Special Module on Media Processing and Communication

Dayalbagh Educational Institute
(DEI)
Dayalbagh Agra

PHM 961

Indian Institute of Technology Delhi
(IITD)
New Delhi

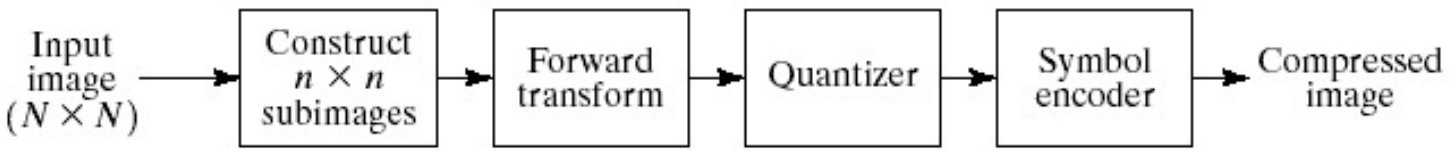
SIV 864

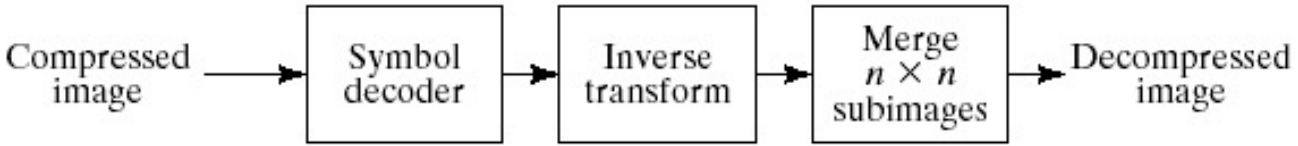
Image Compression

Transform Coding

Pipeline

Compression





Decompression

Image Compression

Transform Coding

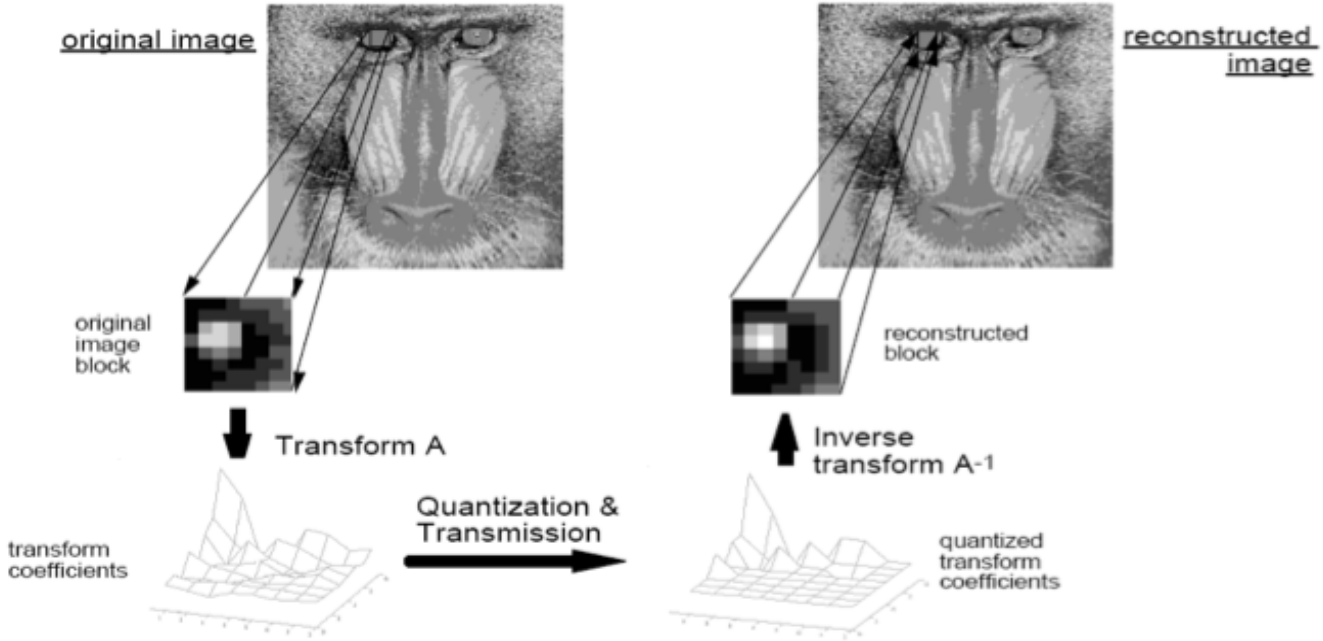


Image Compression

Transform Coding

Why sub image (nxn)?

- Computational benefit
- Typically 8x8, 16x16
- Error is not very high

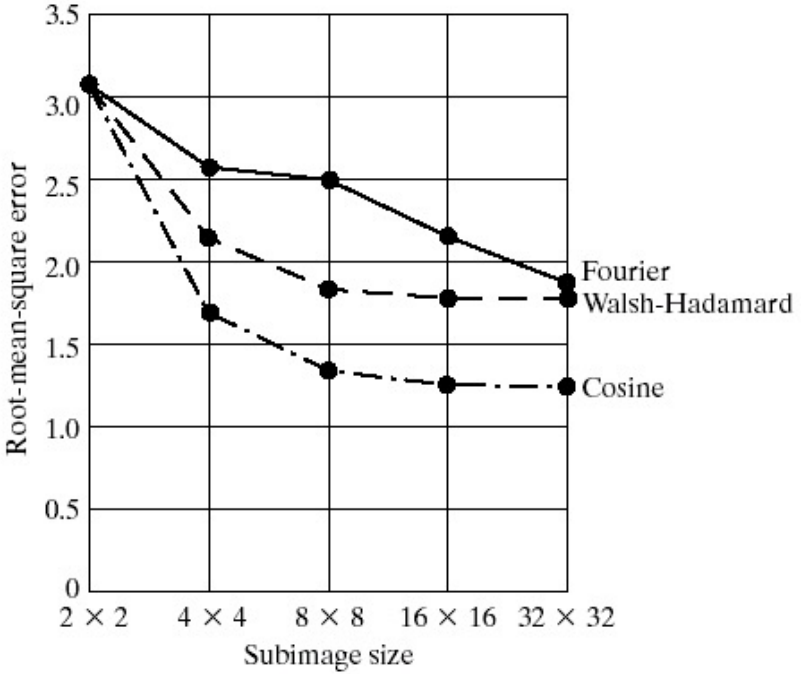


Image Compression

Transform Coding

Why sub image (nxn)?

- Computational benefit
- Typically 8x8, 16x16
- Error is not very high

Which transform?

- Low error for the same number of coefficients
- Computationally fast
- DCT is preferred

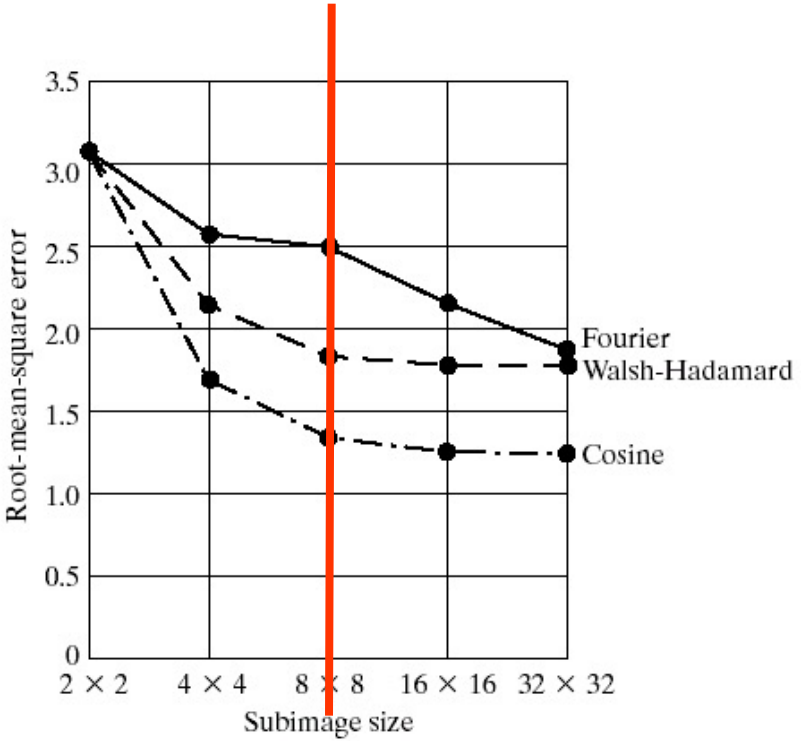


Image Compression

Transform Coding

Quantization Schemes

- Global thresholding
- Local thresholding
- For each block M out of N coefficients to retain

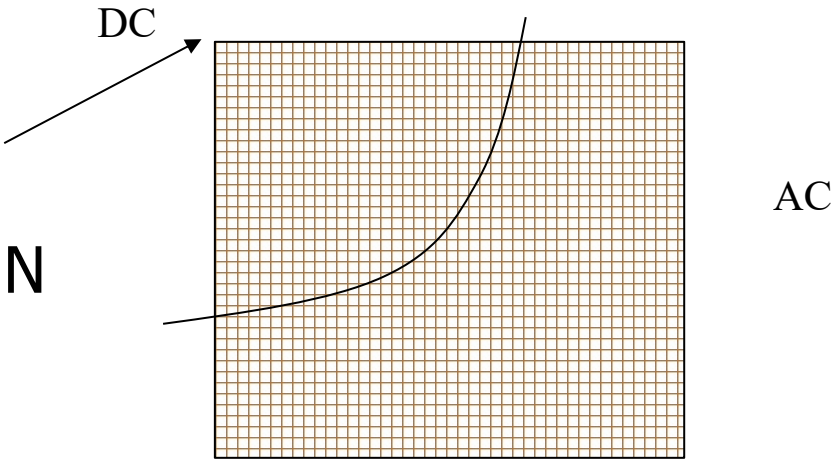
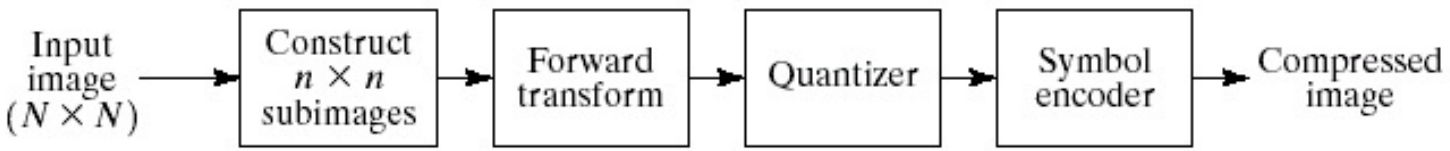


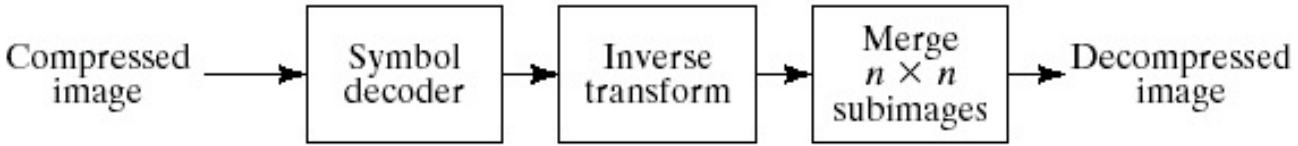
Image Compression

Transform Coding

Pipeline

Compression





Decompression

Image Compression

Transform Coding

Pipeline

Compression

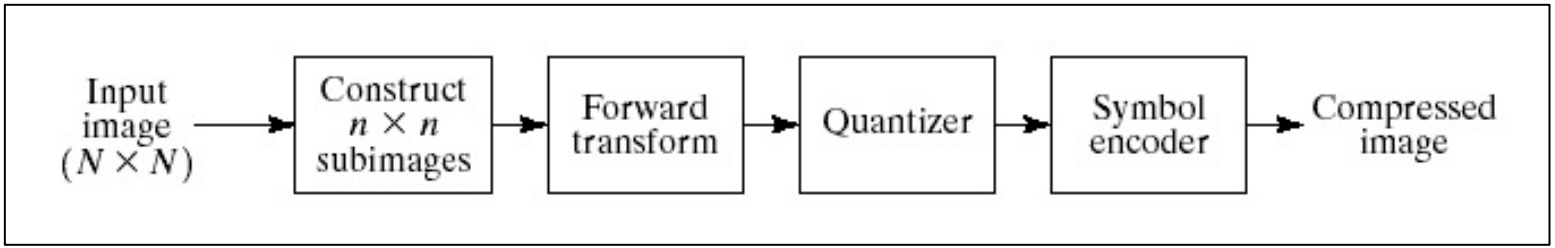
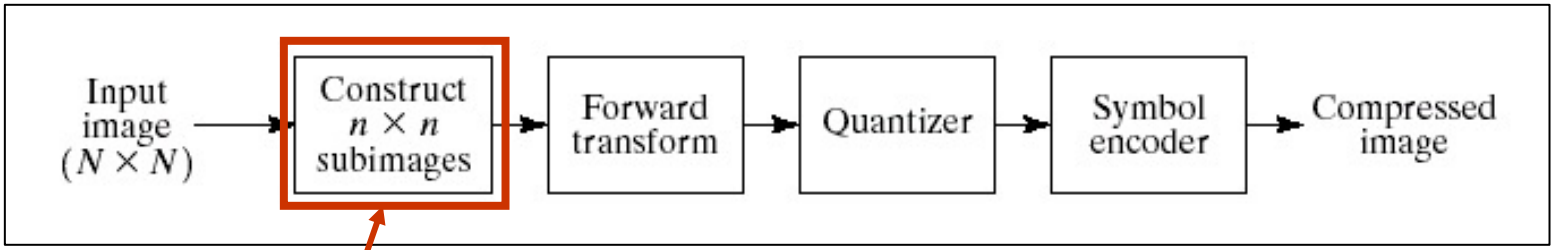


Image Compression

Transform Coding

Pipeline

Compression



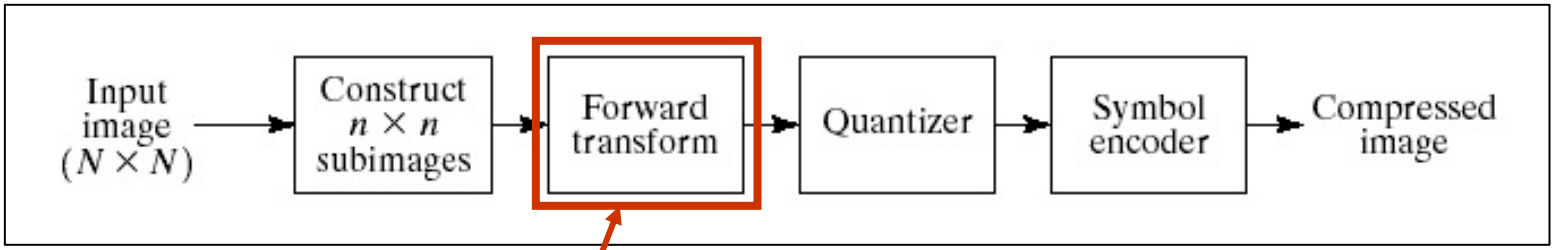
Typically
8x8 or 16x16

Image Compression

Transform Coding

Pipeline

Compression



Discrete Fourier Transform
Discrete Cosine Transform
Karhunen-Loeve Transform
.....

Image Compression

Transform Coding

Pipeline

Compression

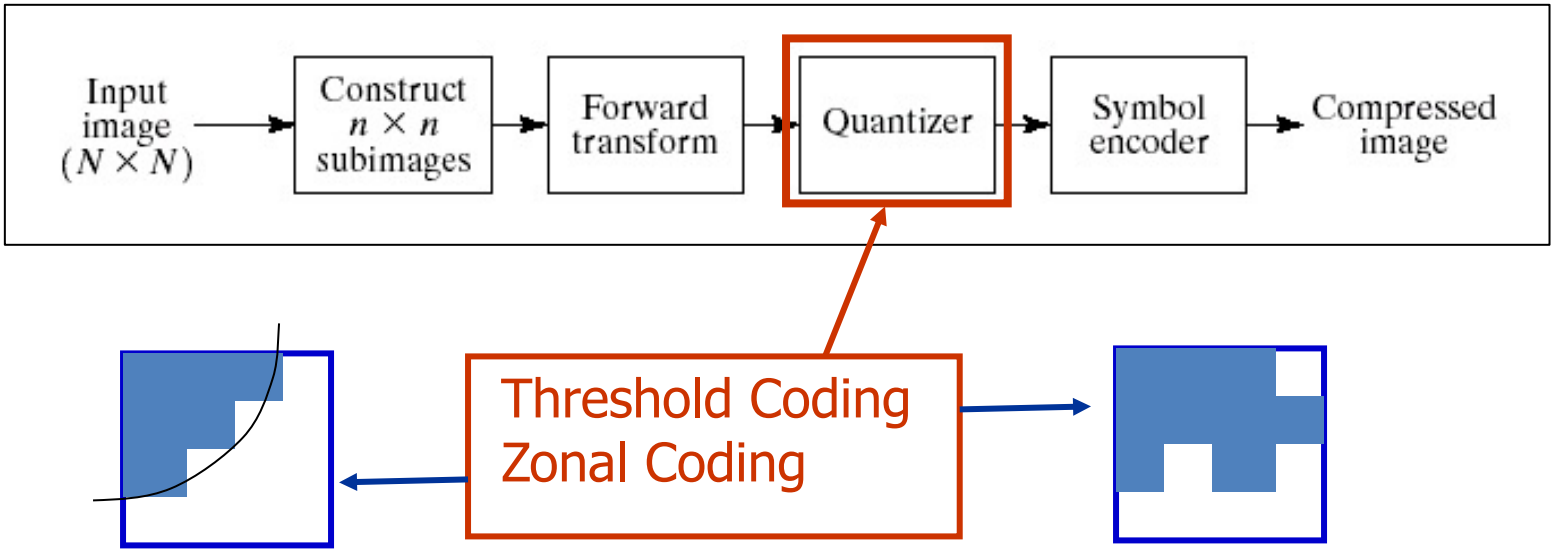
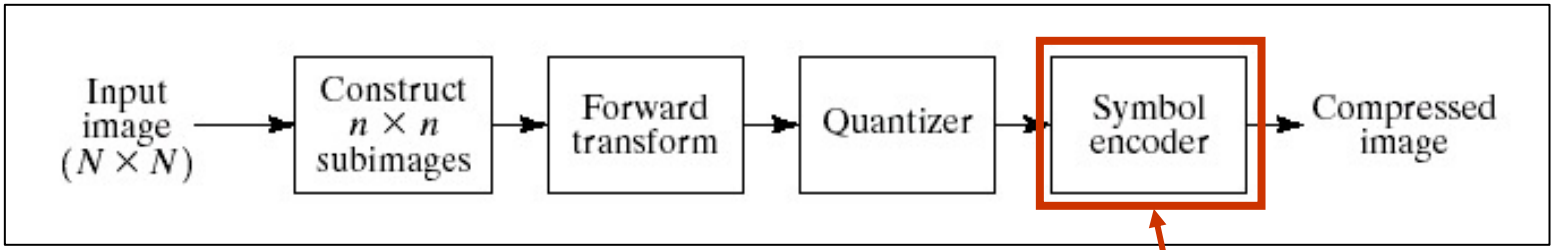


Image Compression

Transform Coding

Pipeline

Compression

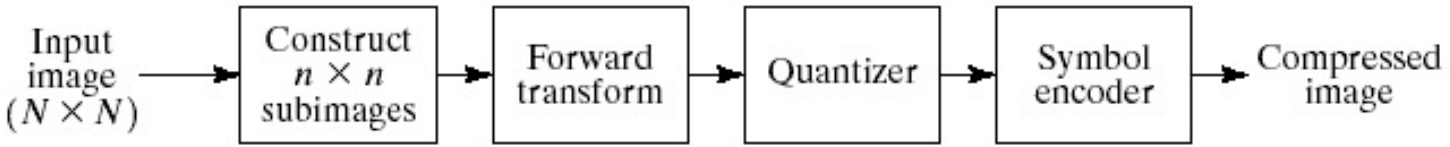


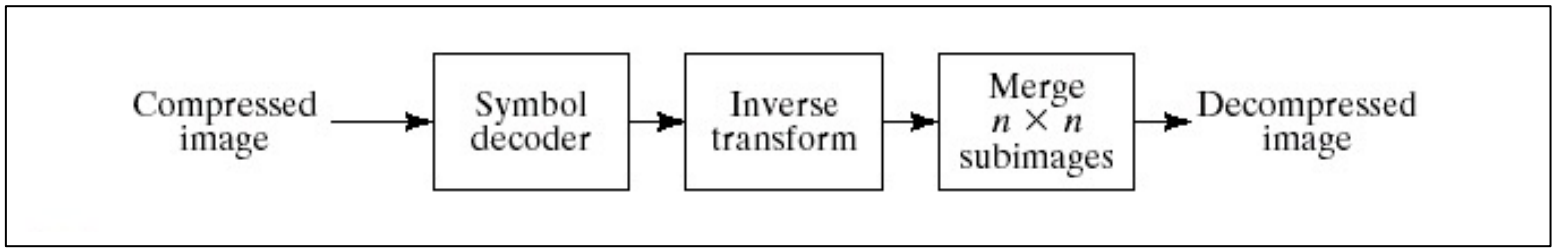
Variable Length Coding (Huffman)

Image Compression

Transform Coding Pipeline

Compression



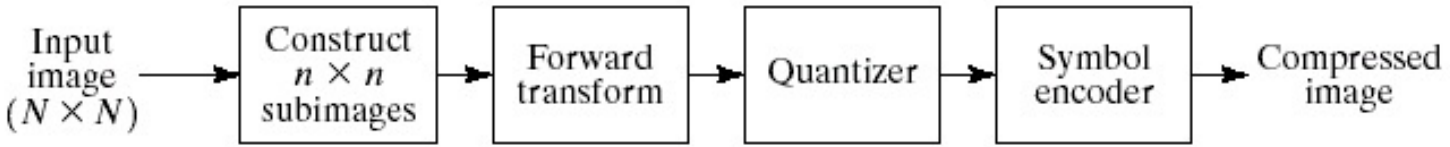


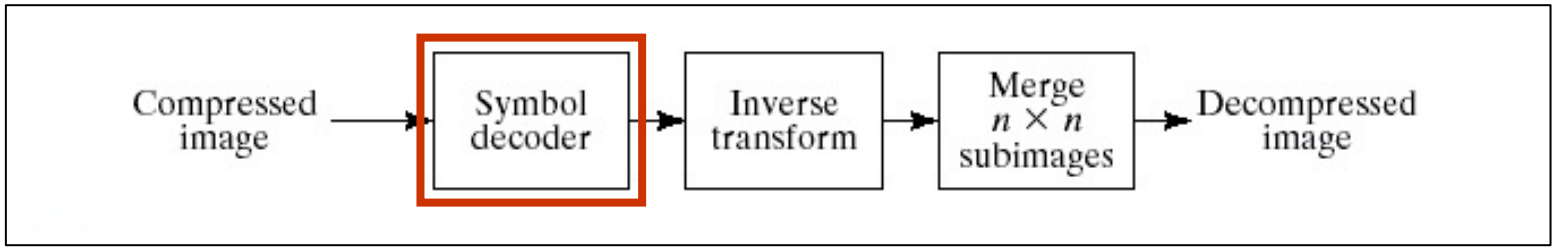
Decompression

Image Compression

Transform Coding Pipeline

Compression



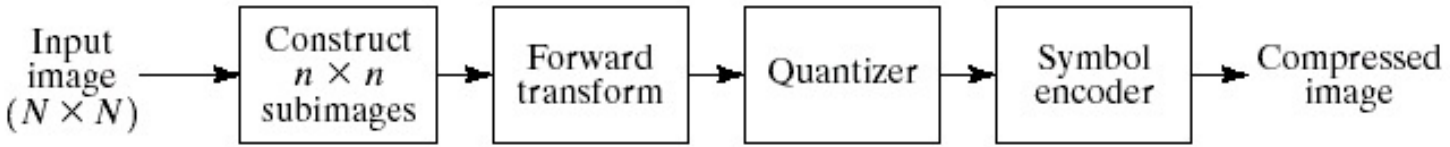


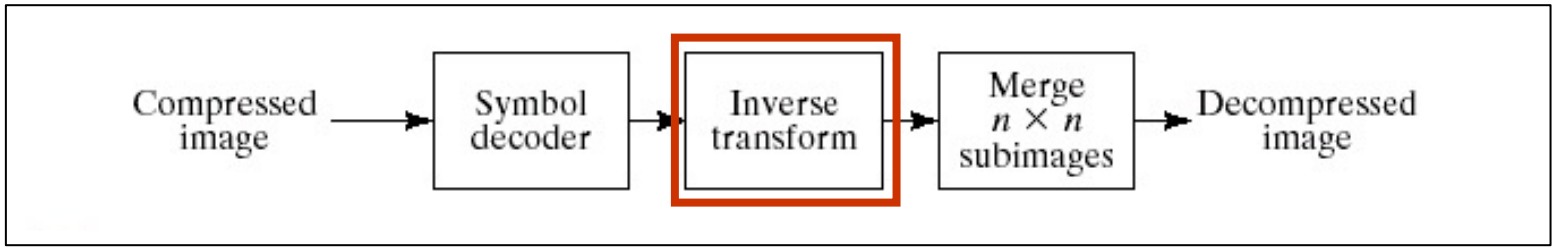
Decompression

Image Compression

Transform Coding Pipeline

Compression



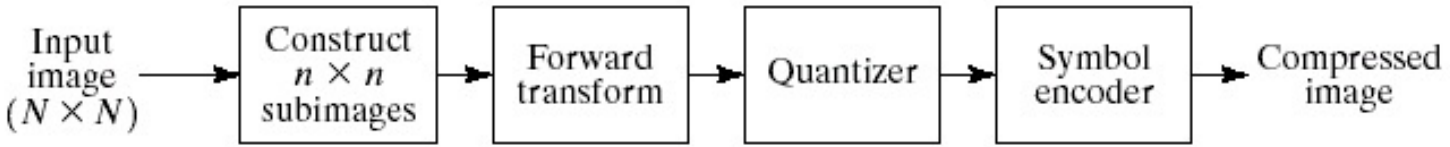


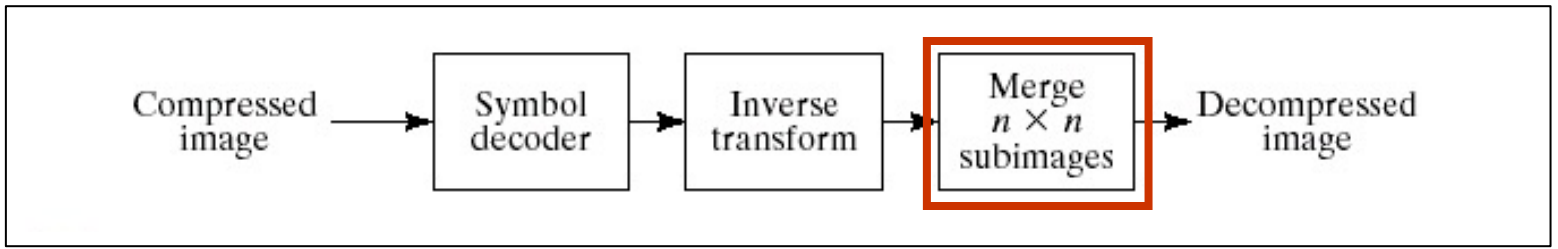
Decompression

Image Compression

Transform Coding Pipeline

Compression





Decompression

Image Compression

JPEG Standard

JPEG - Joint Photographic Experts Group

- Compression of generic continuous-tone still image
- International standard in 1992
- Typical compression 10:1 to 50:1
- Allow for lossy and lossless compression
  - DCT-based lossy compression
  - Predictive-based lossless compression

Image Compression

JPEG Standard

Image Compression

JPEG Standard

Number of modes of operation

Sequential: encoded in left-to-right, top-to-bottom scan
Progressive: encoded in multiple scans to first produce a quick, rough decoded image when the transmission time is long
Hierarchical: encoded at multiple resolution to allow accessing low resolution without full decompression
Lossless : decompressed image is identical to original

Image Compression

JPEG Standard

Sequential

Progressive

Hierarchical

Image Compression

JPEG Standard

Baseline - Sequential

- Simple, lossy compression
  - DCT-based transform coding pipeline
- Preparation
  - Shift to zero-mean by subtracting 128 ➔ [-128, 127]
  - Color space transformation (YCbCr/YUV)
  - Down sampling of color components

Image Compression

JPEG Standard: Steps

Color space transformation

$$Y = 0.3\ R + 0.6\ G + 0.1\ B$$
$$Cb = 0.5\ (B-Y) + 0.5$$
$$Cr = (1/1.6)\ (R-Y) + 0.5$$

Color components can have lower spatial resolution than luminance

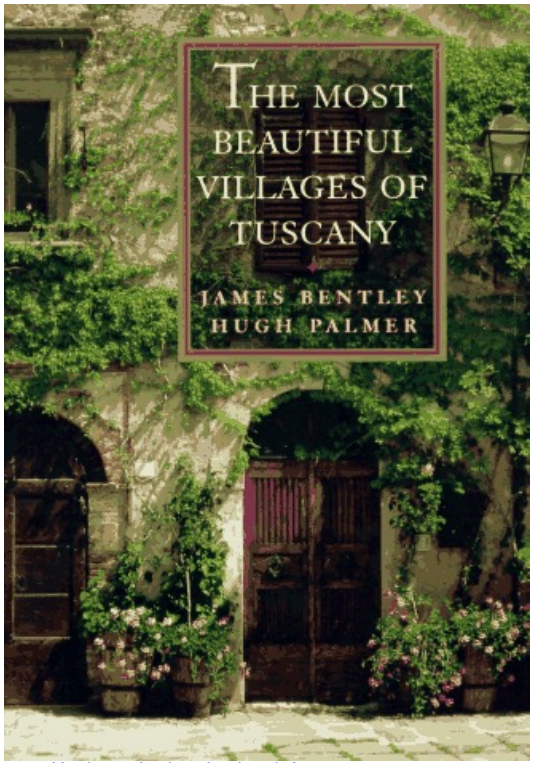
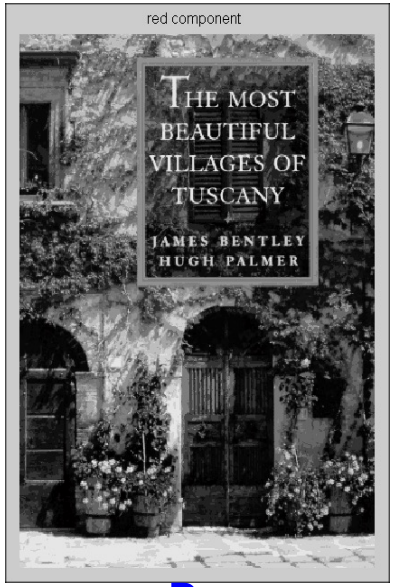


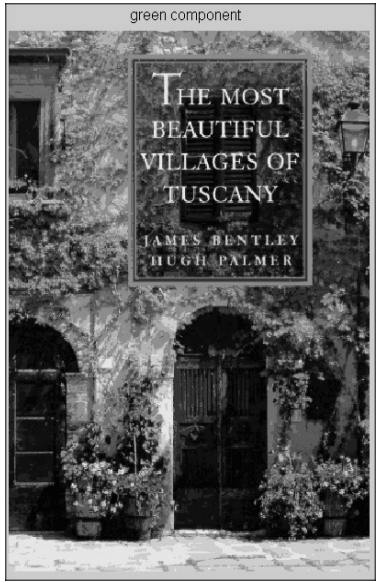
Image Compression

JPEG Standard: Steps

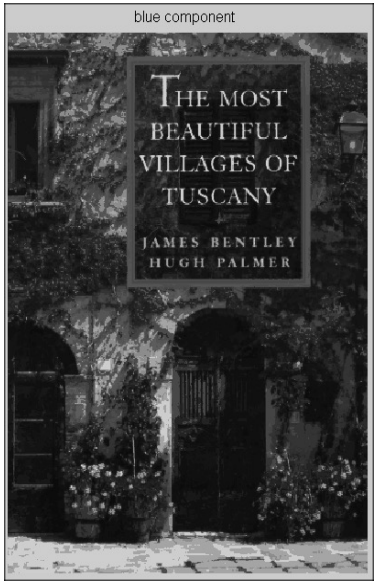
Color space transformation



R



G

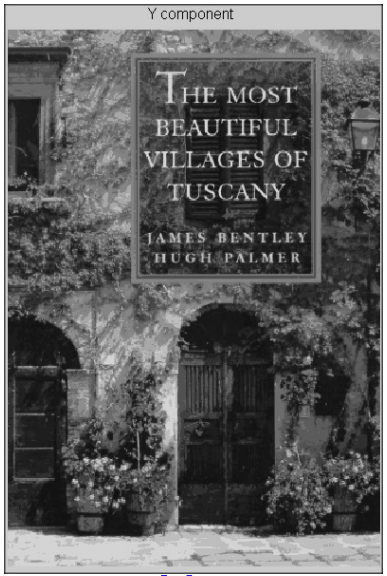


B

Image Compression

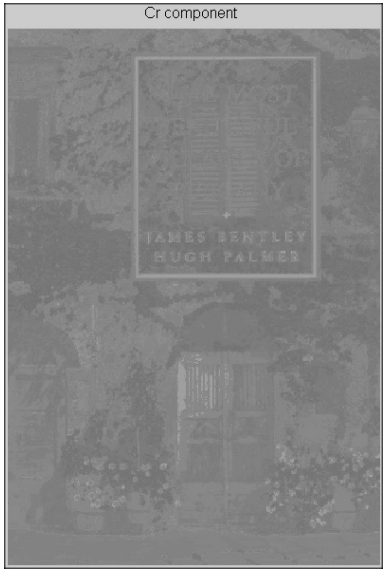
JPEG Standard: Steps

Color space transformation



Y

Cb



Cr

Image Compression

JPEG Standard: Steps

Down sampling

- 4-2-2

Y ●

Cb/Cr □

- 4-1-1

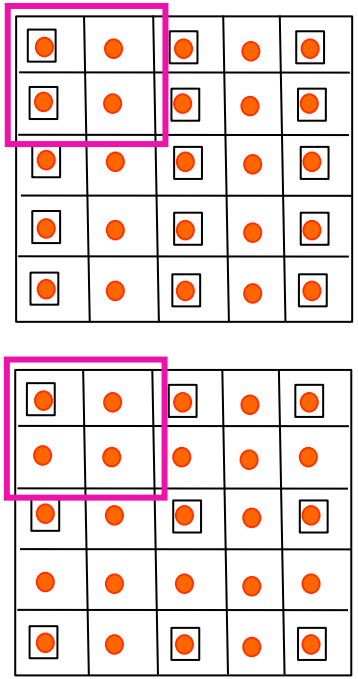


Image Compression

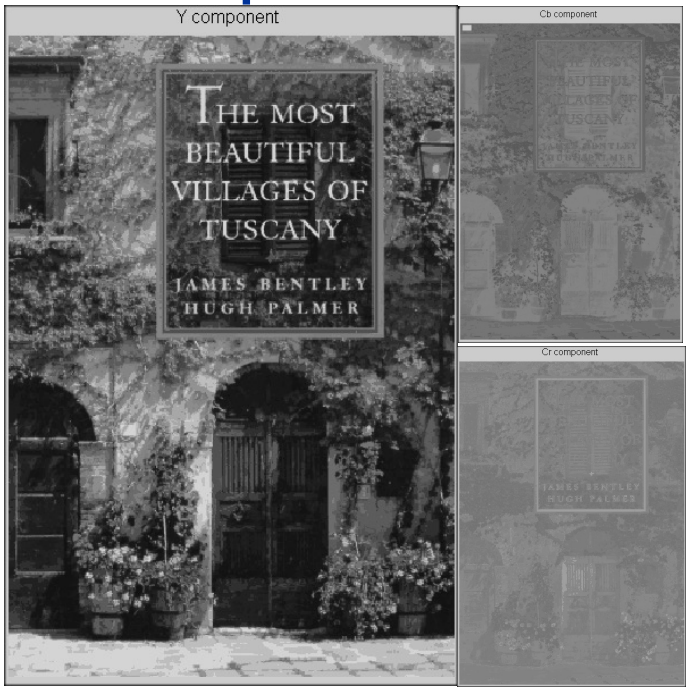
JPEG Standard: Steps

Down sampling

Example

4-1-1

Y



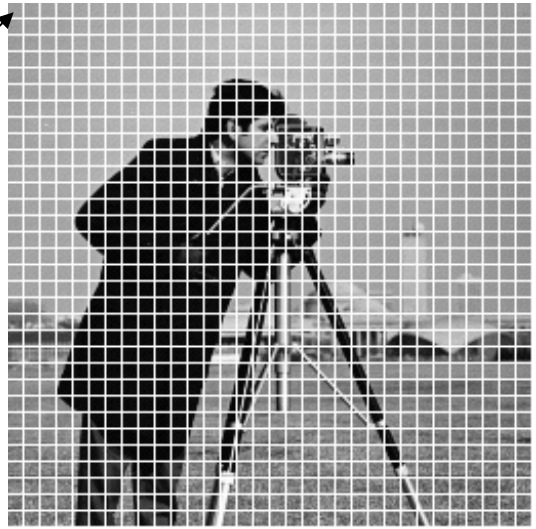
Cb

Cr

Image Compression

JPEG Standard: Steps

Divide image in to sub images

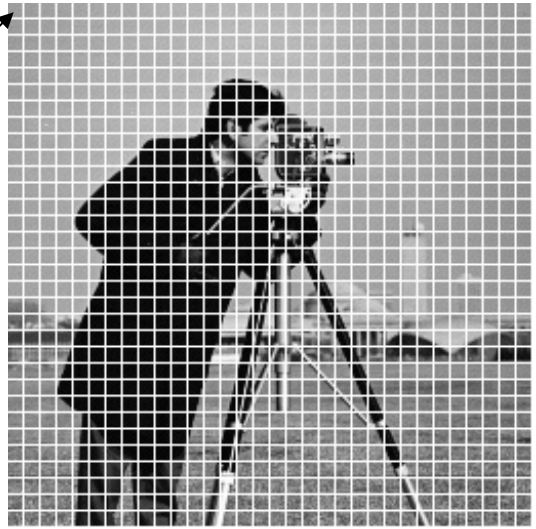


Subimage
of size 8x8

Image Compression

JPEG Standard: Steps

Divide image in to sub images



Subimage of size 8x8

What if the image size is not a multiple of 8x8 block?

Image Compression

JPEG Standard: Steps

Divide image in to sub images

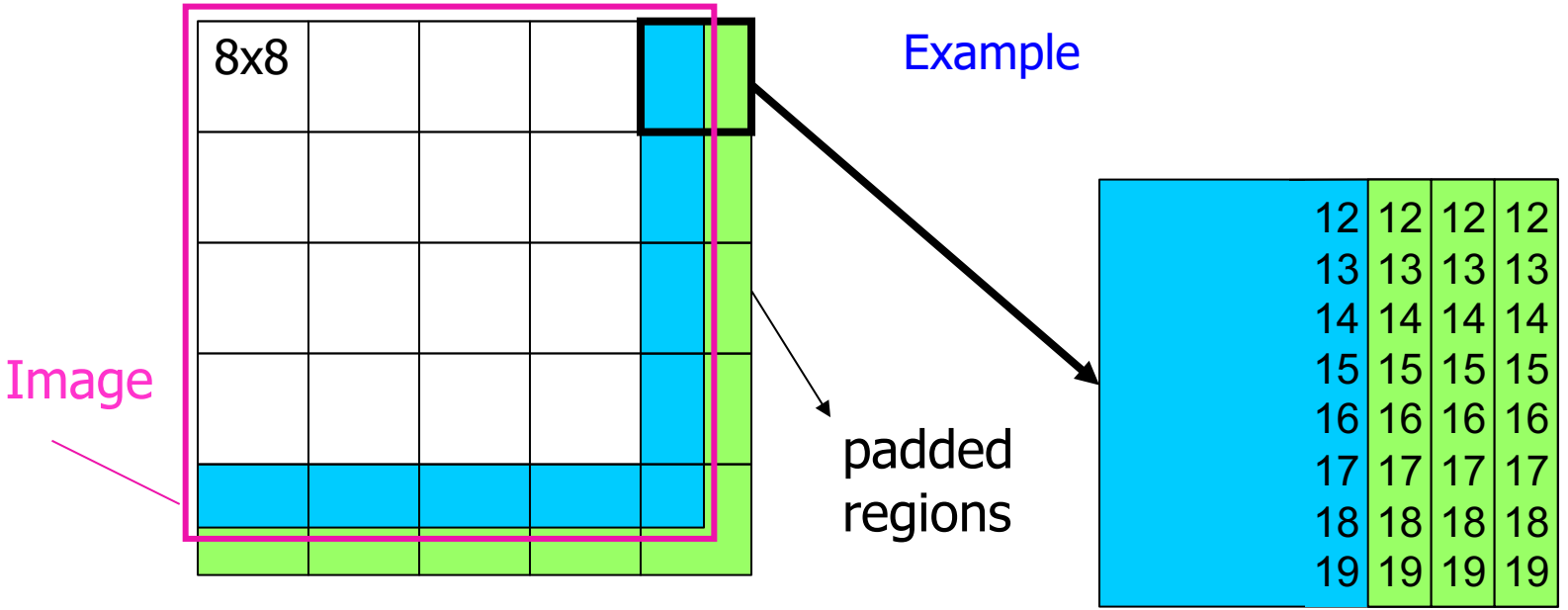


Image Compression

JPEG Standard: Steps

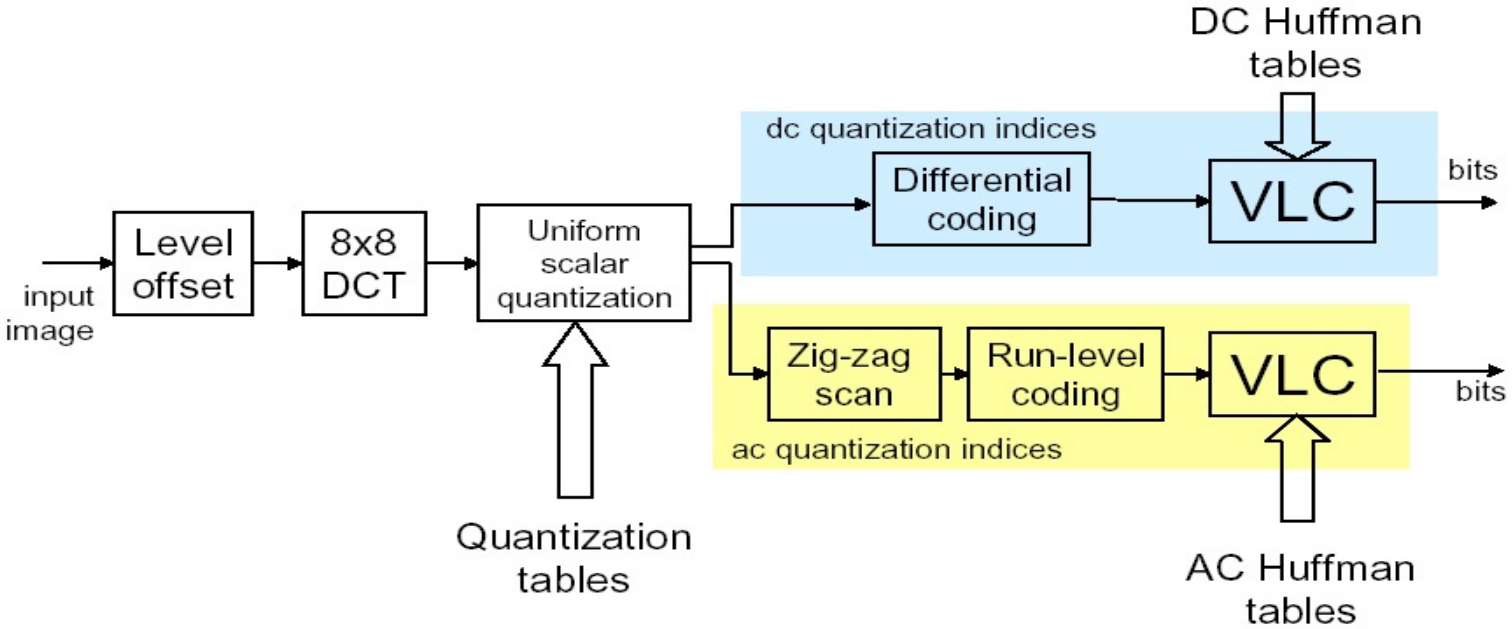


Image Compression

JPEG Standard: Steps

Example

Image

$$\begin{bmatrix} 183 & 160 & 94 & 153 & 194 & 163 & 132 & 165 \\ 183 & 153 & 116 & 176 & 187 & 166 & 130 & 169 \\ 179 & 168 & 171 & 182 & 179 & 170 & 131 & 167 \\ 177 & 177 & 179 & 177 & 179 & 165 & 131 & 167 \\ 178 & 178 & 179 & 176 & 182 & 164 & 130 & 171 \\ 179 & 180 & 180 & 179 & 183 & 169 & 132 & 169 \\ 179 & 179 & 180 & 182 & 183 & 170 & 129 & 173 \\ 180 & 179 & 181 & 179 & 181 & 170 & 130 & 169 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

Preparation Shift to zero-mean by subtracting 128

$$\begin{bmatrix} 183 & 160 & 94 & 153 & 194 & 163 & 132 & 165 \\ 183 & 153 & 116 & 176 & 187 & 166 & 130 & 169 \\ 179 & 168 & 171 & 182 & 179 & 170 & 131 & 167 \\ 177 & 177 & 179 & 177 & 179 & 165 & 131 & 167 \\ 178 & 178 & 179 & 176 & 182 & 164 & 130 & 171 \\ 179 & 180 & 180 & 179 & 183 & 169 & 132 & 169 \\ 179 & 179 & 180 & 182 & 183 & 170 & 129 & 173 \\ 180 & 179 & 181 & 179 & 181 & 170 & 130 & 169 \end{bmatrix} - 128 = \begin{bmatrix} 55 & 32 & -34 & 25 & 66 & 35 & 4 & 37 \\ 55 & 25 & -12 & 48 & 59 & 38 & 2 & 41 \\ 51 & 40 & 43 & 54 & 51 & 42 & 3 & 39 \\ 49 & 49 & 51 & 49 & 51 & 37 & 3 & 39 \\ 50 & 50 & 51 & 48 & 54 & 36 & 2 & 43 \\ 51 & 52 & 52 & 51 & 55 & 41 & 4 & 41 \\ 51 & 51 & 52 & 54 & 55 & 42 & 1 & 45 \\ 52 & 51 & 53 & 51 & 53 & 42 & 2 & 41 \end{bmatrix}$$

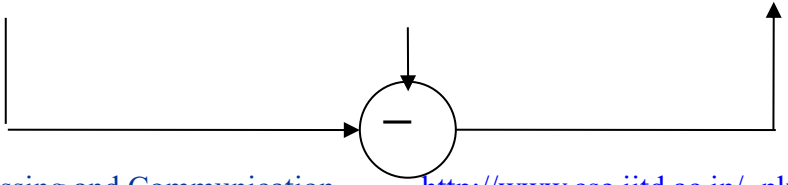


Image Compression

JPEG Standard: Steps

Preparation Shift to zero-mean by subtracting 128

$$\begin{bmatrix} 183 & 160 & 94 & 153 & 194 & 163 & 132 & 165 \\ 183 & 153 & 116 & 176 & 187 & 166 & 130 & 169 \\ 179 & 168 & 171 & 182 & 179 & 170 & 131 & 167 \\ 177 & 177 & 179 & 177 & 179 & 165 & 131 & 167 \\ 178 & 178 & 179 & 176 & 182 & 164 & 130 & 171 \\ 179 & 180 & 180 & 179 & 183 & 169 & 132 & 169 \\ 179 & 179 & 180 & 182 & 183 & 170 & 129 & 173 \\ 180 & 179 & 181 & 179 & 181 & 170 & 130 & 169 \end{bmatrix} - 128 = \begin{bmatrix} 55 & 32 & -34 & 25 & 66 & 35 & 4 & 37 \\ 55 & 25 & -12 & 48 & 59 & 38 & 2 & 41 \\ 51 & 40 & 43 & 54 & 51 & 42 & 3 & 39 \\ 49 & 49 & 51 & 49 & 51 & 37 & 3 & 39 \\ 50 & 50 & 51 & 48 & 54 & 36 & 2 & 43 \\ 51 & 52 & 52 & 51 & 55 & 41 & 4 & 41 \\ 51 & 51 & 52 & 54 & 55 & 42 & 1 & 45 \\ 52 & 51 & 53 & 51 & 53 & 42 & 2 & 41 \end{bmatrix}$$

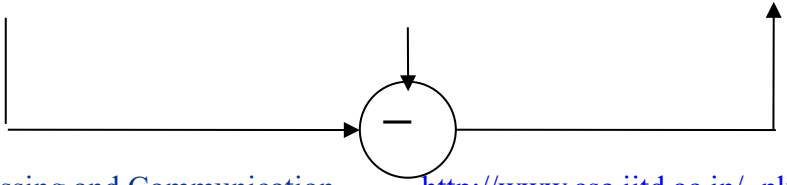


Image Compression

JPEG Standard: Steps

Forward DCT

$$\begin{bmatrix} 55 & 32 & -34 & 25 & 66 & 35 & 4 & 37 \\ 55 & 25 & -12 & 48 & 59 & 38 & 2 & 41 \\ 51 & 40 & 43 & 54 & 51 & 42 & 3 & 39 \\ 49 & 49 & 51 & 49 & 51 & 37 & 3 & 39 \\ 50 & 50 & 51 & 48 & 54 & 36 & 2 & 43 \\ 51 & 52 & 52 & 51 & 55 & 41 & 4 & 41 \\ 51 & 51 & 52 & 54 & 55 & 42 & 1 & 45 \\ 52 & 51 & 53 & 51 & 53 & 42 & 2 & 41 \end{bmatrix}$$

8×8 DCT

$$\begin{bmatrix} 313 & 56 & -27 & 18 & 78 & -60 & 27 & -27 \\ -38 & -27 & 13 & 44 & 32 & -1 & -24 & -10 \\ -20 & -17 & 10 & 33 & 21 & -6 & -16 & -9 \\ -10 & -8 & 9 & 17 & 9 & -10 & -13 & 1 \\ -6 & 1 & 6 & 4 & -3 & -7 & -5 & 5 \\ 2 & 3 & 0 & -3 & -7 & -4 & 0 & 3 \\ 4 & 4 & -1 & -2 & -9 & 0 & 2 & 4 \\ 3 & 1 & 0 & -4 & -2 & -1 & 3 & 1 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

Quantization

Q-table : specifies quantization stepsize

$$\begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

Quantization

Q-table : specifies quantization stepsize

- Q-table can be specified by user
- Q-table is scaled up/down by a chosen quality factor
- Quantization stepsize Q_{ij} is dependent on the coordinates (i,j) within the 8-by-8 block
- Quantization stepsize Q_{ij} increases from top-left to bottom-right

Image Compression

JPEG Standard: Steps

Quantization

x_{ij}

$$\begin{bmatrix} 313 & 56 & -27 & 18 & 78 & -60 & 27 & -27 \\ -38 & -27 & 13 & 44 & 32 & -1 & -24 & -10 \\ -20 & -17 & 10 & 33 & 21 & -6 & -16 & -9 \\ -10 & -8 & 9 & 17 & 9 & -10 & -13 & 1 \\ -6 & 1 & 6 & 4 & -3 & -7 & -5 & 5 \\ 2 & 3 & 0 & -3 & -7 & -4 & 0 & 3 \\ 4 & 4 & -1 & -2 & -9 & 0 & 2 & 4 \\ 3 & 1 & 0 & -4 & -2 & -1 & 3 & 1 \end{bmatrix}$$

f

s_{ij}

$$\begin{bmatrix} 20 & 5 & -3 & 1 & 3 & -2 & 1 & 0 \\ -3 & -2 & 1 & 2 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 1 & 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

Quantization

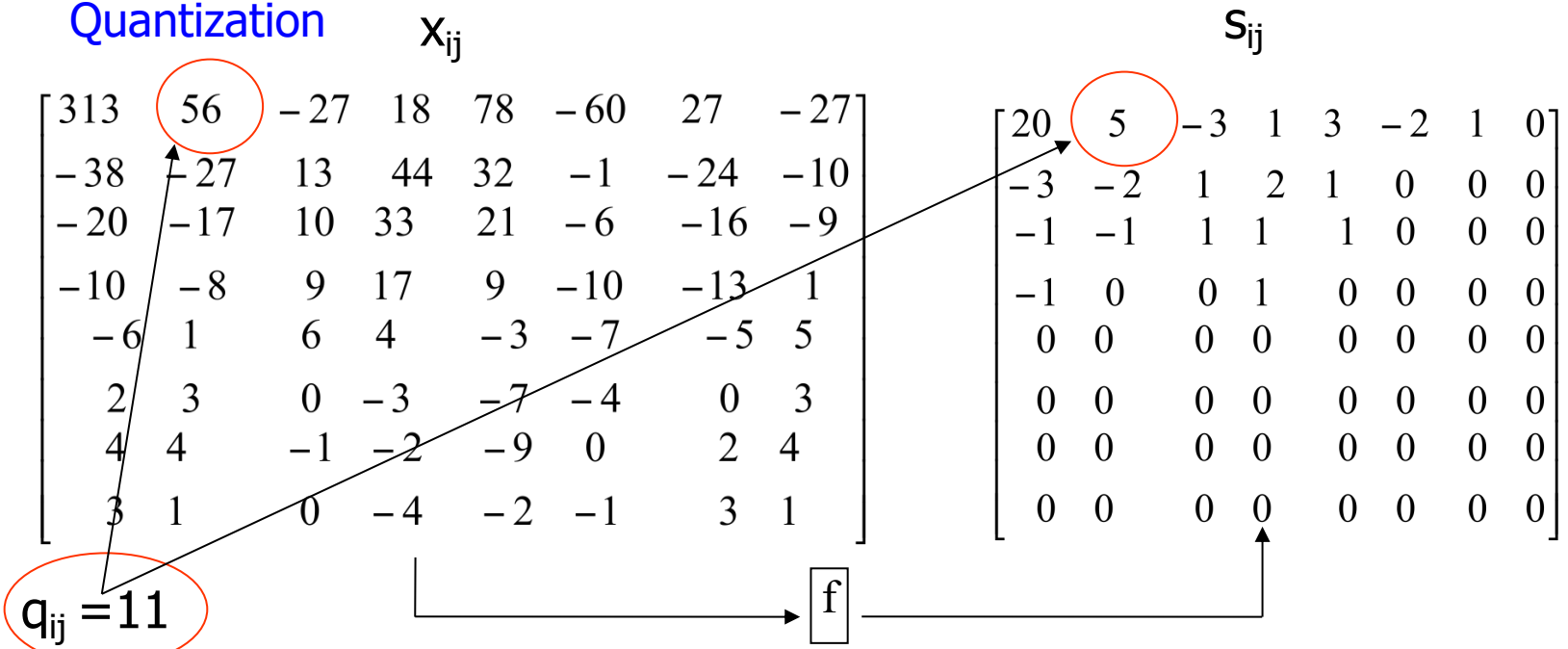


Image Compression

JPEG Standard: Steps

Quantization

x_{ij}

$$\begin{bmatrix} 313 & 56 & -27 & 18 & 78 & -60 & 27 & -27 \\ -38 & -27 & 13 & 44 & 32 & -1 & -24 & -10 \\ -20 & -17 & 10 & 33 & 21 & -6 & -16 & -9 \\ -10 & -8 & 9 & 17 & 9 & -10 & -13 & 1 \\ -6 & 1 & 6 & 4 & -3 & -7 & -5 & 5 \\ 2 & 3 & 0 & -3 & -7 & -4 & 0 & 3 \\ 4 & 4 & -1 & -2 & -9 & 0 & 2 & 4 \\ 3 & 1 & 0 & -4 & -2 & -1 & 3 & 1 \end{bmatrix}$$

f

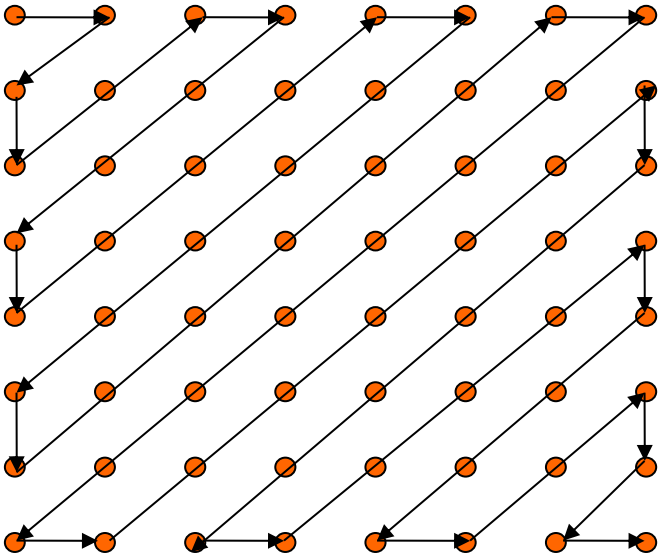
s_{ij}

$$\begin{bmatrix} 20 & 5 & -3 & 1 & 3 & -2 & 1 & 0 \\ -3 & -2 & 1 & 2 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 1 & 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

Quantization



Zigzag Scan

$$\begin{bmatrix} 20 & 5 & -3 & 1 & 3 & -2 & 1 & 0 \\ -3 & -2 & 1 & 2 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 1 & 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

zigzag scan

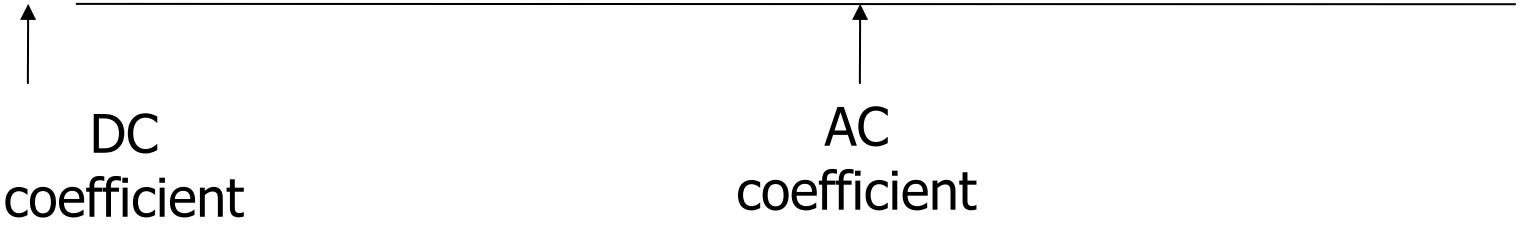
(20,5,-3,-1,-2,-3,1,1,-1,-1,
0,0,1,2,3,-2,1,1,0,0,0,0,0,
0,1,1,0,1,EOB)

Image Compression

JPEG Standard: Steps

Differential Coding, Run Length Coding, Variable Length Coding

(20,5,-3,-1,-2,-3,1,1,-1,-1,0,0,1,2,3,-2,1,1,0,0,0,0,0,0,1,1,0,1,EOB)



- DC coefficient : Differential coding
- AC coefficient : run-length coding (run, level)

→ Huffman coding

Image Compression

JPEG Standard: Steps

Decompression

(20,5,-3,-1,-2,-3,1,1,-1,-1,0,0,1,2,3,-2,1,1,0,0,0,0,0,0,1,1,0,1,EOB)

zigzag

$$\begin{bmatrix} 20 & 5 & -3 & 1 & 3 & -2 & 1 & 0 \\ -3 & -2 & 1 & 2 & 1 & 0 & 0 & 0 \\ -1 & -1 & 1 & 1 & 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \xrightarrow{f^{-1}} \begin{bmatrix} 320 & 55 & -30 & 16 & 72 & -80 & 51 & 0 \\ -36 & -24 & 14 & 38 & 26 & 0 & 0 & 0 \\ -14 & -13 & 16 & 24 & 40 & 0 & 0 & 0 \\ -14 & 0 & 0 & 29 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

$$\begin{bmatrix} 320 & 55 & -30 & 16 & 72 & -80 & 51 & 0 \\ -36 & -24 & 14 & 38 & 26 & 0 & 0 & 0 \\ -14 & -13 & 16 & 24 & 40 & 0 & 0 & 0 \\ -14 & 0 & 0 & 29 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Decompression

8 × 8 IDCT

$$\begin{bmatrix} 67 & 12 & -9 & 20 & 69 & 43 & -8 & 43 \\ 58 & 25 & 15 & 30 & 65 & 40 & -4 & 47 \\ 46 & 41 & 44 & 40 & 59 & 38 & 0 & 49 \\ 41 & 52 & 59 & 43 & 57 & 42 & 3 & 42 \\ 44 & 54 & 58 & 40 & 58 & 47 & 1 & 33 \\ 53 & 50 & 53 & 46 & 63 & 41 & 0 & 45 \\ 55 & 50 & 56 & 53 & 64 & 34 & -1 & 57 \\ 52 & 51 & 53 & 51 & 53 & 42 & 2 & 41 \end{bmatrix}$$

128

+

$$\begin{bmatrix} 195 & 140 & 119 & 148 & 197 & 171 & 120 & 170 \\ 186 & 153 & 143 & 158 & 193 & 168 & 124 & 175 \\ 174 & 169 & 172 & 168 & 187 & 166 & 128 & 177 \\ 169 & 180 & 187 & 171 & 185 & 170 & 131 & 170 \\ 172 & 182 & 186 & 168 & 186 & 175 & 129 & 161 \\ 181 & 178 & 181 & 174 & 191 & 169 & 128 & 173 \\ 183 & 178 & 184 & 181 & 192 & 162 & 127 & 185 \\ 180 & 179 & 181 & 179 & 181 & 170 & 130 & 169 \end{bmatrix}$$

Image Compression

JPEG Standard: Steps

$$X = \begin{bmatrix} 183 & 160 & 94 & 153 & 194 & 163 & 132 & 165 \\ 183 & 153 & 116 & 176 & 187 & 166 & 130 & 169 \\ 179 & 168 & 171 & 182 & 179 & 170 & 131 & 167 \\ 177 & 177 & 179 & 177 & 179 & 165 & 131 & 167 \\ 178 & 178 & 179 & 176 & 182 & 164 & 130 & 171 \\ 179 & 180 & 180 & 179 & 183 & 169 & 132 & 169 \\ 179 & 179 & 180 & 182 & 183 & 170 & 129 & 173 \\ 180 & 179 & 181 & 179 & 181 & 170 & 130 & 169 \end{bmatrix}$$

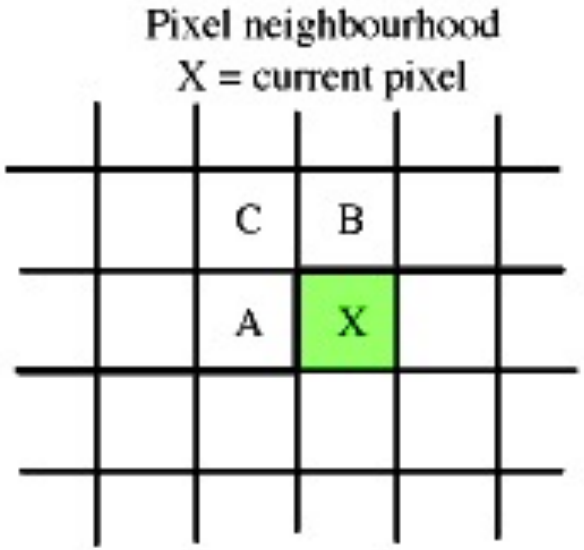
$$\hat{X} = \begin{bmatrix} 195 & 140 & 119 & 148 & 197 & 171 & 120 & 170 \\ 186 & 153 & 143 & 158 & 193 & 168 & 124 & 175 \\ 174 & 169 & 172 & 168 & 187 & 166 & 128 & 177 \\ 169 & 180 & 187 & 171 & 185 & 170 & 131 & 170 \\ 172 & 182 & 186 & 168 & 186 & 175 & 129 & 161 \\ 181 & 178 & 181 & 174 & 191 & 169 & 128 & 173 \\ 183 & 178 & 184 & 181 & 192 & 162 & 127 & 185 \\ 180 & 179 & 181 & 179 & 181 & 170 & 130 & 169 \end{bmatrix}$$

Distortion calculation: $MSE = ||X - \hat{X}||^2$

Image Compression

JPEG Standard

Predictive Lossless



Encoder type	Prediction method
0	no prediction
1	A
2	B
3	C
4	A + B – C
5	A + ((B – C) / 2)
6	B + ((A – C) / 2)
7	(A + B) / 2

Image Compression JPEG 2000

JPEG: DCT

JPEG 2000: Wavelets