CSEP 590
Data Compression
Autumn 2007

EBCOT

JPEG 2000

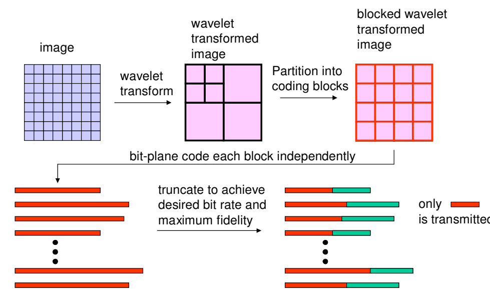
History

- Embedded Block Coding with Optimized Truncation (EBCOT)
  - Taubman – journal paper 2000
  - Algorithm goes back to 1998 or maybe earlier
  - Basis of JPEG 2000
- Embedded
  - Prefixes of the encoded bit stream are legal encodings at lower fidelity, like SPIHT and GTW
- Block coding
  - Entropy coding of blocks of bit planes, not block transform coding like JPEG.

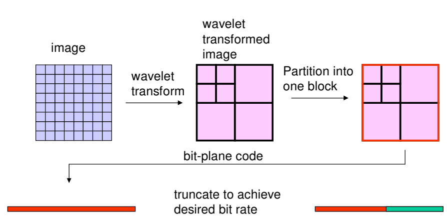
Features at a High Level

- SNR scalability (Signal to Noise Ratio)
  - Embedded code - The compressed bit stream can be truncated to yield a smaller compressed image at lower fidelity
  - Layered code – The bit stream can be partitioned into a base layer and enhancement layers. Each enhancement layer improves the fidelity of the image
- Resolution scalability
  - The lowest subband can be transmitted first yielding a smaller image at high fidelity.
  - Successive subbands can be transmitted to yield larger and larger images

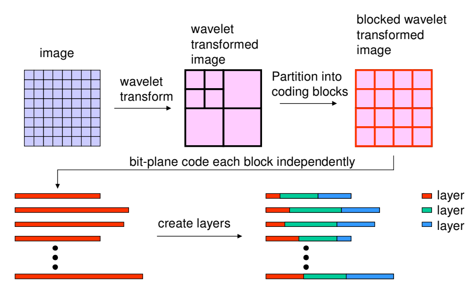
Block Diagram of Encoder



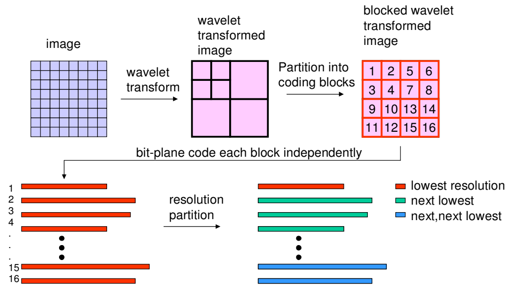
Extreme Case is Normal



Layering



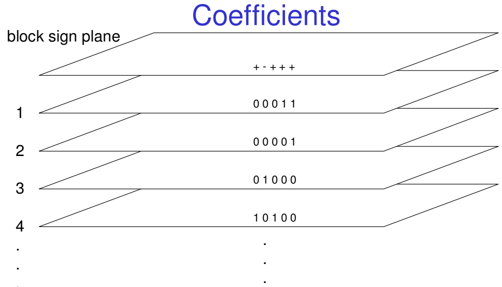
Resolution Ordering



Block Coding

- Assume we are in block k, and c(i,j) is a coefficient in block k.
- Divide c(i,j) into its sign s(i,j) and m(i,j) its magnitude.
- Quantize to $v(i,j) = \lfloor m(i,j)/q_k + .5 \rfloor$ where q_k is the quantization step for block k.
- Example: c(i,j) = -10, q_k = 3.
  - s(i,j) = 0
  - v(i,j) = floor(-10/3 + .5) = -2

Bit Planes of Normalized Quantized Coefficients



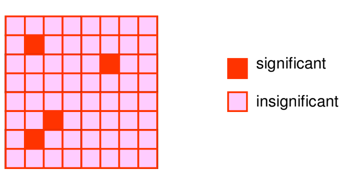
Quantized coefficients are normalized between –1 and 1

Bit-Plane Coding of Blocks

- Sub-block significance coding (like group testing)
  - Some sub-blocks are declared insignificant
  - Significant sub-blocks must be coded
- Contexts are defined based on the previous bit-plane significance.
  - Zero coding (ZC) – 9 contexts
  - Run length coding (RLC) – 1 context
  - Sign coding (SC) – 5 contexts
  - Magnitude refinement coding (MR) – 3 contexts
- Block coded in raster order using arithmetic coding

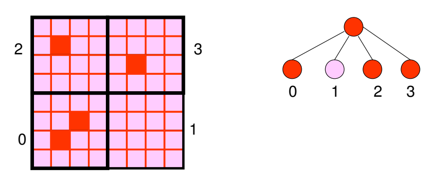
Sub-Block Significance Coding

- Quad-tree organized group testing
- Block divided into 16x16 sub-blocks
- Identify in few bits the sub-blocks that are significant

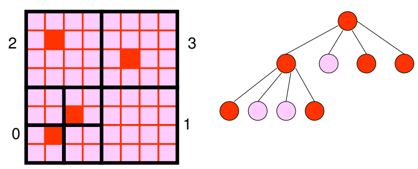


block

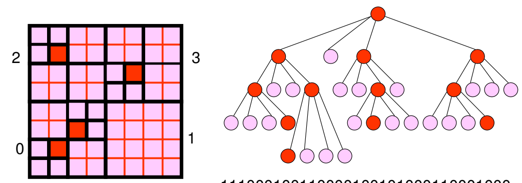
Quad-Tree Subdivision



Quad-Tree Subdivision



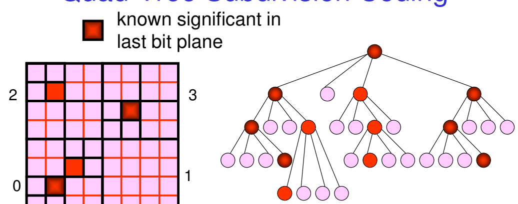
Quad-Tree Subdivision Coding



111000100110000100101000110001000

Depth-first code = 1 for significant
0 for insignificant

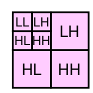
Quad-Tree Subdivision Coding



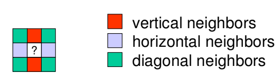
111000100110000100101000110001000

Skip symbols that are already known:
1. nodes significant in previous bit plane
2. last child of significant parent of other children are insignificant

ZC – Zero Coding



- LH is transposed so that it can be treated the same as HL. $(LH)^T$ has similar characteristics to HL.
- Each coefficient has its neighbors in the same subband



ZC Contexts

- v = number of vertical neighbors significant in the previous bit-plane
- h = number of horizontal neighbors significant in the previous bit-plane
- d = number of diagonal neighbors significant in the previous bit-plane

$0 \le h, v \le 2$
$0 \le d \le 4$

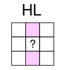
higher labels mean more likely to be significant

	HL	(LH)^T	LL	HH	
label	h	v	d	d	h+v
0	0	0	0	0	0
1	0	0	1	0	1
2	0	0	> 1	0	> 1
3	0	1	*	1	0
4	0	2	*	1	1
5	1	0	0	1	> 1
6	1	0	> 0	2	0
7	1	> 0	*	2	> 0
8	2	*	*	> 2	*

Examples

significant in previous bit-plane

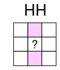
HL



h = 0
v = 2
d = 0

Context 4

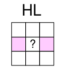
HH



h = 0
v = 2
d = 0

Context 2

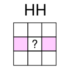
HL



h = 2
v = 0
d = 0

Context 8

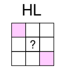
HH



h = 2
v = 0
d = 0

Context 2

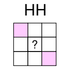
HL



h = 0
v = 0
d = 2

Context 2

HH

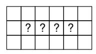


h = 0
v = 0
d = 2

Context 6

RLC – Run Length Coding

- Looks for runs of 4 that are likely to be insignificant



- If all insignificant then code as a single symbol
- Main purpose – to lighten the load on the arithmetic coder.

SC – Sign Coding

$$hs = \begin{cases} 0 & \text{if horizontal neighbors are both insignificant or of opposite sign} \\ 1 & \text{if at least one horizontal neighbor is positive} \\ -1 & \text{if at least one horizontal neighbor is negative} \end{cases}$$

$$vs = \begin{cases} 0 & \text{if vertical neighbors are both insignificant or of opposite sign} \\ 1 & \text{if at least one vertical neighbor is positive} \\ -1 & \text{if at least one vertical neighbor is negative} \end{cases}$$

hs	1	1	1	0	0	0	-1	-1	-1
vs	1	0	-1	1	0	-1	1	0	-1
sign prediction	1	1	1	-1	1	1	-1	-1	-1
label	4	3	2	1	0	1	2	3	4

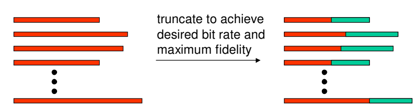
MR – Magnitude Refinement

- This is the refinement pass.
- Define t = 0 if first refinement bit, t = 1 otherwise.

label	t	h + v
0	0	0
1	0	> 0
2	1	*

Bit Allocation

- How do we truncate the encoded blocks to achieve a desired bit rate and get maximum fidelity



Basic Set Up

- Encoded block k can be truncated to n_k bits.
- Total Bit Rate

$$\sum_k n_k$$

- Distortion attributable to block k is

$$D_k^{n_k} = w_k^2 \sum_{(i,j)\in B_k} (c^{n_k}(i,j) - c(i,j))^2$$

where w_k is the “weight” of the basis vectors for block k and $c^{n_k}(i,j)$ is the recovered coefficients from n_k bits of block k.

Bit Allocation as an Optimization Problem

- Input: Given m embedded codes and a bit rate target R
- Output: Find truncation values n_k, $1 \leq k \leq m$, such that

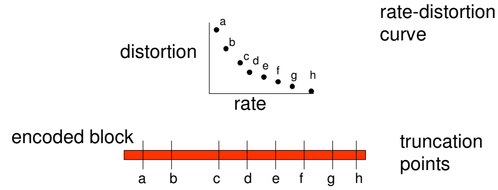
$$D = \sum_k D_k^{n_k} \quad \text{is minimized and}$$

$$\sum_k n_k \leq R$$

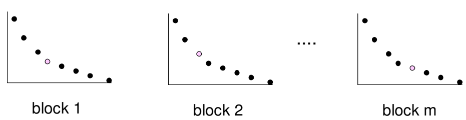
Facts about Bit Allocation

- It is an NP-hard problem generally
- There are fast approximate algorithms that work well in practice
  - GBFOS
  - Lagrange multiplier method
  - Multiple choice knapsack method

Rate-Distortion Curve



Picture of Bit Allocation



Pick one point from each curve so that the sum of the x values is bounded by R and the sum of the y values is minimized.

Good approximate algorithms exist because the curves are almost convex.

Notes on EBCOT

- EBCOT is quite complicated with many features.
- JPEG 2000 based on EBCOT but differs to improve compression and decompression time.
- EBCOT has
  - resolution scalability
  - SNR scalability
  - quantization
  - bit allocation
  - arithmetic coding with context and adaptivity
  - group testing (quad trees)
  - sign and refinement bit contexts
  - lots of engineering

Notes on Wavelet Compression

- Wavelets appear to be excellent for image compression
  - No blocking artifacts
  - Wavelet coding techniques abound and are very effective
- Some of the wavelet coding techniques can apply to block transforms.
- Newest generation of image compressor use wavelets, JPEG 2000.