CSEP 590
Data Compression
Autumn 2007

EBCOT

JPEG 2000

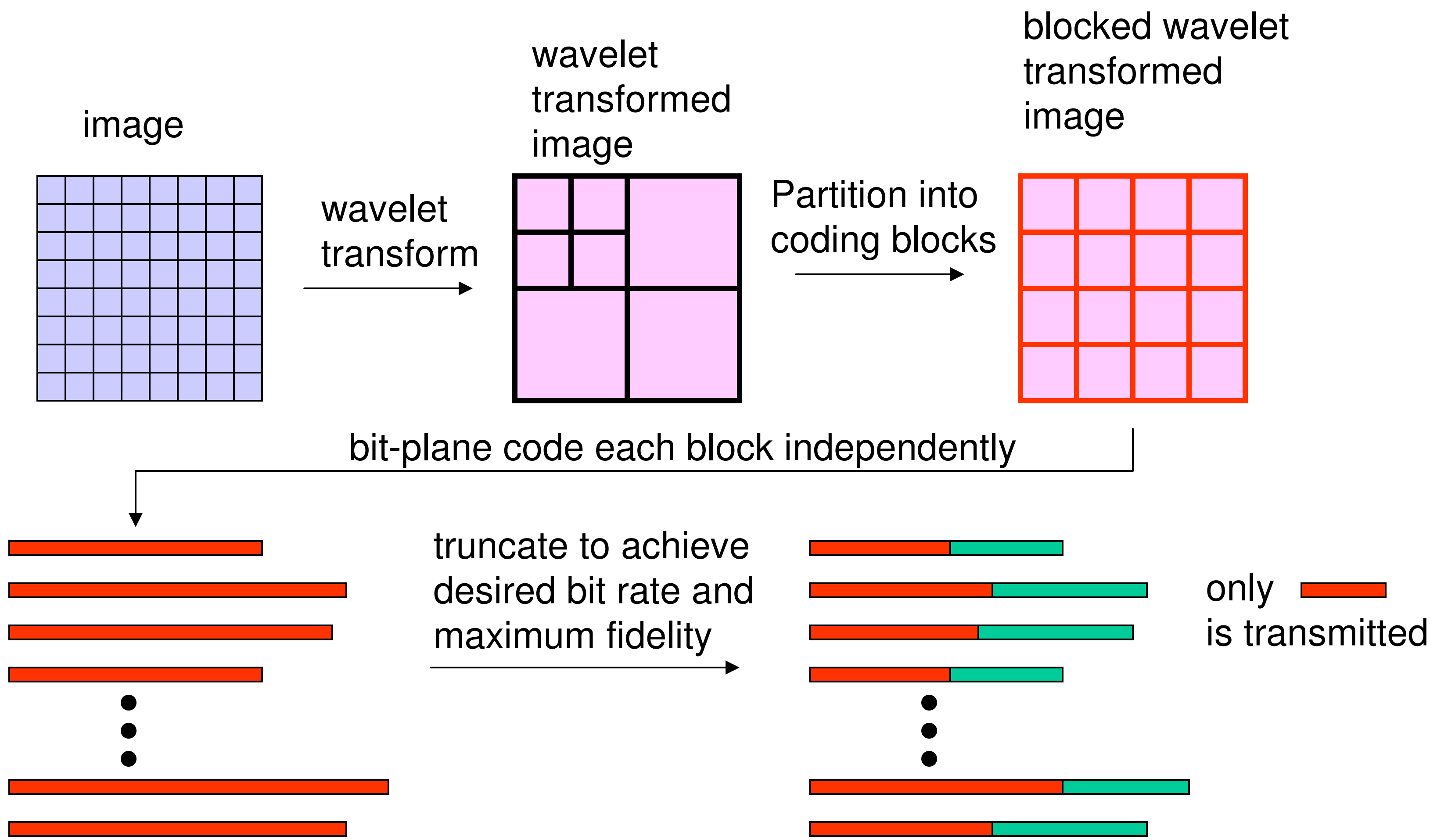
History

- 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.

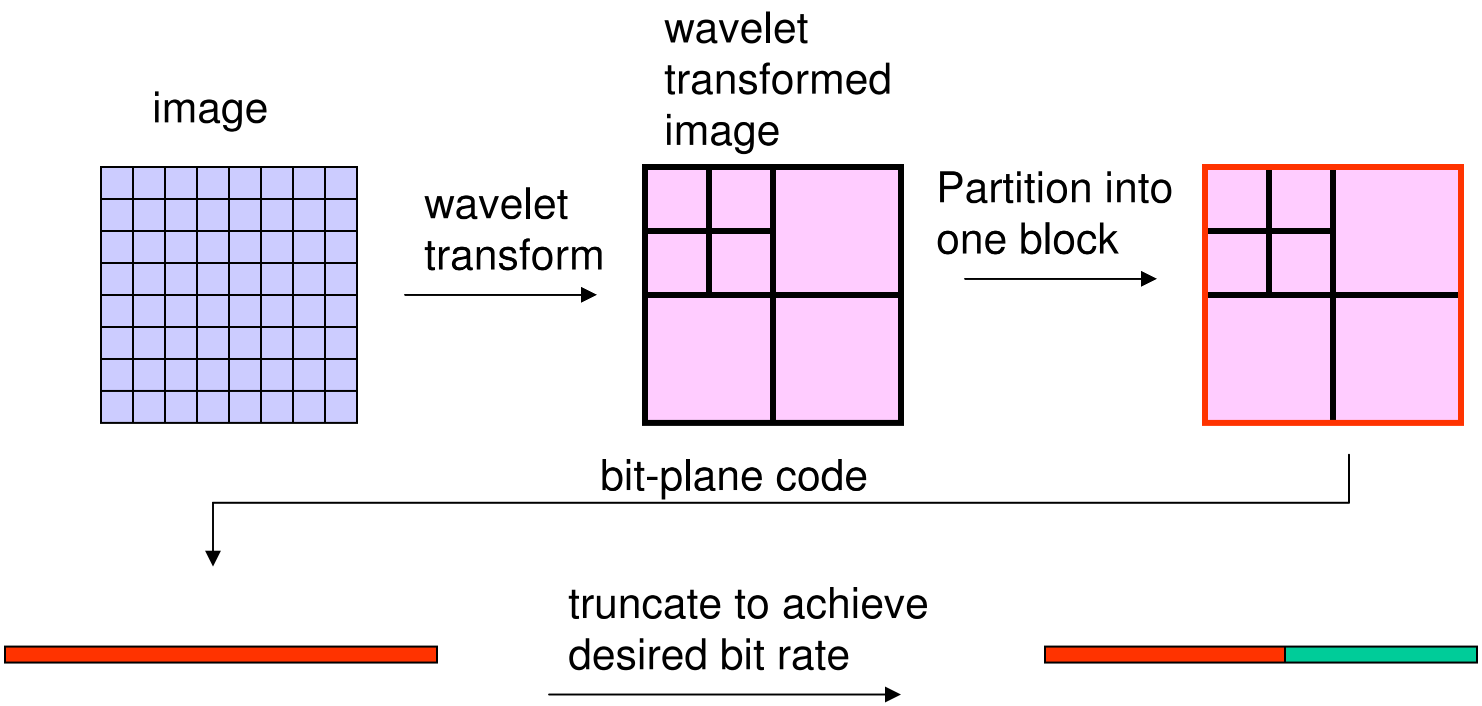
Features at a High Level

- 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

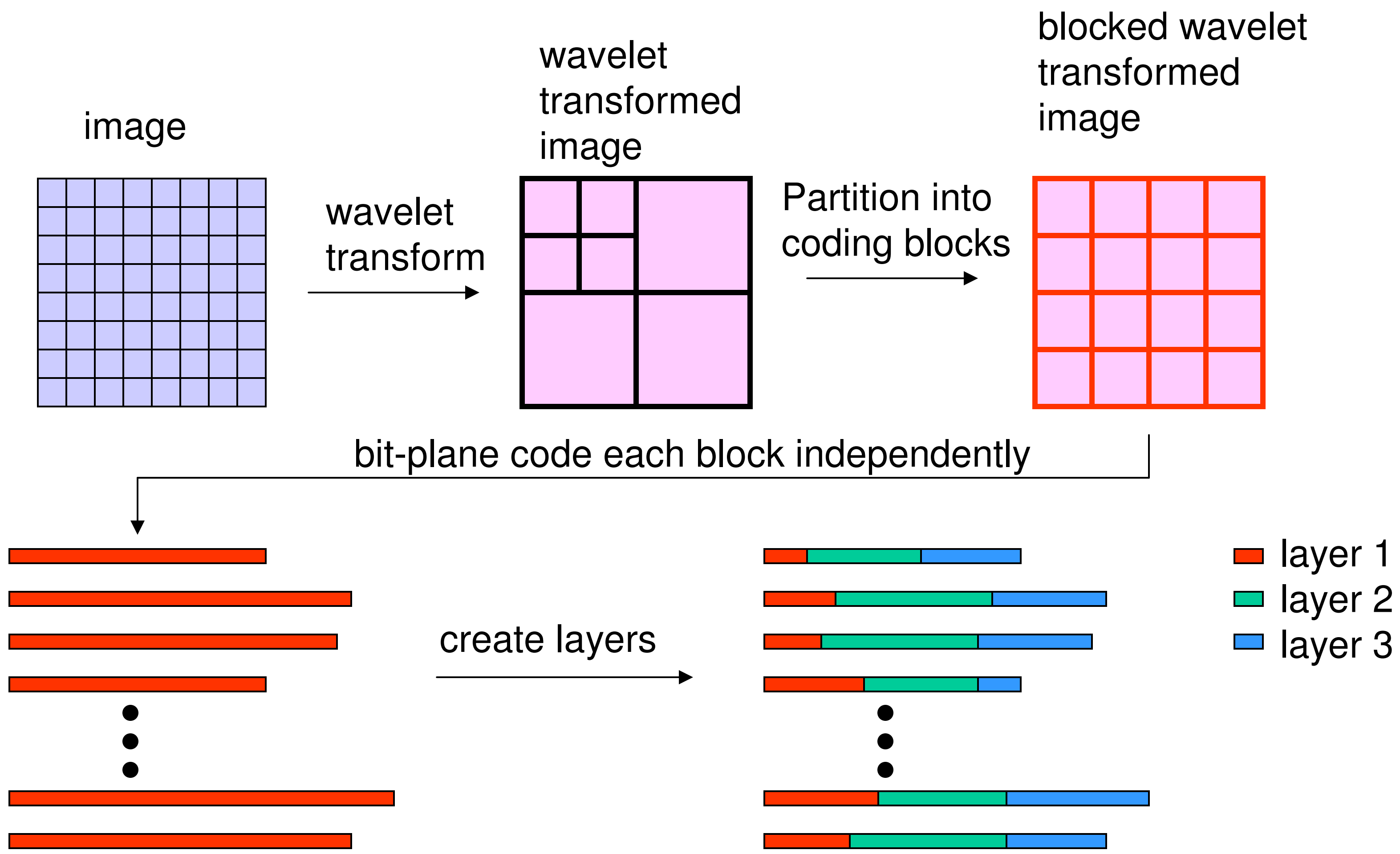
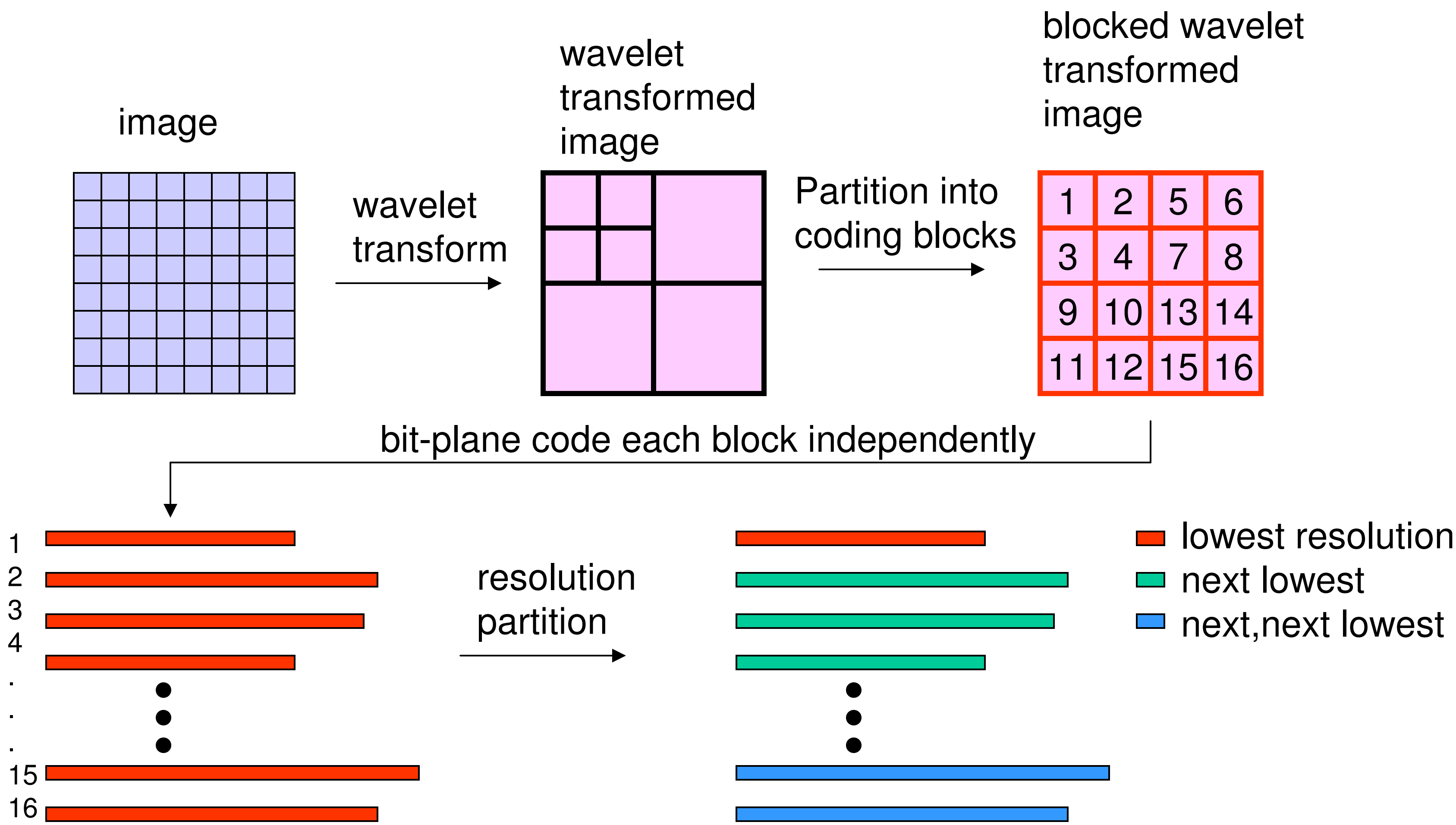


image
wavelet
transform
wavelet
transformed
image
Partition into
coding blocks
blocked wavelet
transformed
image
bit-plane code each block independently
create layers
layer 1
layer 2
layer 3

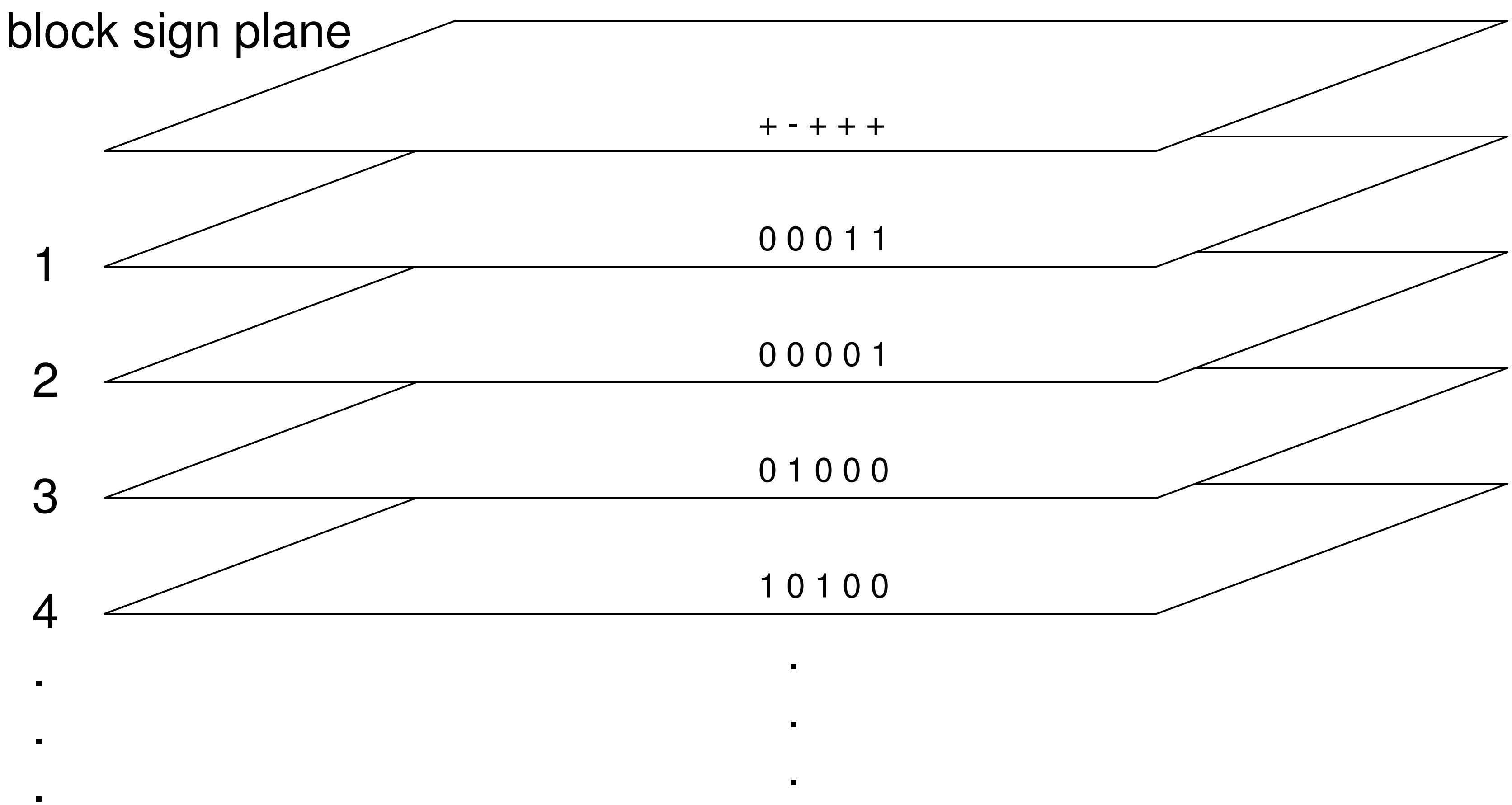
Resolution Ordering



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



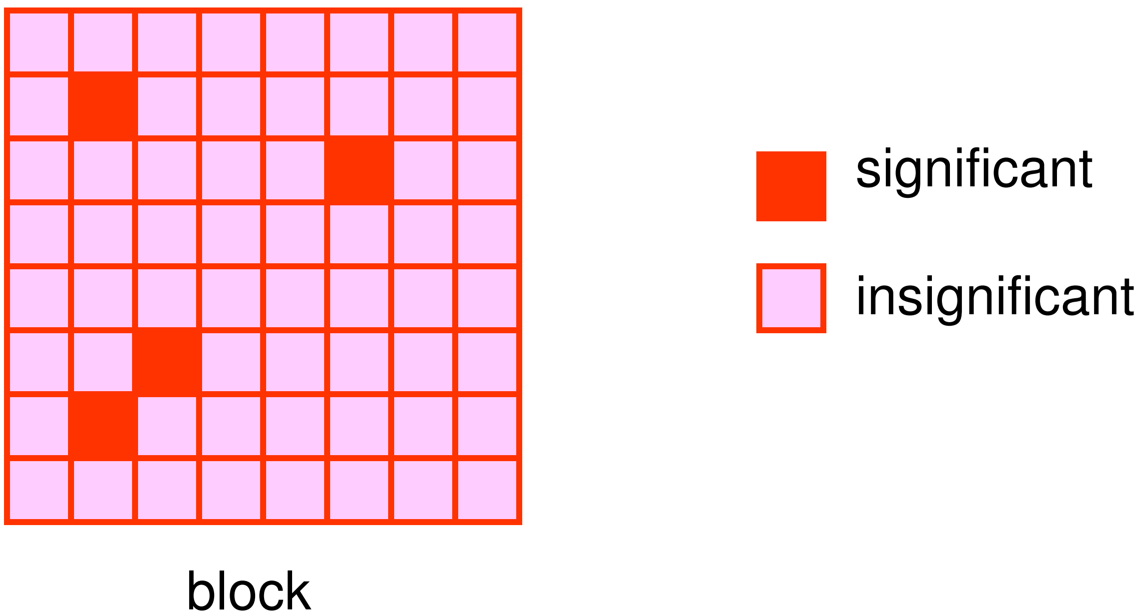
Quantized coefficients are normalized between –1 and 1

Bit-Plane Coding of Blocks

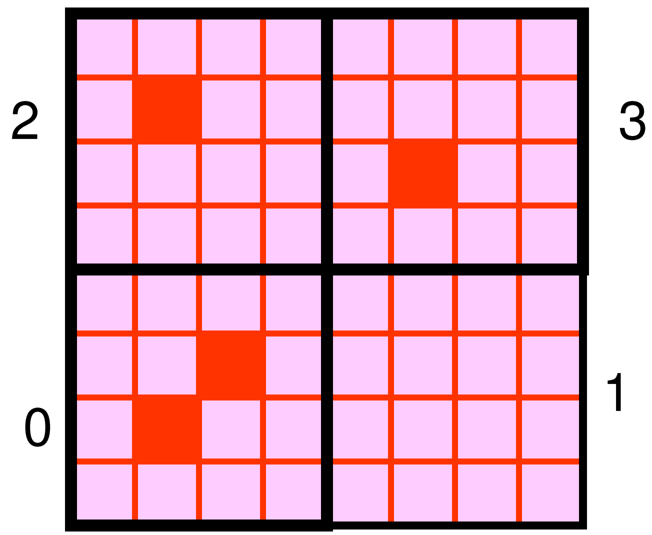
- Sub-block significance coding (like group testing)
  - Some sub-blocks are declared insignificant
  - Significant sub-blocks must be coded
- Contexts are defined based on the previous bit-plane significance.
  - Zero coding (ZC) – 9 contexts
  - Run length coding (RLC) – 1 context
  - Sign coding (SC)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

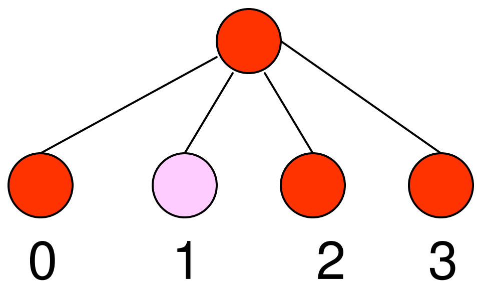
Sub-Block Significance Coding

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

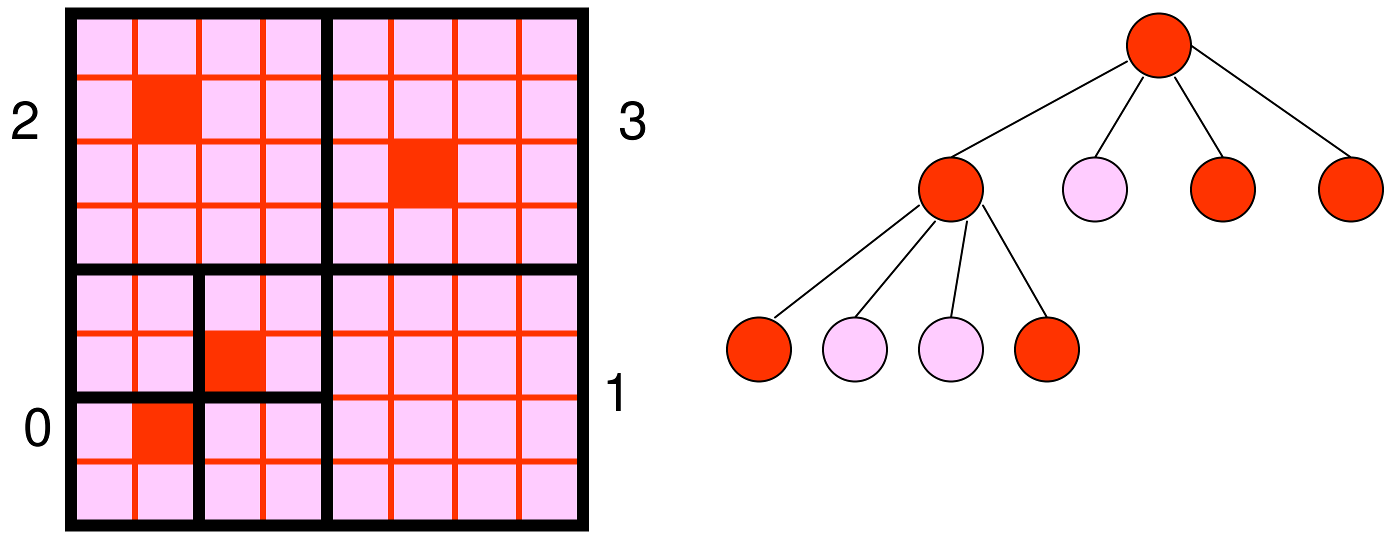


Quad-Tree Subdivision

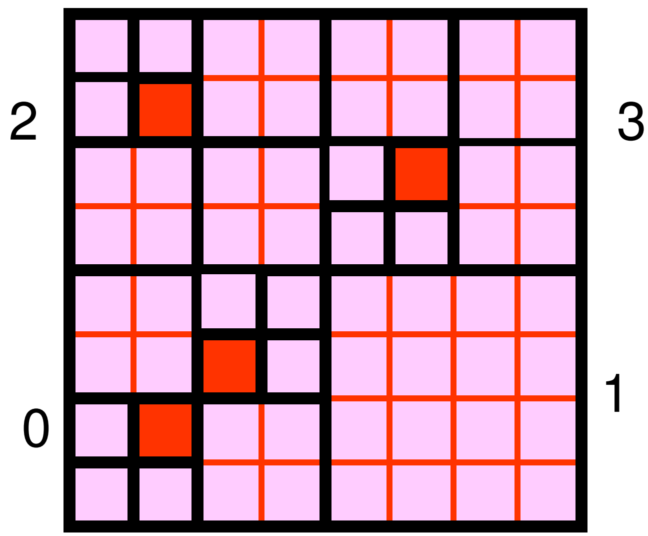


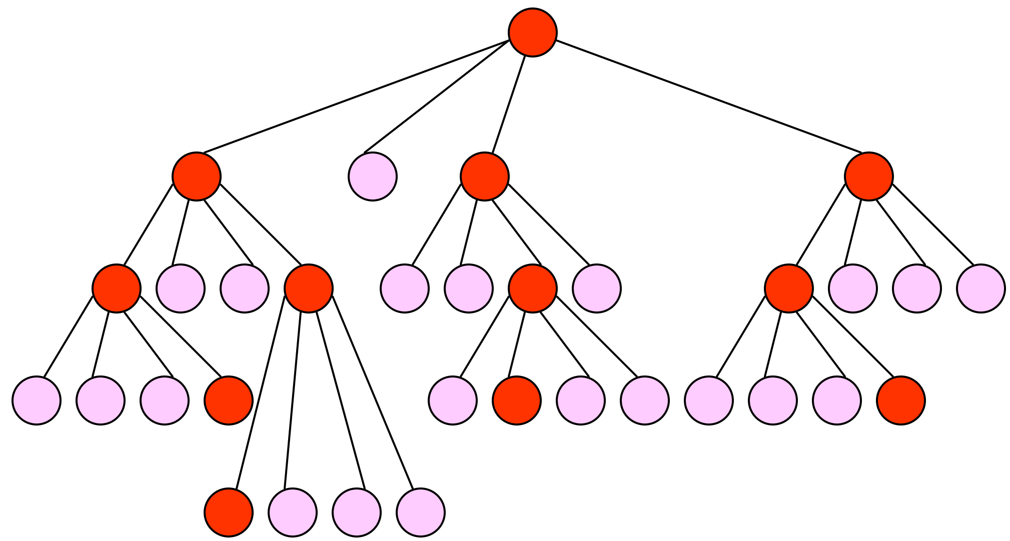


Quad-Tree Subdivision



Quad-Tree Subdivision Coding

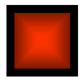




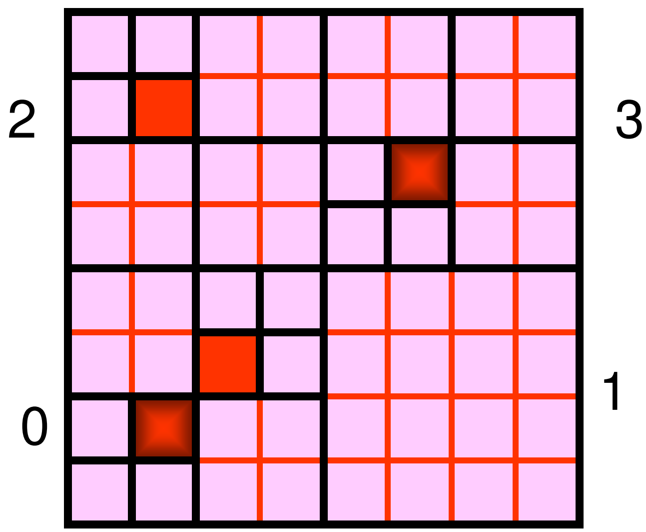
1110001001100001001010001100001000

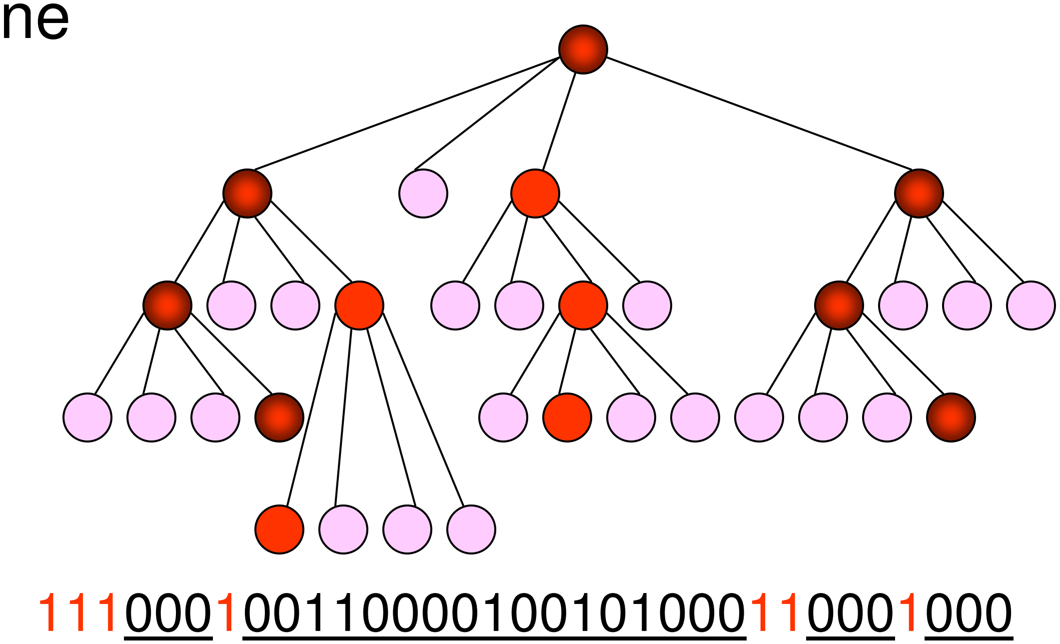
Depth-first code = 1 for significant
0 for insignificant

Quad-Tree Subdivision Coding



known significant in
last bit plane

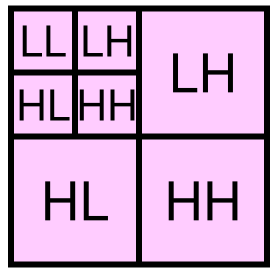




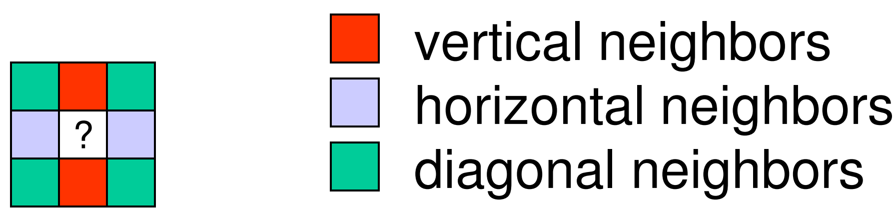
Skip symbols that are already known:

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

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

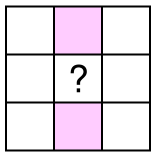
higher labels mean more likely to be significant

	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

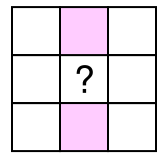
HL



h = 0
v = 2
d = 0

Context 4

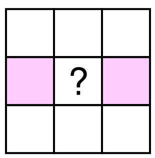
HH



h = 0
v = 2
d = 0

Context 2

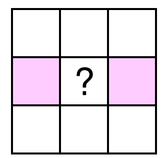
HL



h = 2
v = 0
d = 0

Context 8

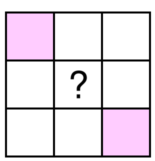
HH



h = 2
v = 0
d = 0

Context 2

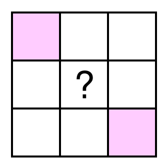
HL



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

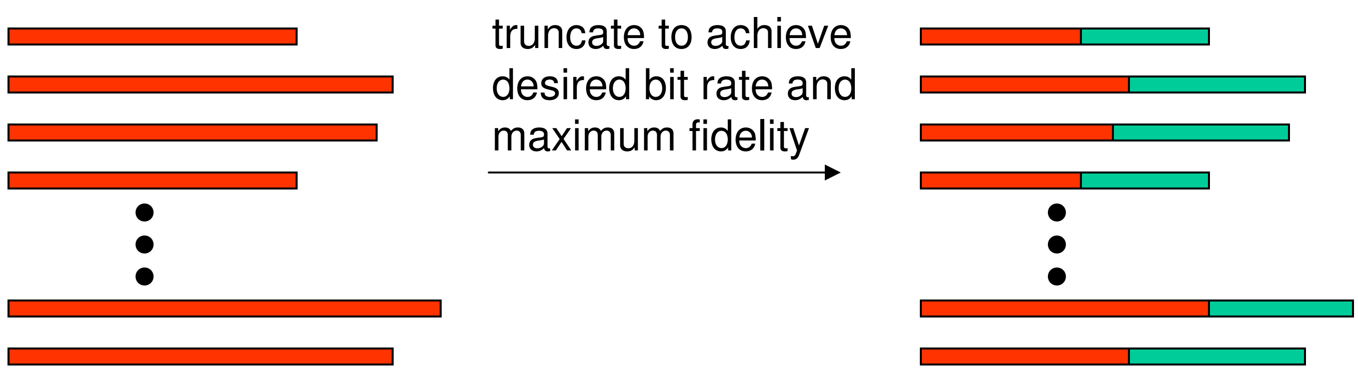
MR – Magnitude Refinement

- 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

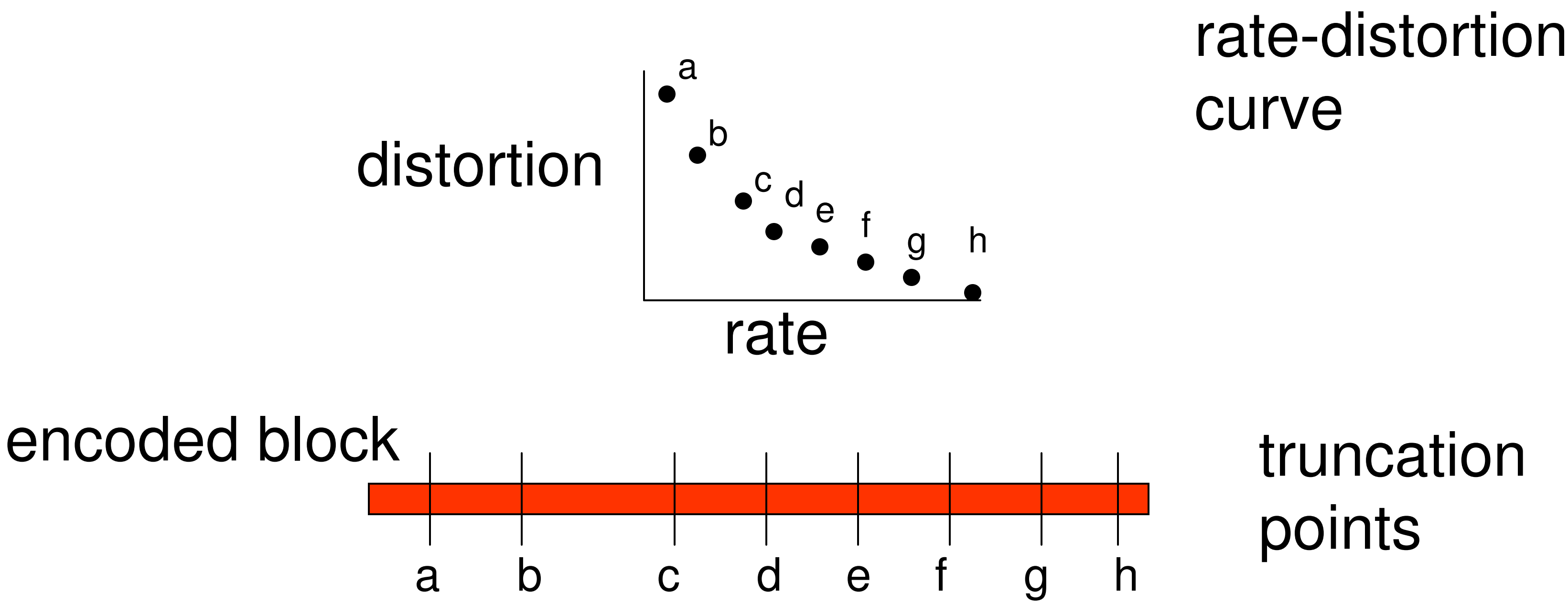
$$D = \sum_k D_k^{n_k}$$ is minimized and

$$\sum_k n_k \leq R$$

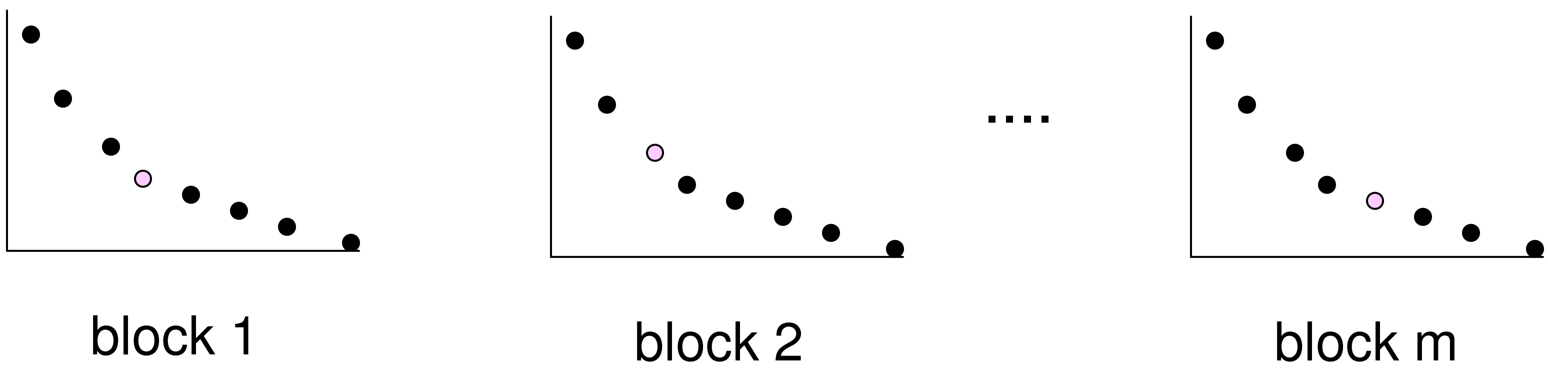
Facts about Bit Allocation

- 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.