Fundamentals of Multimedia

Lecture 7
JPEG Compression

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Outcomes of Lecture 6

- *Lossy Compression*
  - Definition
  - Distortion measure
- *Quantization*
  - Uniform scale quantization
  - Nonuniform scale quantization

Outline

- *Definition of transform coding*
  - Compression scheme for transform coding
- *JPEG Compression*

Outline

- ***Definition of transform coding***
  - Compression scheme for transform coding
- *JPEG Compression*

Transform Coding

- *Example of transform coding*
  - Original data X: {100 100 100 100 100 100 100 100}
  - Transform coding T: $d_i - d_{i-1}$ and $d_0 = 0$;
  - Transformed vector Y: {100 0 0 0 0 0 0 0}
- *Transform coding*
  - Y is the result of a linear transform T of the input vector X in such a way that the components of Y are much less correlated
- *Compression scheme for transform coding*
  - If most information is accurately described by the first few components, then the remaining components can be quantized
  - Y': {100}

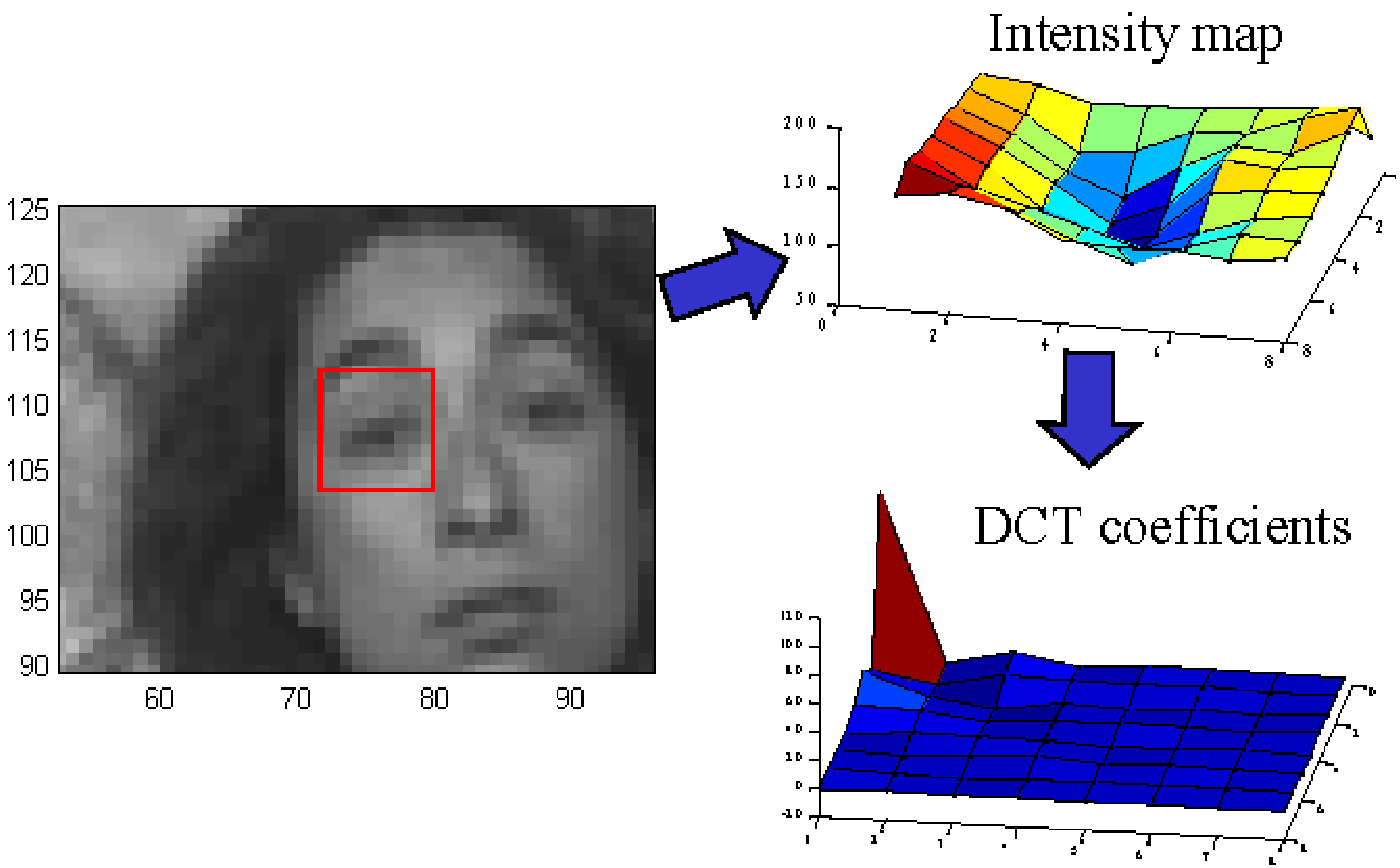
Discrete Cosine Transform

- *The Discrete Cosine Transform (DCT) is a widely used transform coding technique*
    - Spatial frequency indicates how many times pixel values change across an image block
    - The DCT formalizes this notion in terms of how much the image contents change in correspondence to the number of cycles of a cosine wave per block
    - The role of the DCT is to decompose the original signal into its DC (Direct Current) and AC (Alternating Current) components; the role of the IDCT is to reconstruct (re-compose) the signal

DCT for Image Data

- *Useful image contents change relatively slowly*
  - DCT can concentrate the information within first several components
  - The value in the location F[0,0] of the transformed matrix is called the ***DC*** coefficient, the other values are called the ***AC*** coefficients.
  - Spatial frequency coefficients increase as we move from left to right (horizontally) or from top to bottom (vertically). Low spatial frequencies are clustered in the left top corner.
- *Human **are not sensitive** to the loss of information of **high spatial frequency***

DCT for Image Data



Uniform Scalar Quantization

1 Top-left coefficient per block

3 top-left coefficients

6 top-left coefficients

All coefficients

Outline

- *Definition of transform coding*
  - Compression scheme for transform coding
- ***JPEG Compression***

Image Compression Standard JPEG

- *Developed by the "Joint Photographic Experts Group"*
- *Accepted as an international standard in 1992*
- *JPEG combines several lossless and lossy compression techniques:*
  - Color model transformation
  - Transform coding
  - Quantization
  - Differential Pulse Code Modulation (DPCM), Run-length coding
  - Entropy coding (Huffman)

Image Compression Standard JPEG

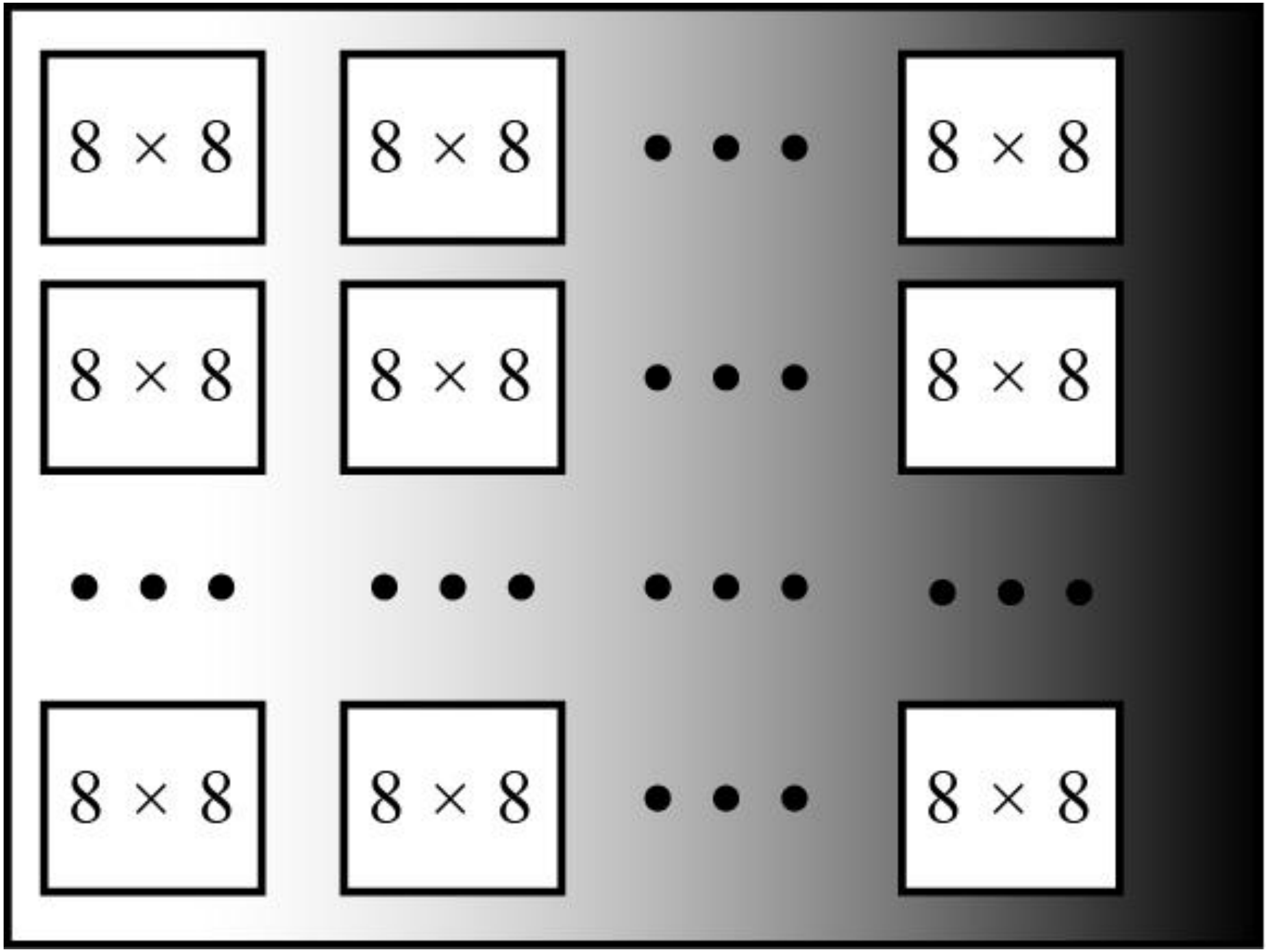


Image Compression Standard JPEG

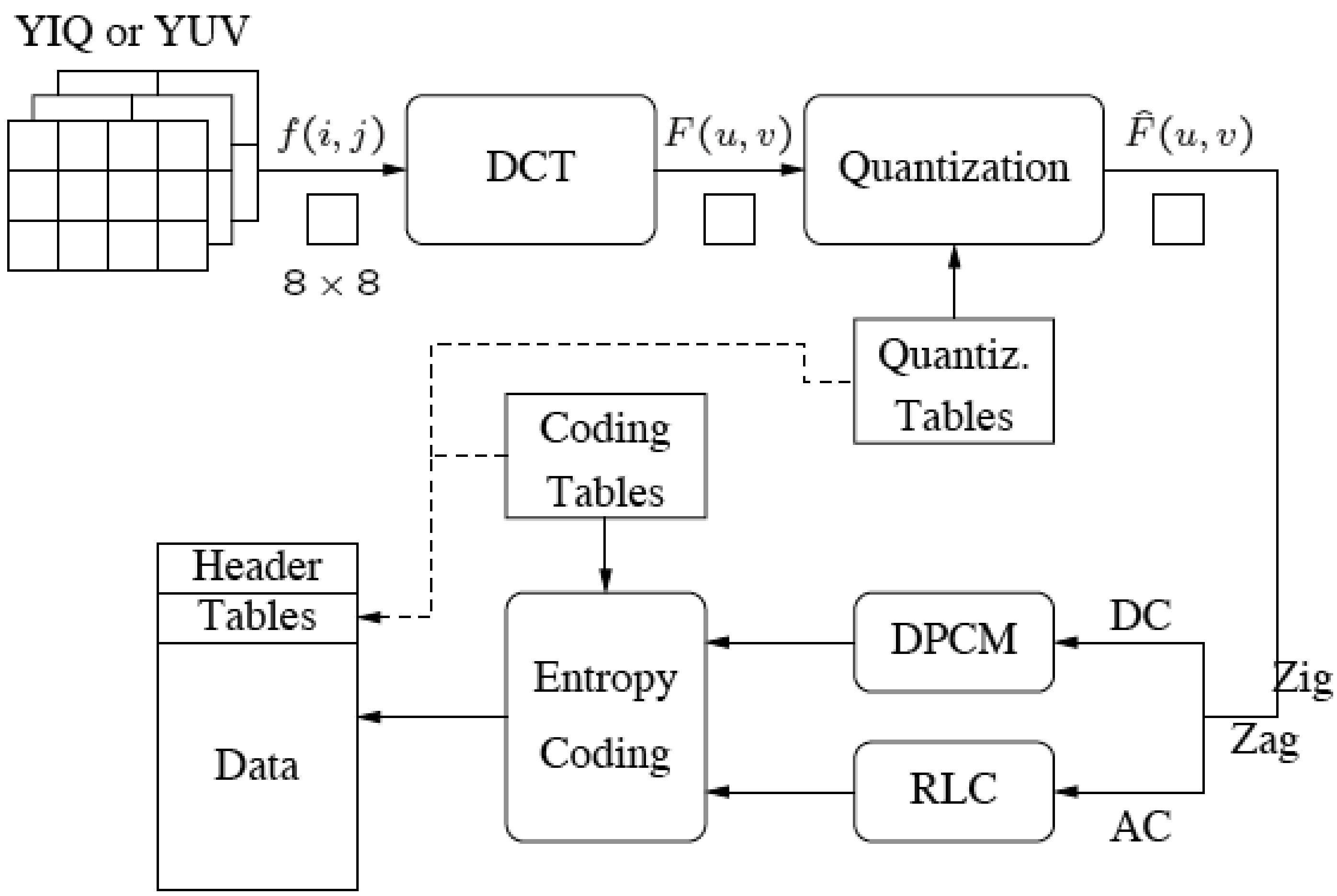
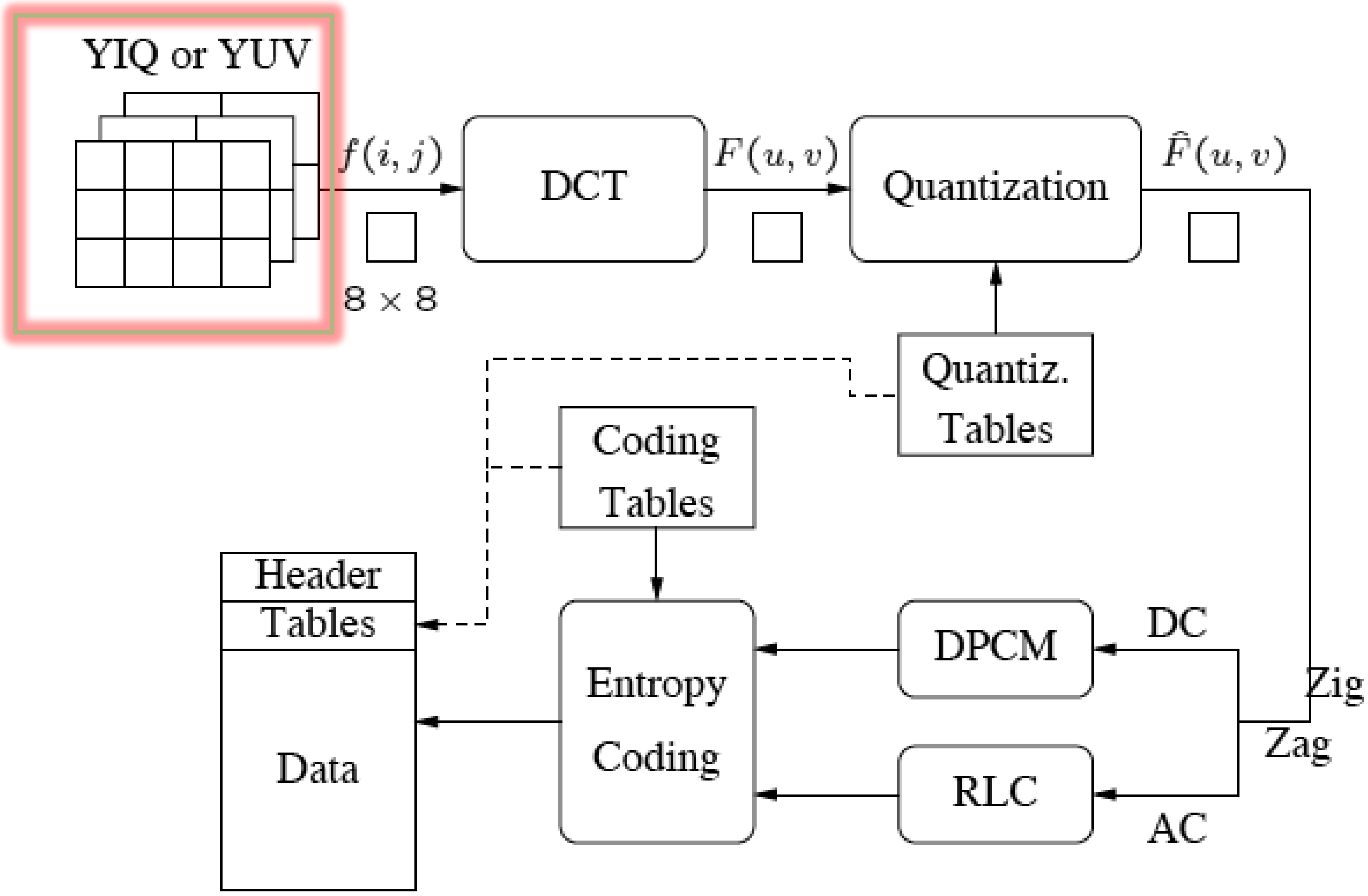


Image Compression Standard JPEG

- *The main steps in JPEG encoding are the following*
  - Transform RGB to YUV or YCbCr and subsample color
  - DCT on 8x8 image blocks
  - Quantization
  - Zig-zag ordering and run-length encoding
  - Entropy coding (Huffman)

Image Compression Standard JPEG



Transform RGB Color Model to YUV or YIQ

- *Motivation*
  - Human's eye is much more sensitive for gray than for color
- *YUV color model*
  - Y: luminance information (**gray**)
  - U and V: chrominance information (**color**)
- *Subsample chrominance components*
  - We can use the full resolution for the luminance and use half resolution for the chrominance components U and V

Transform RGB Color Model to YUV or YIQ

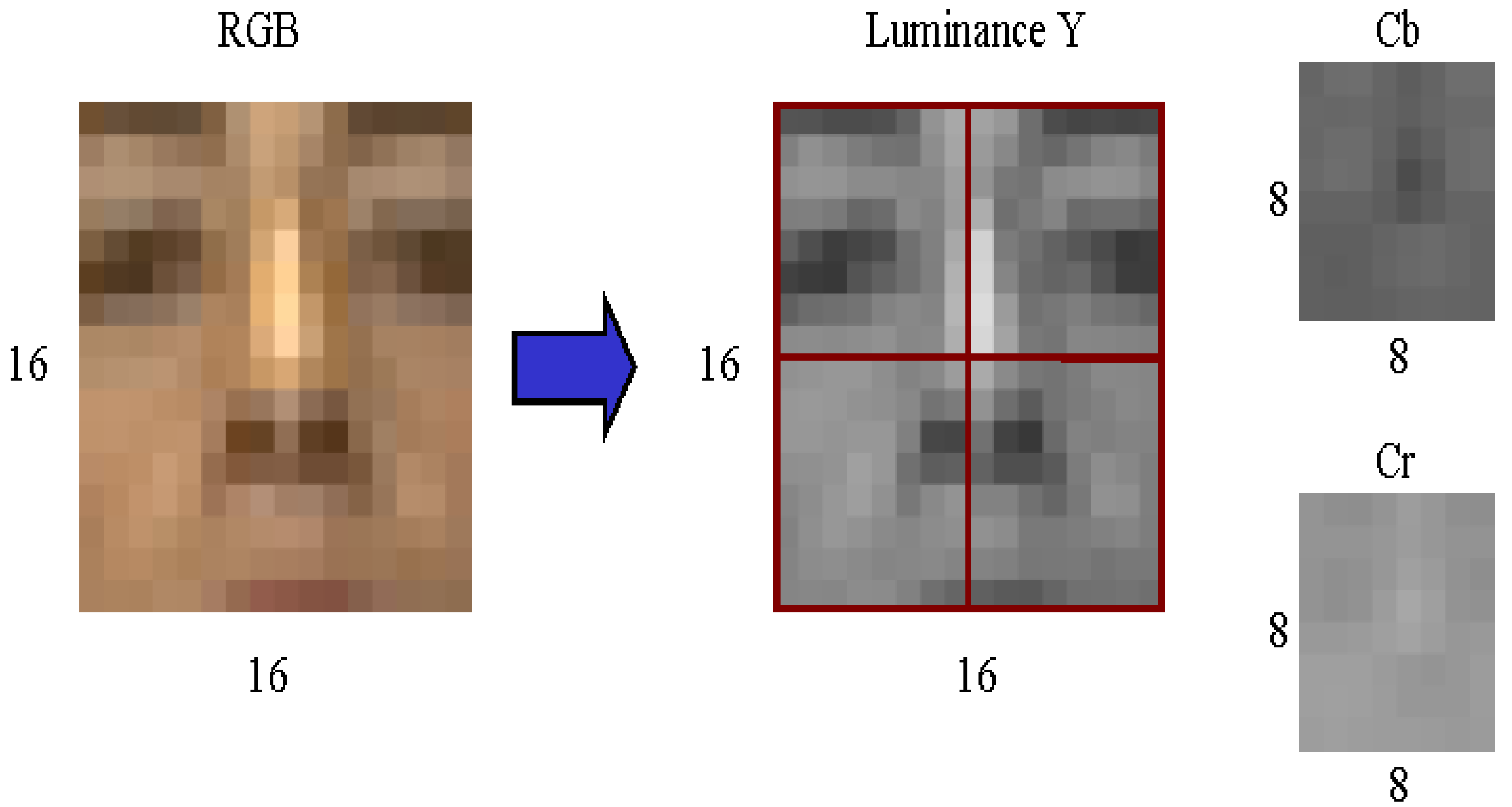
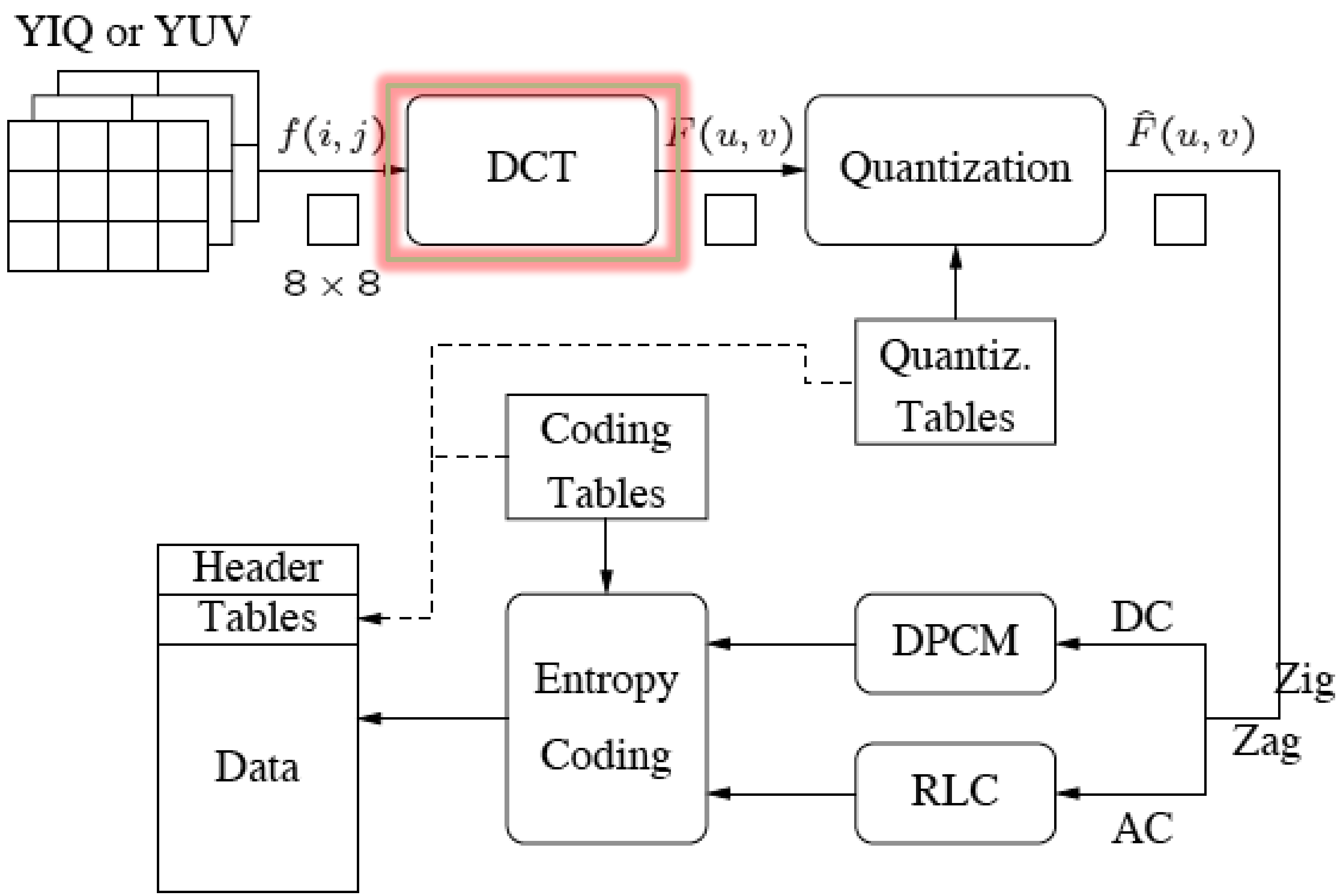
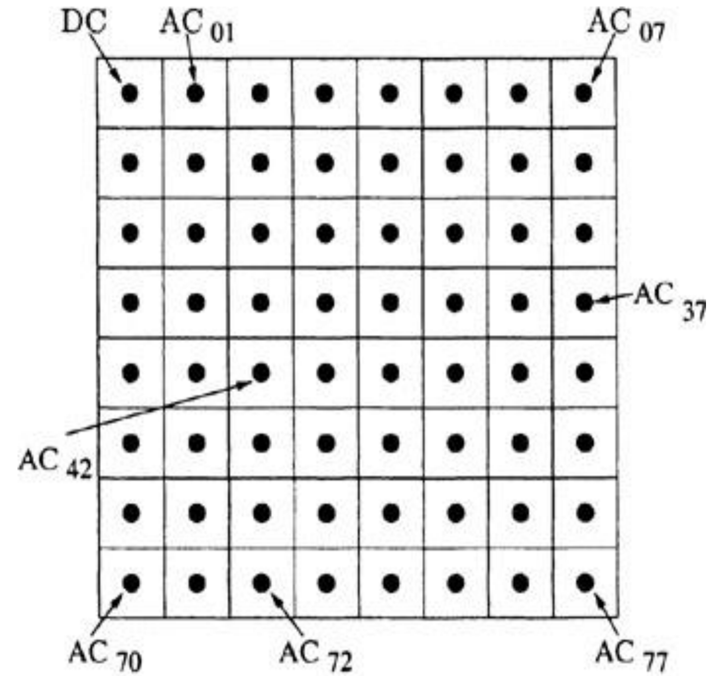


Image Compression Standard JPEG



DCT Coding of an Image Block

- *Transformed 8 × 8 block now consists of 64 DCT coefficients*
  - The first coefficient F(0, 0) is the DC component of the block
  - Remaining 63 coefficients are AC components



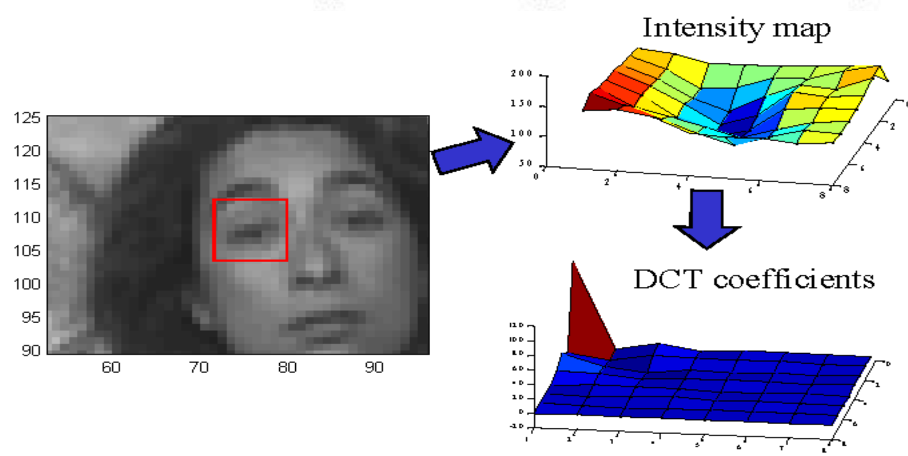
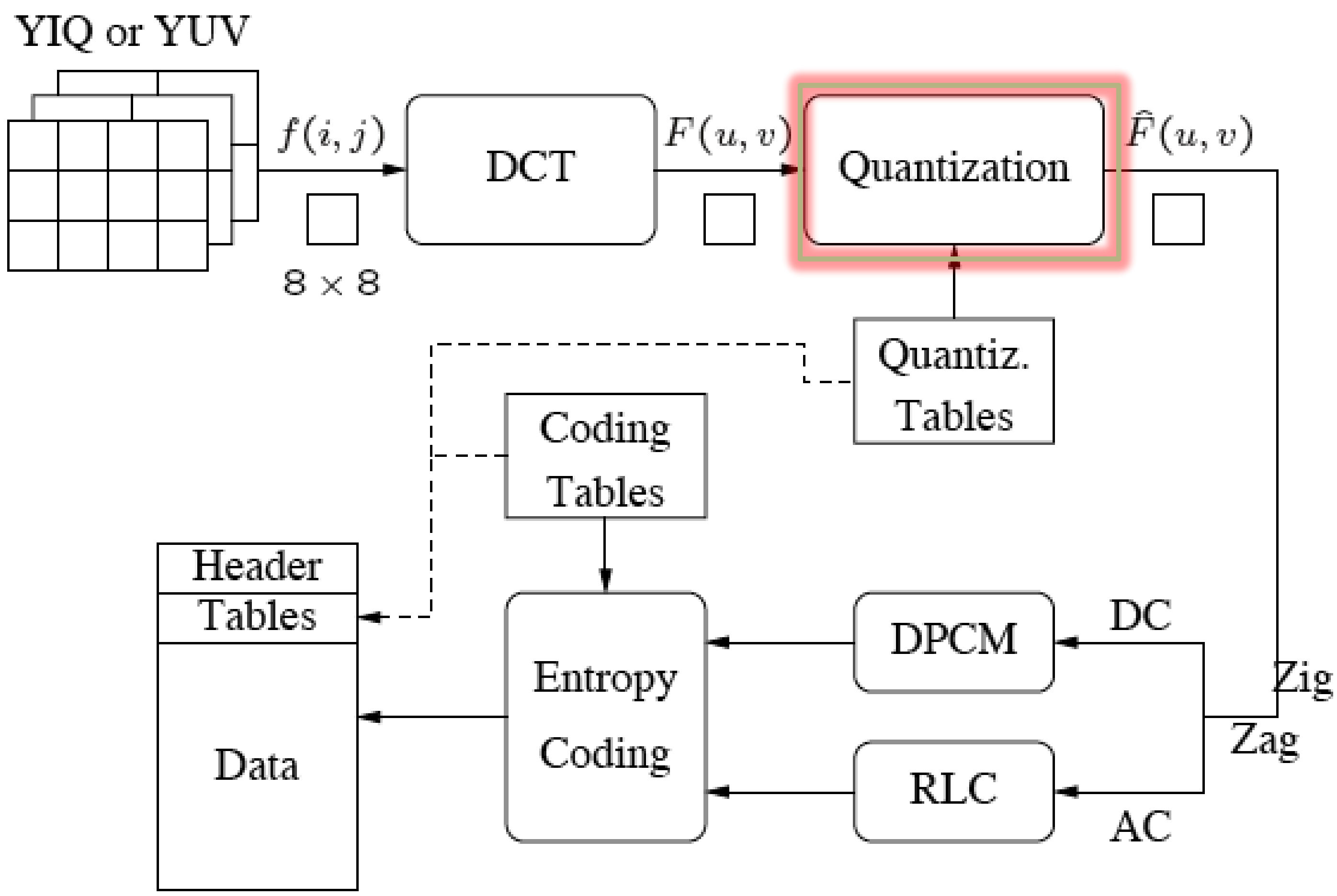


Image Compression Standard JPEG



Uniform Scalar Quantization

- *Each of the 64 coefficients are uniformly quantized*
- *The human eyes are more reactive to low frequencies than to high ones. Quantization is used to discard perceptibly insignificant information.*
- *It basically converts each real DCT coefficient to an integer by scaling it by a factor and then discarding the digits after the decimal point.*

Uniform Scalar Quantization

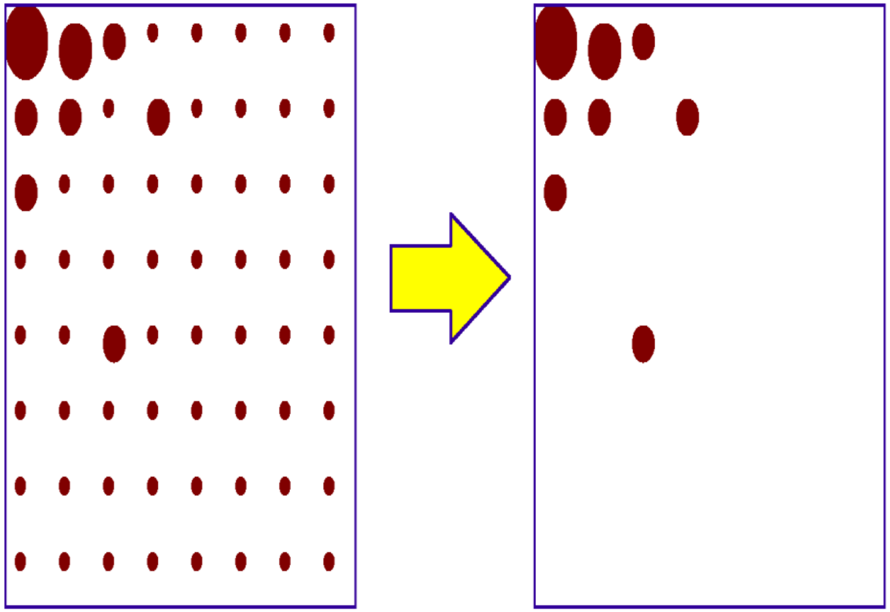
1 Top-left coefficient per block

3 top-left coefficients

6 top-left coefficients

All coefficients

Example: Original and DCT



An 8 × 8 block from the Y ima

200	202	189	188	189	175	175	175
200	203	198	188	189	182	178	175
203	200	200	195	200	187	185	175
200	200	200	200	197	187	187	187
200	205	200	200	195	188	187	175
200	200	200	200	200	190	187	175
205	200	199	200	191	187	187	175
210	200	200	200	188	185	187	186

$f(i,j)$

5

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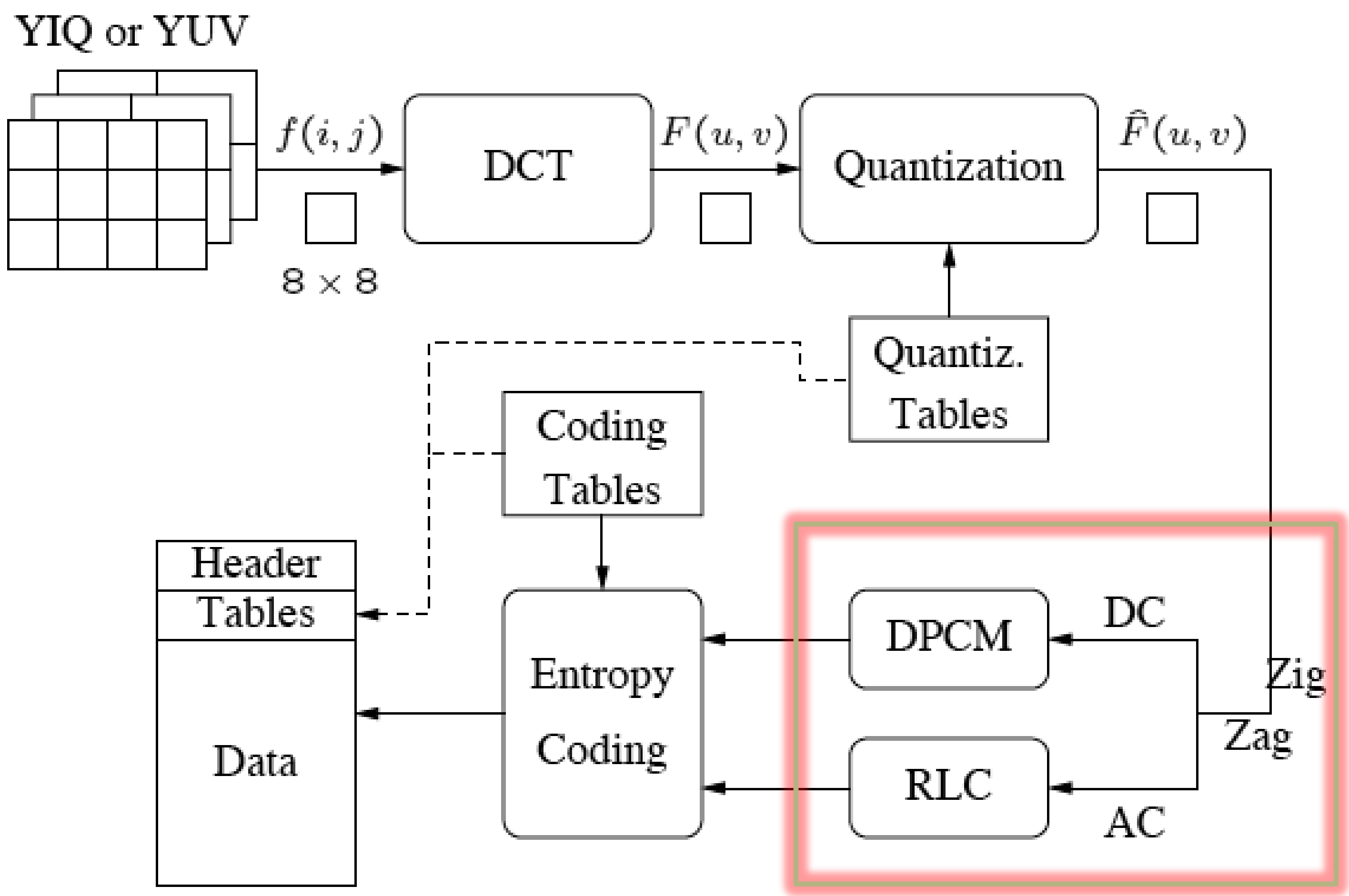
32	6	-1	0	0	0	0	0
-1	0	0	0	0	0	0	0
-1	0	1	0	0	0	0	0
-1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

$\hat{F}(u,v)$

Image Compression Standard JPEG



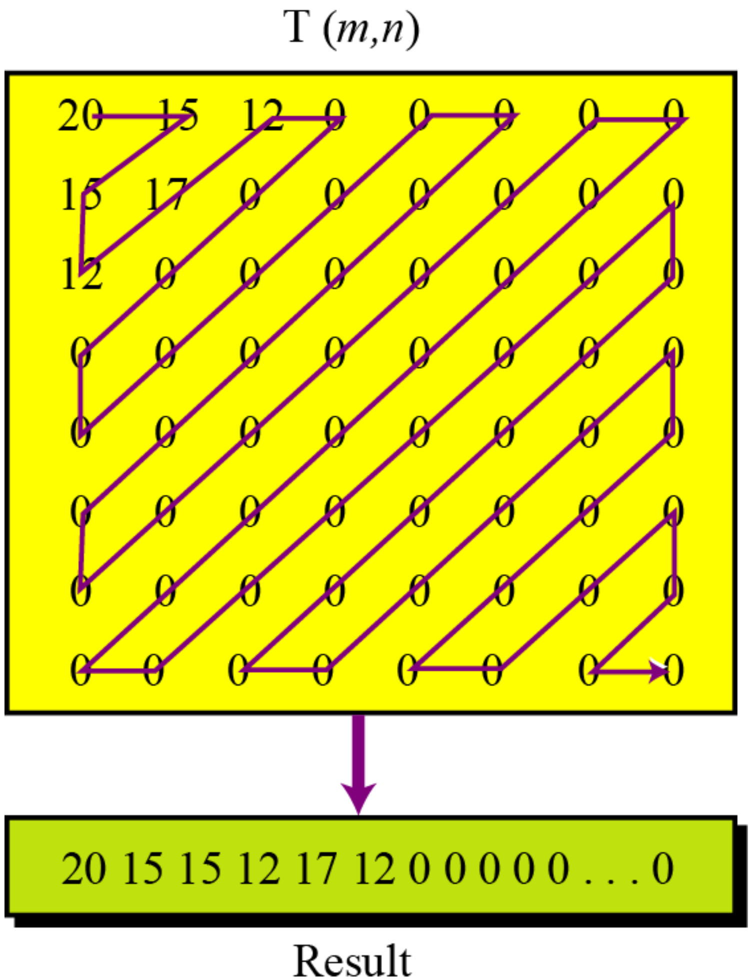
Preparation for Entropy Coding

- *We have seen two main steps in JPEG coding:* ***DCT and quantization***
- *The remaining steps all lead up to entropy coding of the quantized DCT coefficients*
  - These additional data compression steps are lossless
  - Most of the lossiness is in the quantization step

Run Length Coding

- *The AC and DC components are treated differently*
- *Since after quantization we have many 0 AC components, RLC is a good idea*
- *Note that most of the zero components are towards the lower right corner (high spatial frequencies)*
- *To take advantage of this, use* ***zigzag*** *scanning to create a 64-vector*

Zigzag Scanning



Run Length Coding

- *Now the RLC step replaces values in a 64-vector (previously an 8x8 block) by a pair (RUNLENGTH, VALUE), where **RUNLENGTH** is the **number of zeroes** in the run and **VALUE** is the **next non-zero value***
  - From the first example we have (32, 6, -1, -1, 0, -1, 0, 0, 0, -1, 0, 0, 1, 0, 0, …, 0)
  - This becomes (0,6) (0,-1)(0,-1)(1,-1)(3,-1)(2,1)(0,0)
  - **Note that DC coefficient is ignored**

Coding of DC Coefficients

- *1 DC per block*
- *DC coefficients may vary greatly over the whole image, but change slowly from one block to its neighbor.*
- *So apply* ***Differential Pulse Code Modulation*** *(DPCM) for the DC coefficients*
  - If the first five DC coefficients are 150, 155, 149, 152, 144, we come up with DPCM code- 150, 5, -6, 3, -8

Image Compression Standard JPEG

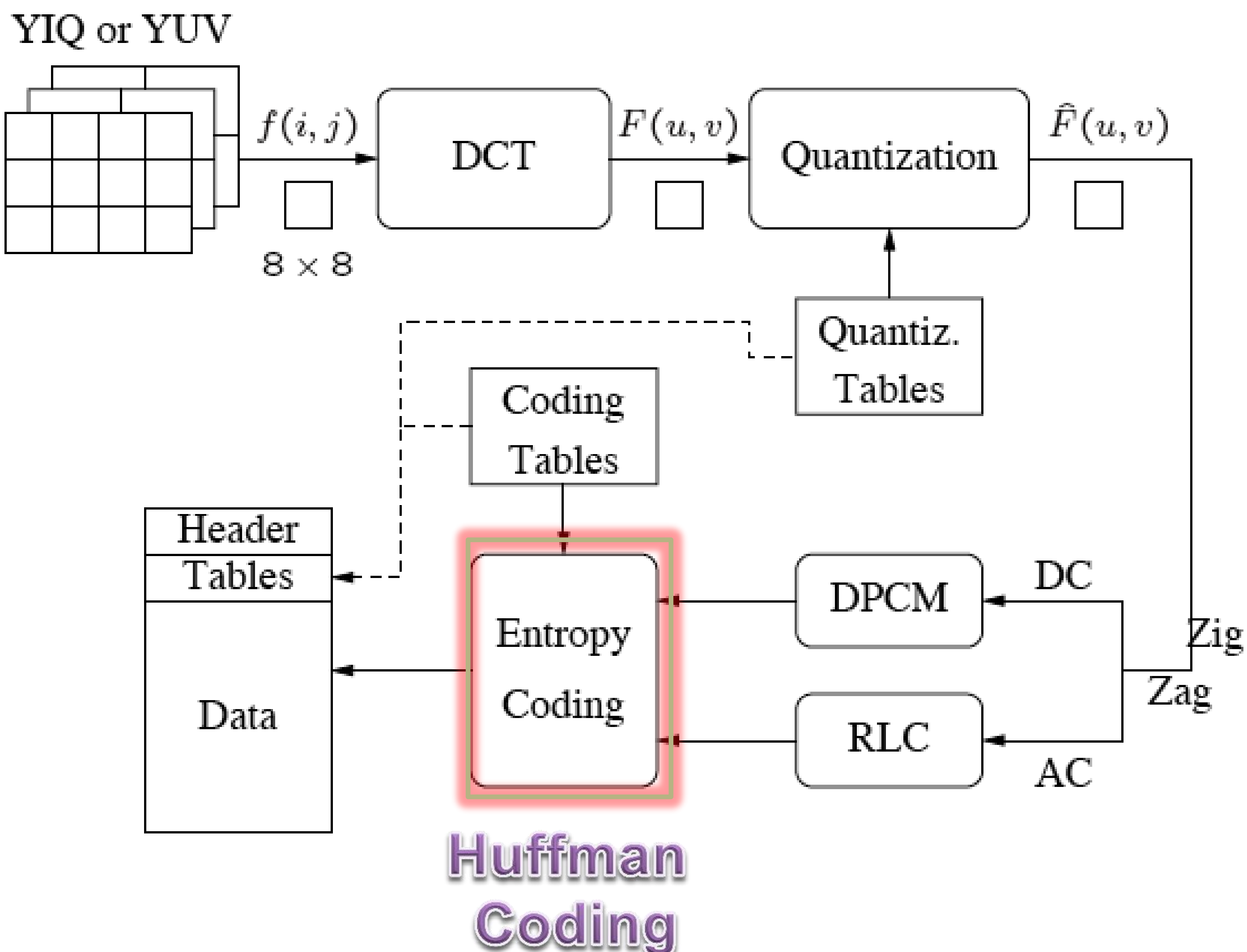
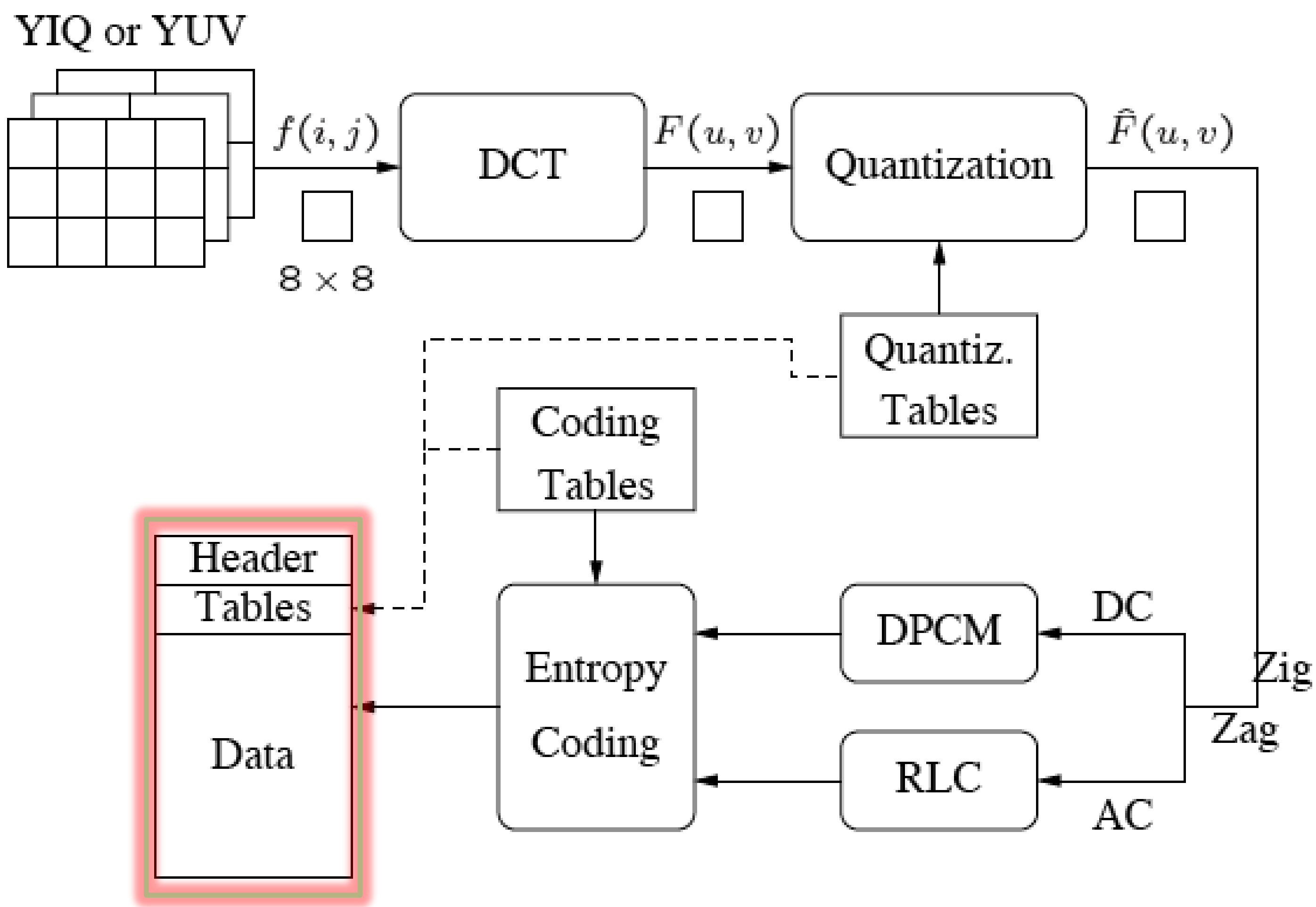
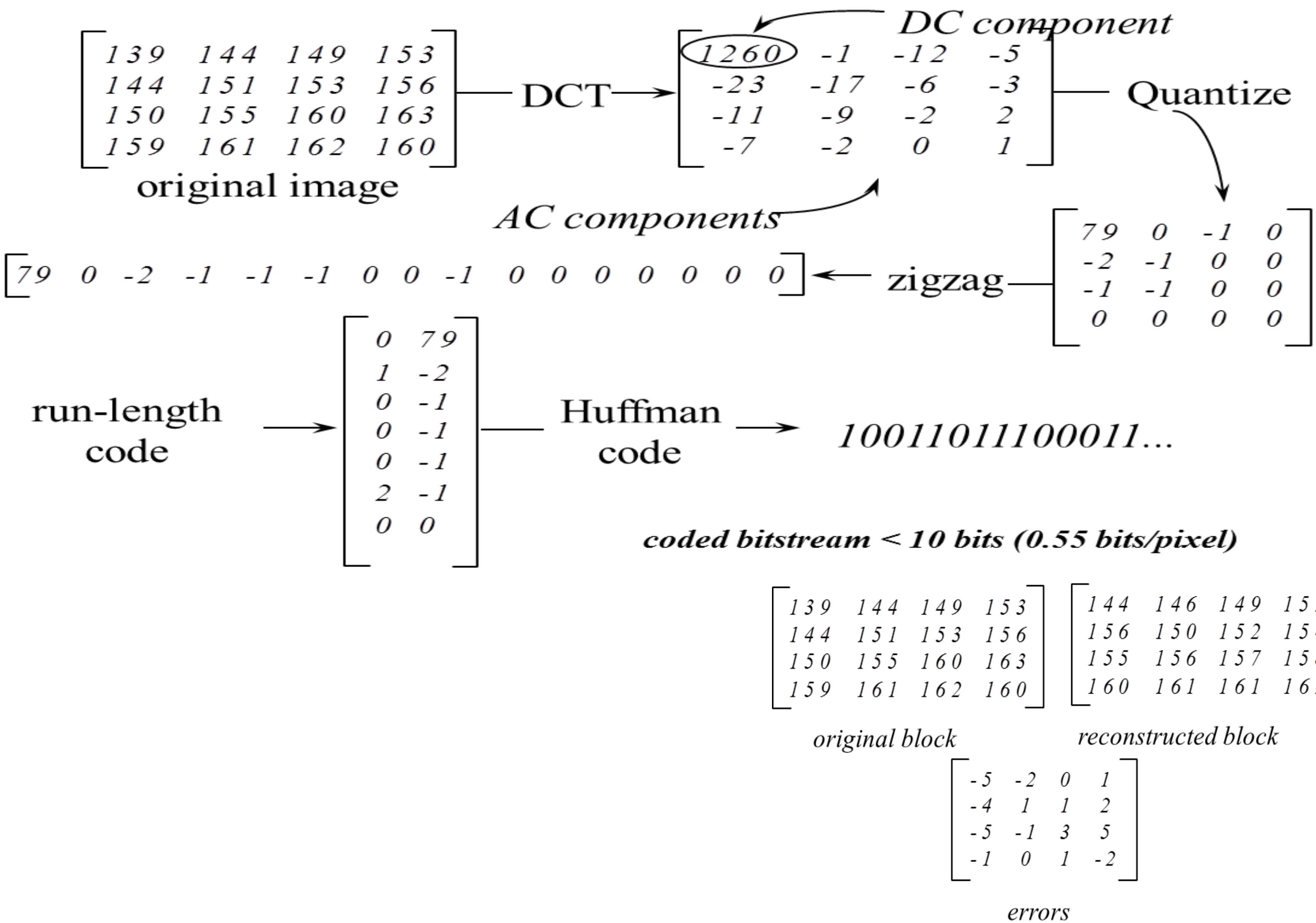


Image Compression Standard JPEG




139 144 149 153
144 151 153 156
150 155 160 163
159 161 162 160
original image
DCT
DC component
1260 -1 -12 -5
-23 -17 -6 -3
-11 -9 -2 2
-7 -2 0 1
AC components
Quantize
79 0 -1 0
-2 -1 0 0
-1 -1 0 0
0 0 0 0
zigzag
79 0 -2 -1 -1 -1 0 0 -1 0 0 0 0 0 0 0
run-length code
0 79
1 -2
0 -1
0 -1
0 -1
2 -1
0 0
Huffman code
10011011100011...
coded bitstream < 10 bits (0.55 bits/pixel)
139 144 149 153
144 151 153 156
150 155 160 163
159 161 162 160
original block
144 146 149 152
156 150 152 154
155 156 157 158
160 161 161 162
reconstructed block
-5 -2 0 1
-4 1 1 2
-5 -1 3 5
-1 0 1 -2
errors