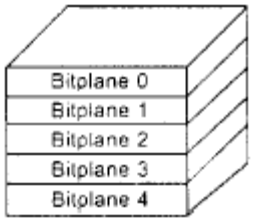
$$
\begin{aligned}
&1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,\ldots 0,0 \quad \text{(MSB)}\\
&0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,\ldots 0,0 \quad \text{(MSB-1)}\\
&1,0,1,0,0,1,0,1,1,0,0,1,0,0,0,0,\ldots 0,0 \quad \text{(MSB-2)}\\
&0,0,0,0,0,1,0,0,0,0,0,0,0,0,1,0,\ldots 0,0 \quad \text{(MSB-3).}
\end{aligned}
$$

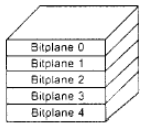


BIT ROW

	sign	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
msb	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	→		1	1	0	0	0	0	0	0	0	0	0	0	0
	3	→	→			1	1	1	1	0	0	0	0	0	0	0
	2	→	→	→	→	→	→	→		1	1	1	1	1	1	1
	1	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
lsb	0	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→

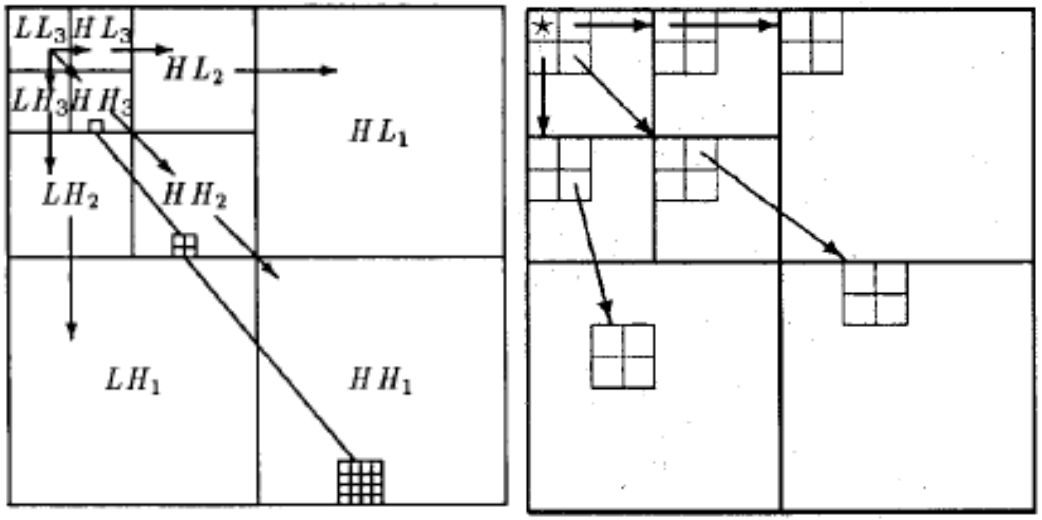
Binary representation of the magnitude-ordered coefficients.





Relationship to scalar quantization

Cross-Subband Dependency



Parent-children dependency across subband

EZW Coding

To perform the embedded coding, successive-approximation quantization (SAQ) is applied. As will be seen, SAQ is related to bit-plane encoding of the magnitudes. The SAQ sequentially applies a sequence of thresholds $T_0, \cdots, T_{N-1}$ to determine significance, where the thresholds are chosen so that $T_i = T_{i-1}/2$. The initial threshold T_0 is chosen so that $|X_j| < 2T_0$ for all transform coefficients x_j.

Two-pass:

Dominant Pass: find significant coefficients

subordinate pass: refine the quantization of significant coefficients

repeat

EZW EXample

63	−34	49	10	7	13	−12	7
−31	23	14	−13	3	4	6	−1
15	14	3	−12	5	−7	3	9
−9	−7	−14	8	4	−2	3	2
−5	9	−1	47	4	6	−2	2
3	0	−3	2	3	−2	0	4
2	−3	6	−4	3	6	3	6
5	11	5	6	0	3	−4	4

Comment	Subband	Coefficient Value	Symbol	Reconstruction Value
(1)	LL3	63	POS	48
	HL3	-34	NEG	-48
(2)	LH3	-31	IZ	0
(3)	HH3	23	ZTR	0
	HL2	49	POS	48
(4)	HL2	10	ZTR	0
	HL2	14	ZTR	0
	HL2	-13	ZTR	0
	LH2	15	ZTR	0
(5)	LH2	14	IZ	0
	LH2	-9	ZTR	0
	LH2	-7	ZTR	0
(6)	HL1	7	Z	0
	HL1	13	Z	0
	HL1	3	Z	0
	HL1	4	Z	0
	LH1	-1	Z	0
(7)	LH1	47	POS	48
	LH1	-3	Z	0
	LH1	-2	Z	0

JPEG2000 History

Timeline

- Feb 96 (Geneva) started with original proposal
- Nov 96 (Palo Alto) test method agreed
- Mar 97 (Dijon) call for proposals
- Jul 97 (Sapporo) requirements analysis started
- Nov 97 (Sydney) algorithm competition & selection
- VM 1 (Mar 98), VM 2 (Aug 98), split to VM 3A and 3B Nov 98. Converged to VM4 and WD in Mar 99
- Promotion to CD, FCD, FDIS as well as creation of different parts

Applications

JPEG2000 Markets and Applications

- Internet
- Mobile
- Printing
- Scanning
- Digital Photography
- Remote Sensing
- Facsimile
- Medical
- Digital Libraries
- E-Commerce

New Features - Spatial Scalability

- The bit stream can be decompressed at different resolution level

New Features - SNR Scalability

- The bit stream can be decompressed at different quality levels (SNR)

Decompressed image “bike” at (a) 0.125 b/p, (b) 0.25 b/p, (c) 0.5 b/p

Progressive coding

New Features - Region of Interest Coding

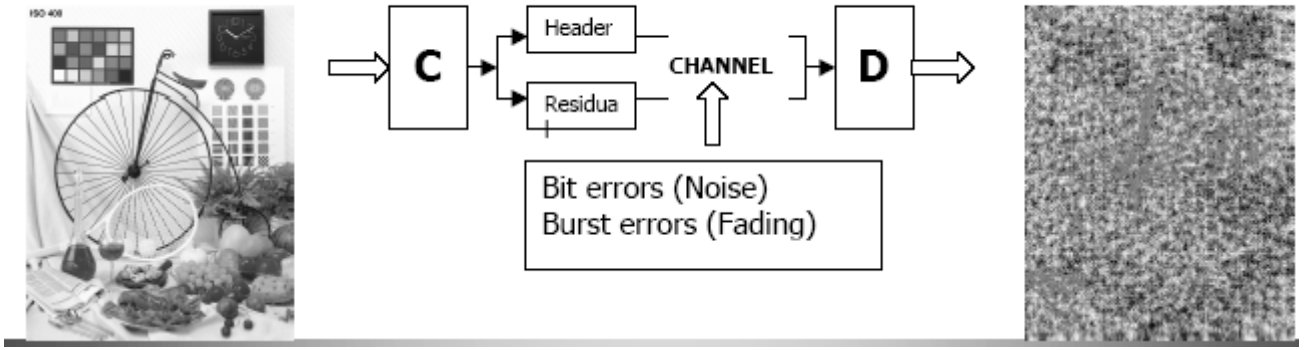
Allows certain parts of an image to be coded or decoded in better quality

69:1 overall compression ratio

New Features - Region of Interest Coding

New Features - Error Resilience

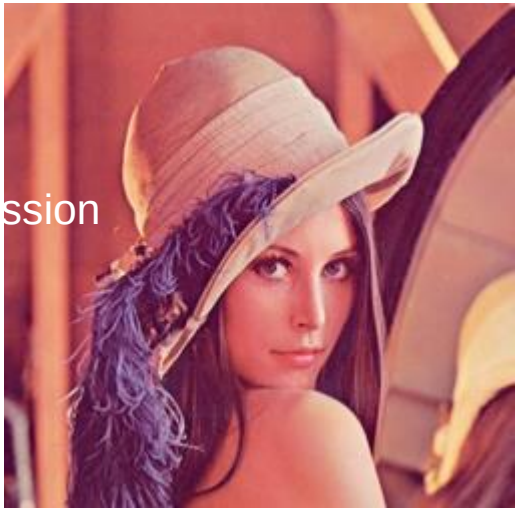
- Most still image coders use Entropy Coding
- Variable Length Coding is known to be prone to channel or transmission errors
- Loss of synchronization



Comparison With JPEG

JPEG2000: the new international standard for image compression, is much more efficient than the old JPEG international standard.
For the same compression ratio / bit rate / file size, the JPEG2000 picture has much better quality.

Original Picture



JPEG

JPEG2000

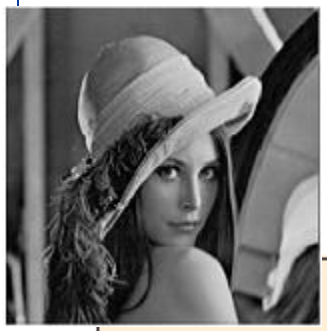
Strong blockiness

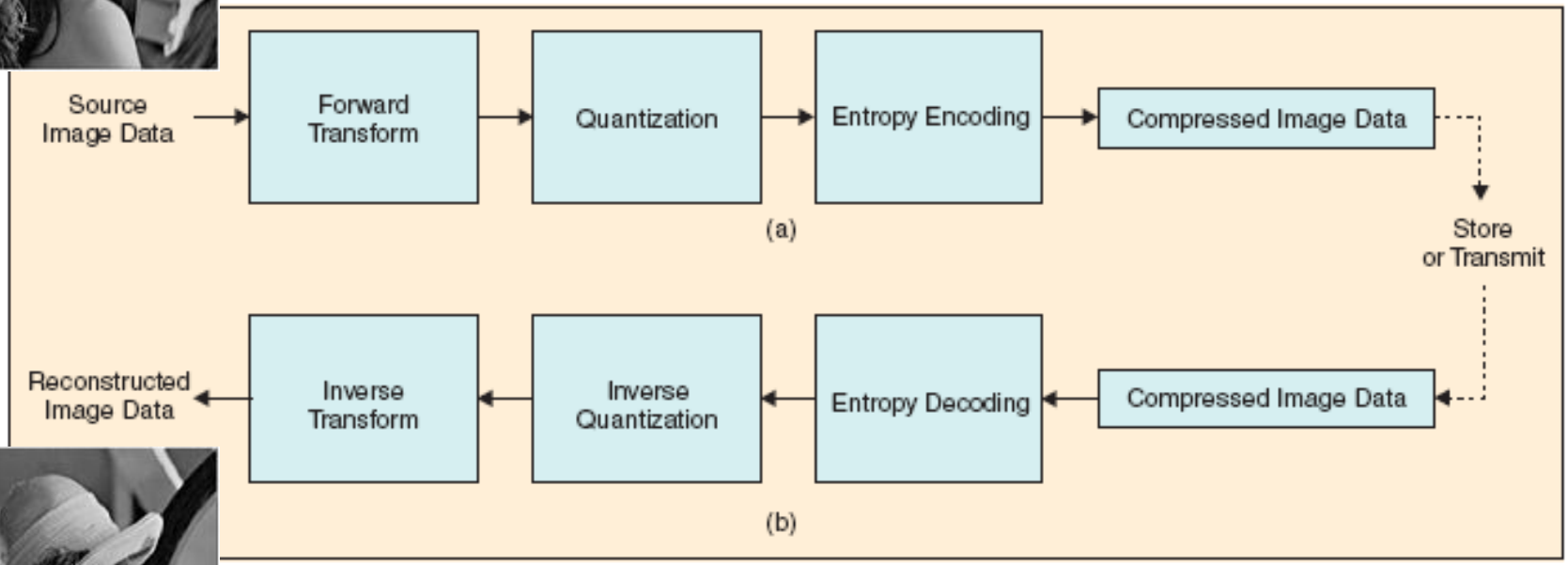
Comparison With JPEG

JPEG at 0.125 bpp

JPEG2000 at 0.125 bpp

JPEG2000 Block Diagram

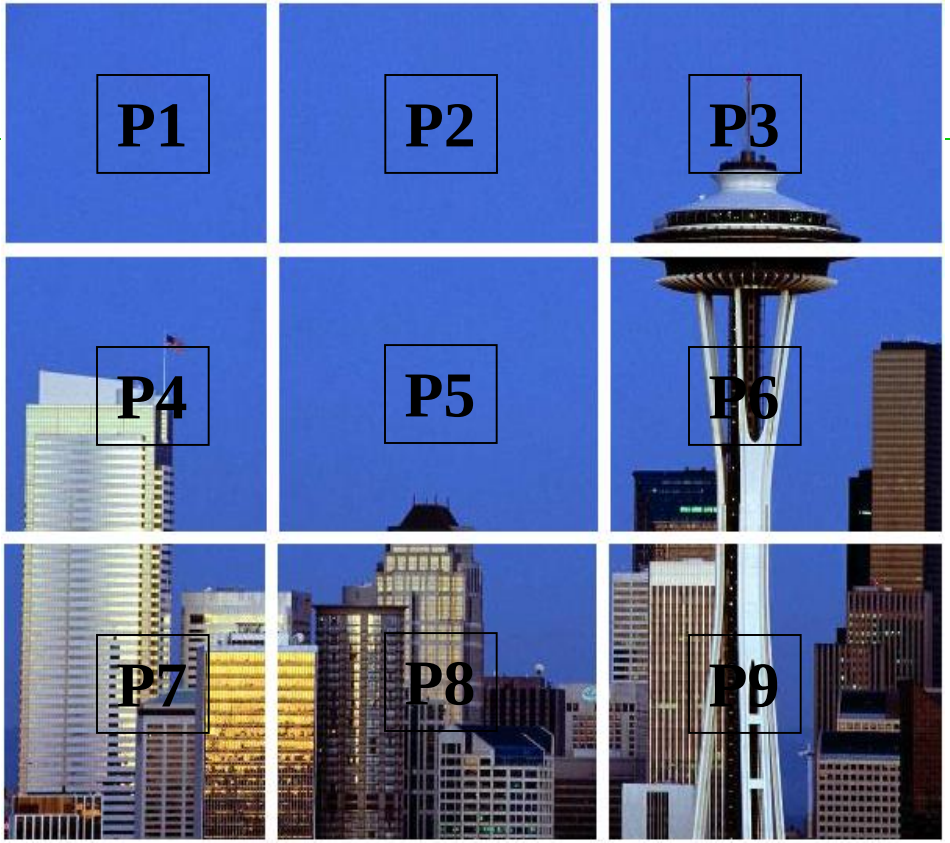




Tiling

High-resolution

Medium size tile
(256x256 or
128 x 128)



(a) JPEG (b) JPEG2000 (c) JPEG2000 with tiling

Tiling

Table 1. The Effect of Tiling on Image Quality.			
Tiling Bit Rate (b/p)	No Tiling	Tiles of Size 128×128	Tiles of Size 64×64
0.125	24.75	23.42	20.07
0.25	26.49	25.69	23.95
0.5	28.27	27.79	26.80
PSNR (in dB) for the color image "ski" (of size 720×576 pixels per component)			

Color Transform

Color Transform

$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.16875 & -0.33126 & 0.5 \\ 0.5 & -0.41869 & 0.08131 \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1.0 & 0 & 1.402 \\ 1.0 & -0.34413 & -0.71414 \\ 1.0 & 1.772 & 0 \end{pmatrix} \cdot \begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix}$$

Wavelet Transform

Daubechies 9/7 analysis and synthesis filter coefficients

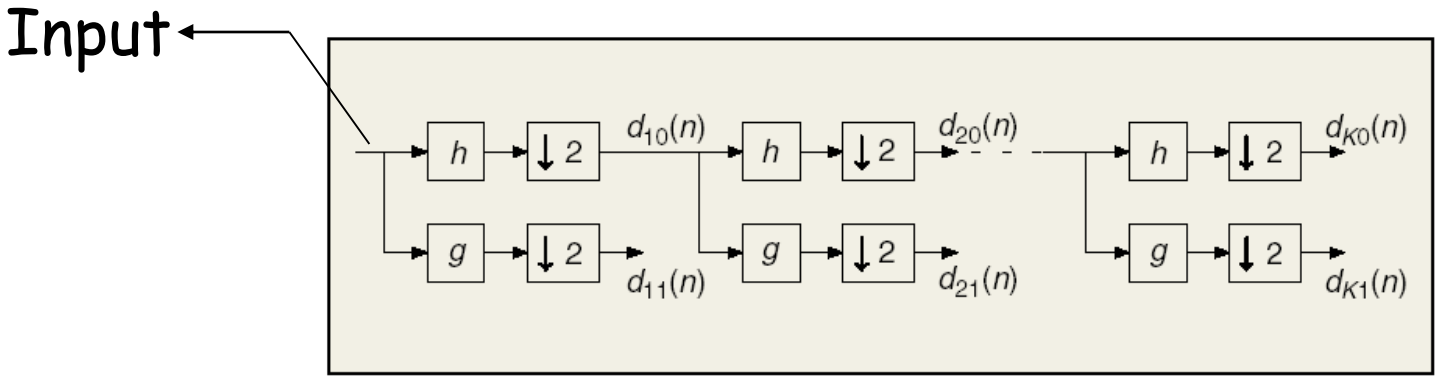
Analysis Filter Coefficients		
i	Lowpass Filter $h_L(i)$	Highpass Filter $h_H(i)$
0	0.6029490182363579	1.115087052456994
±1	0.2668641184428723	-0.5912717631142470
±2	-0.07822326652898785	-0.05754352622849957
±3	-0.01686411844287495	0.09127176311424948
±4	0.02674875741080976	

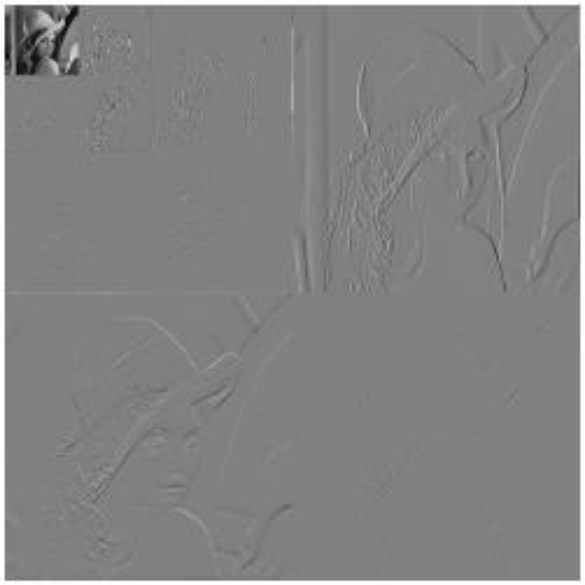
Synthesis Filter Coefficients		
i	Lowpass Filter $g_L(i)$	Highpass Filter $g_H(i)$
0	1.115087052456994	0.6029490182363579
±1	0.5912717631142470	-0.2668641184428723
±2	-0.05754352622849957	-0.07822326652898785
±3	-0.09127176311424948	0.01686411844287495
±4		0.02674875741080976

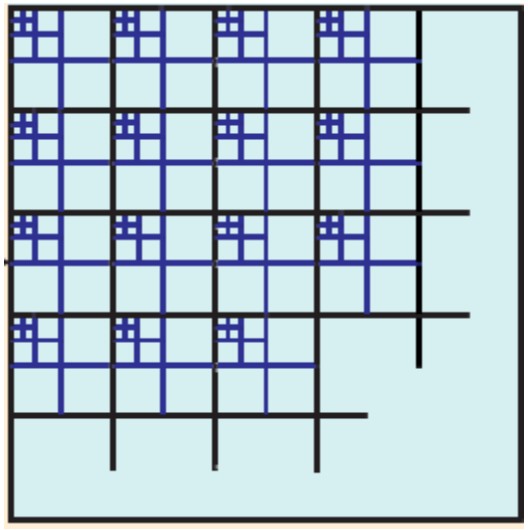
5/3 analysis and synthesis filter coefficients

	Analysis Filter Coefficients		Synthesis Filter Coefficients	
i	Lowpass Filter $h_L(i)$	Highpass Filter $h_H(i)$	Lowpass Filter $g_L(i)$	Highpass 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

Wavelet Transform

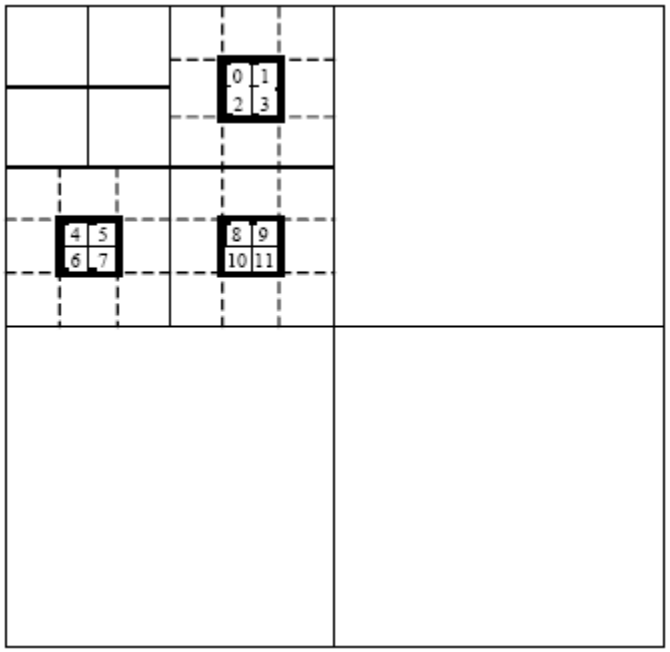






Bit-plane Coding in JPEG2000

- Trade-off between coding efficiency and error robustness, random access.
- Partition subbands in to packets
- Partition each packet into code-blocks (32x32 or 64x64)



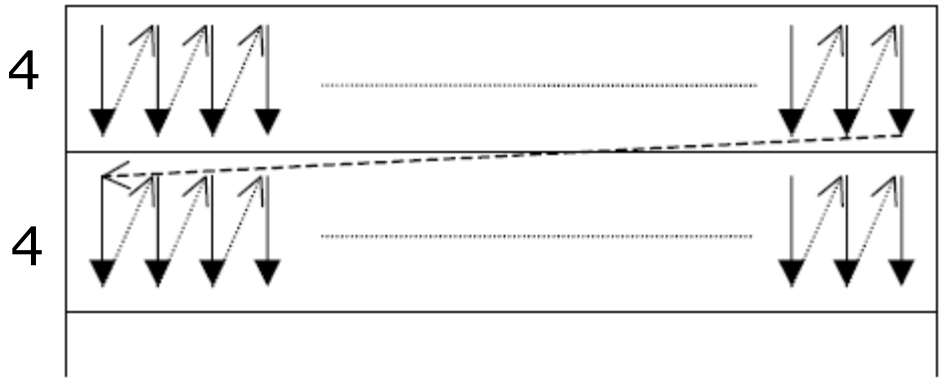


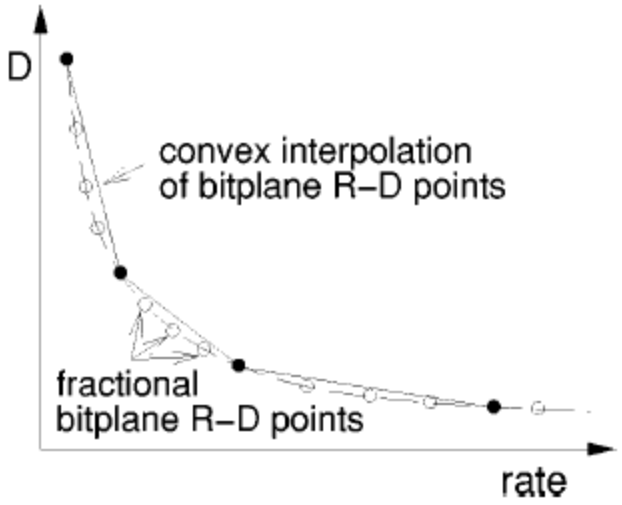
Figure 2: Scan pattern for bitplane coding.

Rate-Distortion Optimization

For a given quality level of the image, determine the bit rate Ri for each code-block

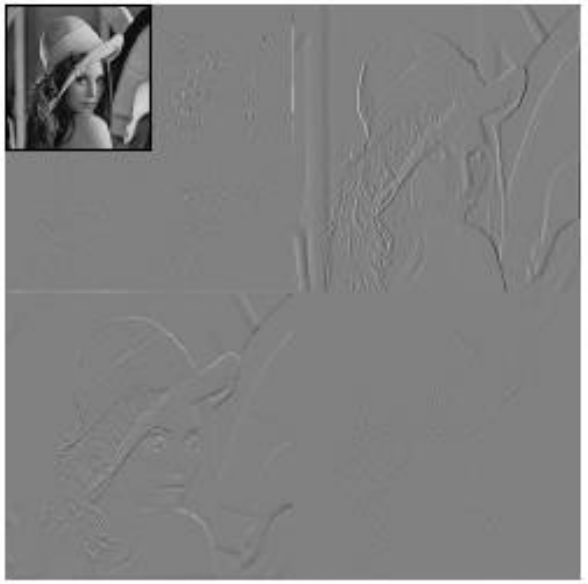
$$D = \sum_i D_i^{n_i}$$

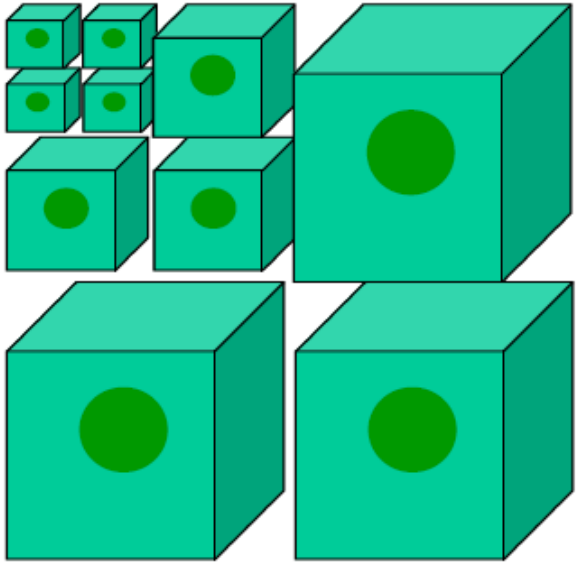
$$R^{\max} \geq R = \sum_i R_i^{n_i}.$$



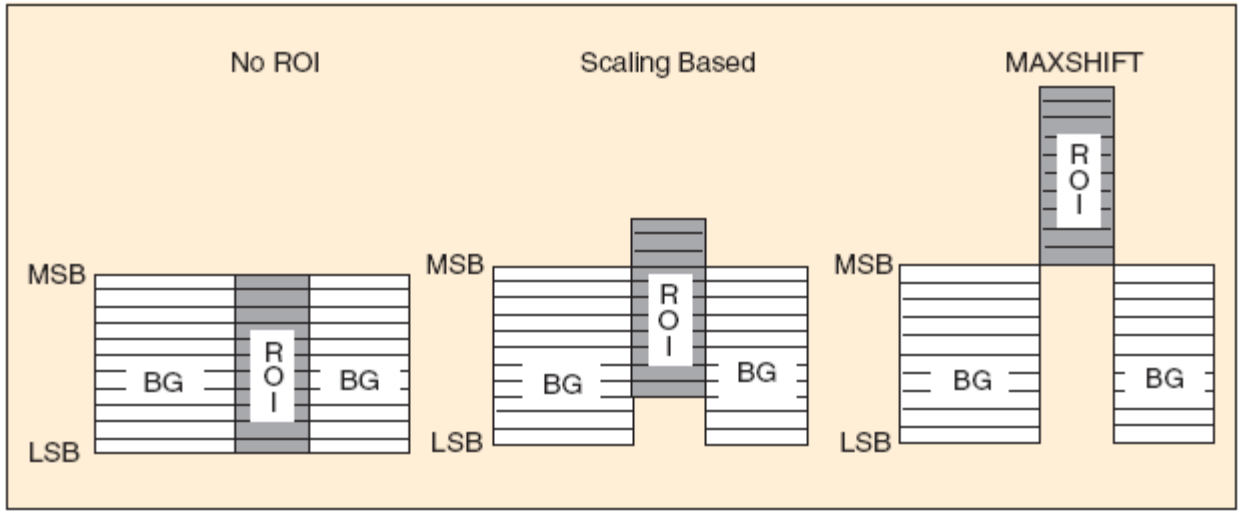
How to get R(D) function / curve (Progressive coding)

ROI coding



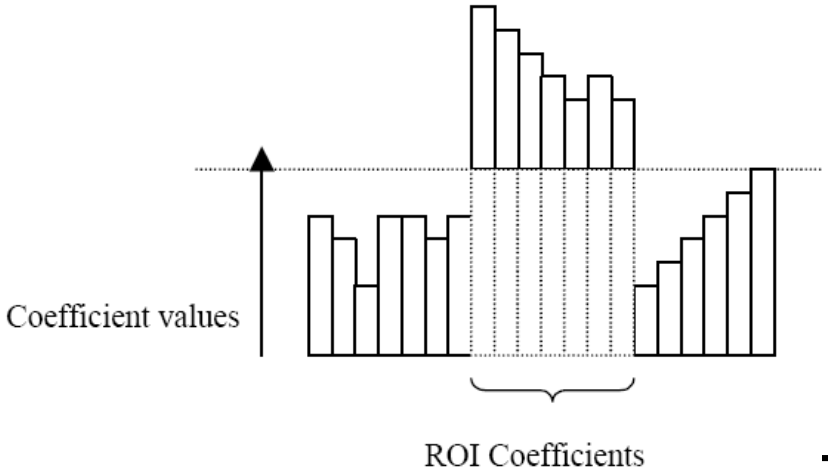


ROI coding - Bit-plane shifting



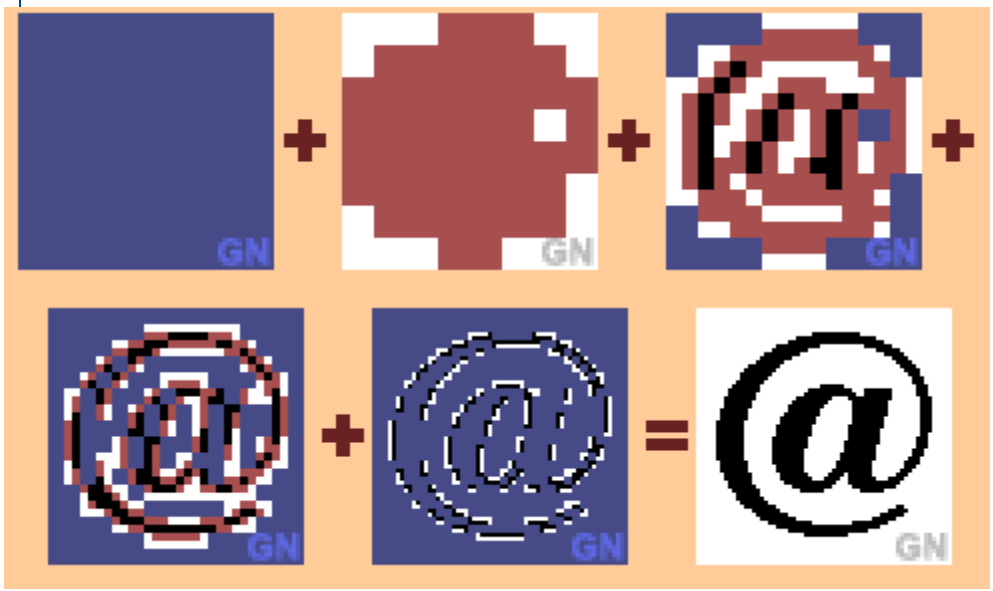
▲ *12. Scaling of the ROI coefficients.*

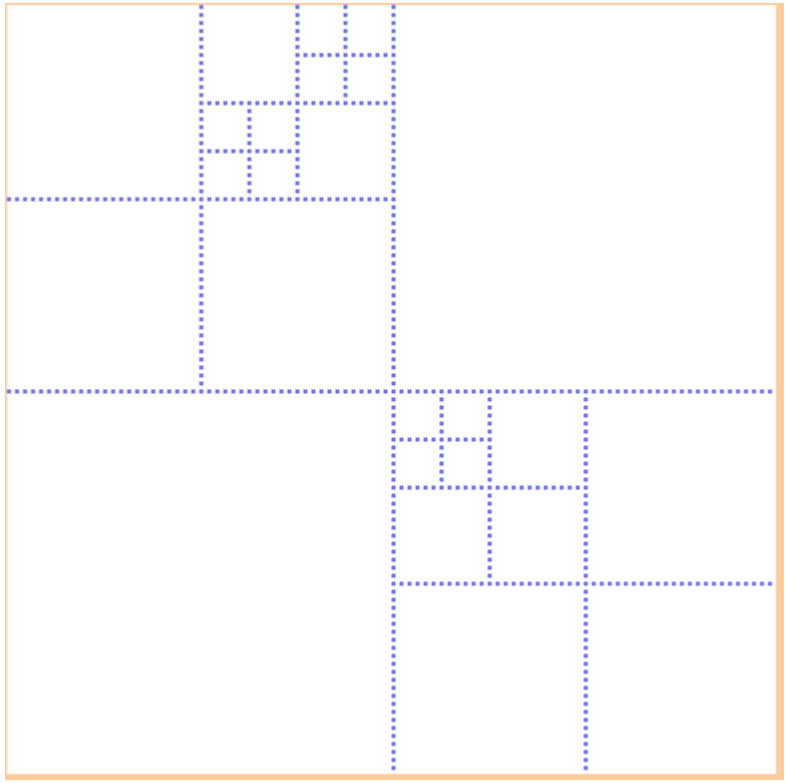
ROI MaxShift method



Other Coding Schemes

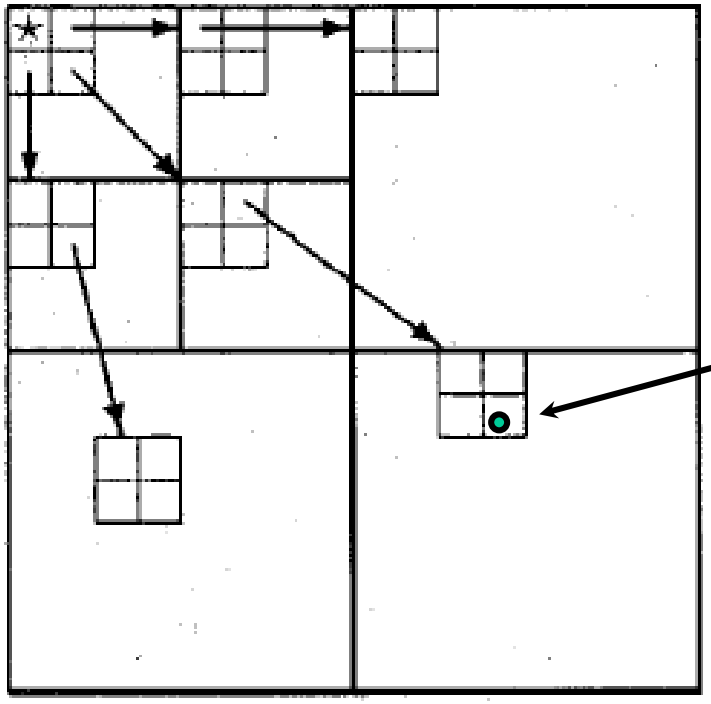
Quad-tree





Spatial-Frequency Quantization

Space-frequency Quantization for Wavelet Image Coding (1997) Zixiang Xiong, Kannan Ramchandran, Michael T. Orchard IEEE Transactions on Image Processing



Orphan non-zero coefficient

Set the orphan non-zero coefficients to zeros

- get more zero-tree
- increase coding distortion
- Rate-distortion optimization

UCLA Image compression competition

http://www.icsl.ucla.edu/~ipl/psnr_results.html