# Compresión de la señal digital y su distribución: JPEG

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# JPEG

- Joint Photographic Experts Group
- Establecido en 1992. Basado en la DCT, transformada de coseno discreta.

- ISO/IEC 10918, *Information Technology – Digital compression and coding of continuous-tone still images.*

- *No existía la World Wide Web → ¡se proyectaba utilizarlo en máquinas de fax a color!*

# Reducción de la tasa de bits en video

- Redundancia estadística de datos.
  - Redundancia espacial.
  - Redundancia temporal.
- Redundancia psicovisual.
  - El sistema visual humano no percibe de la misma forma todos los valores posibles de las muestras.
- Codificación
  - Un evento menos probable provee más información que uno más probable.

# Características del Sistema Visual Humano

- Sensibilidad de frecuencia espacial: altas frecuencias son menos visibles.
- Errores en regiones texturadas son difíciles de ver. Somos muy sensibles a errores en regiones uniformes.
- Errores cerca de los bordes son difíciles de ver.
- El umbral visual aumenta con la iluminación del fondo.
- Errores en porciones claras son más difíciles de ver.

# Técnicas de reducción de la tasa de bits

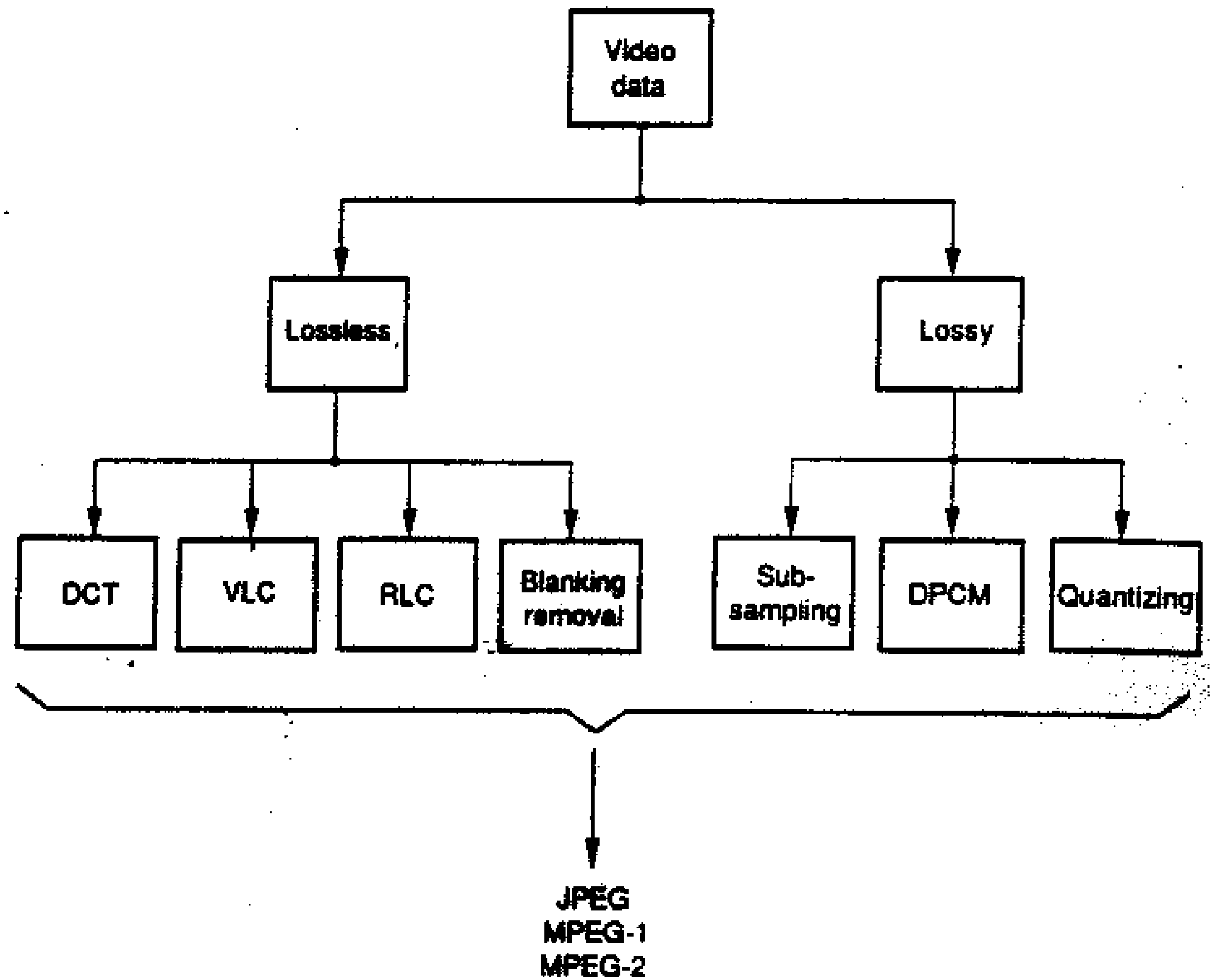



**Figure 9.5** Summary of lossless and lossy data reduction techniques which are combined to generate JPEG and MPEG data signals.

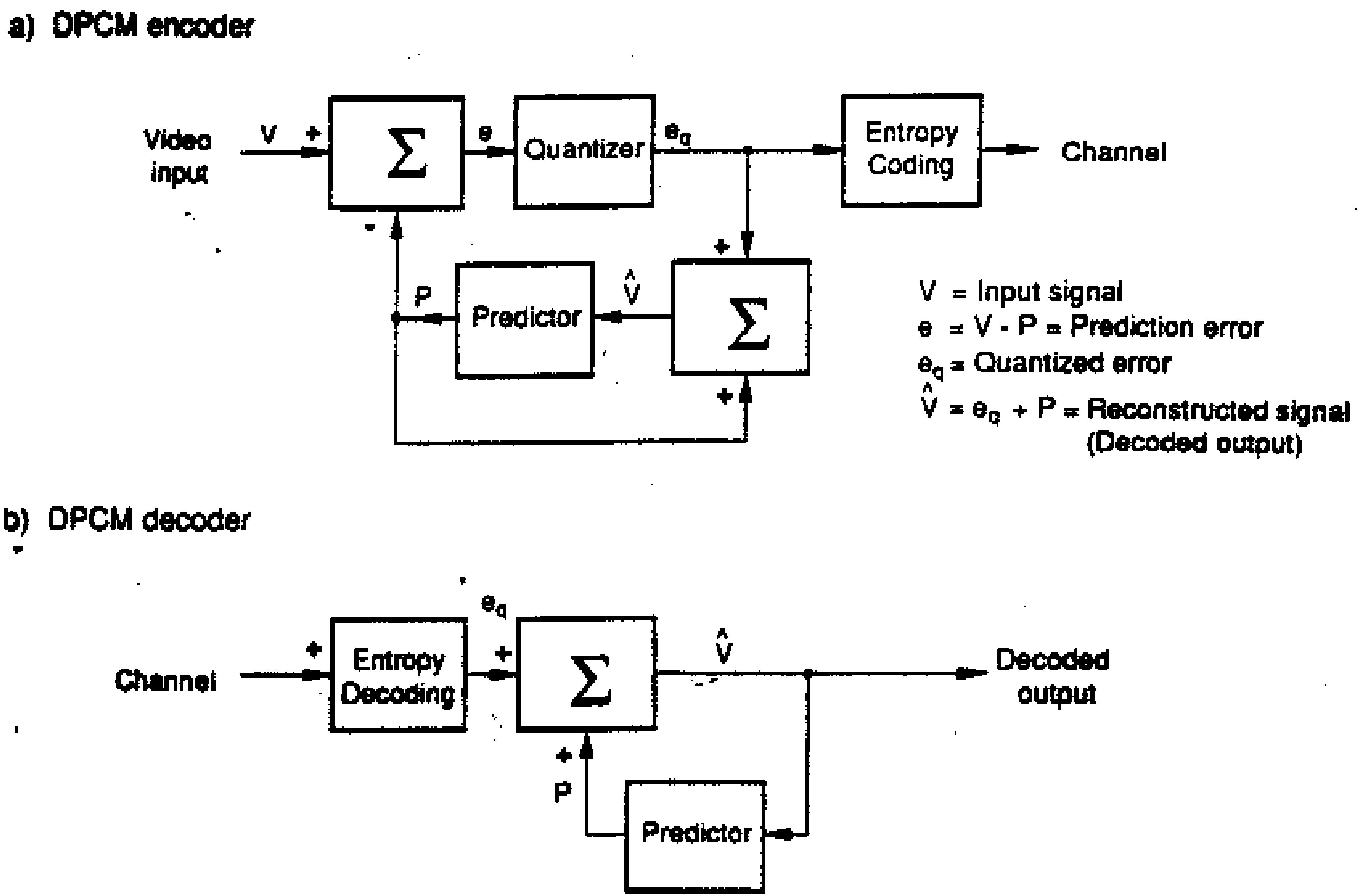
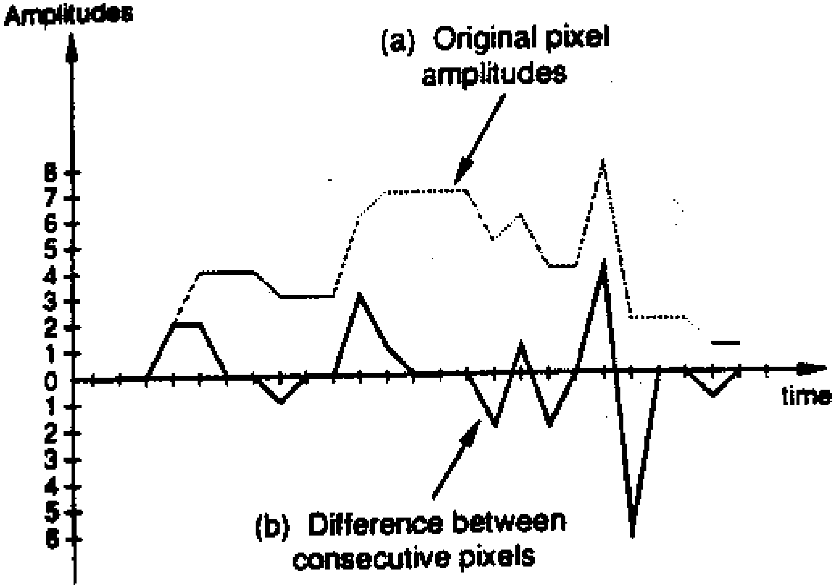
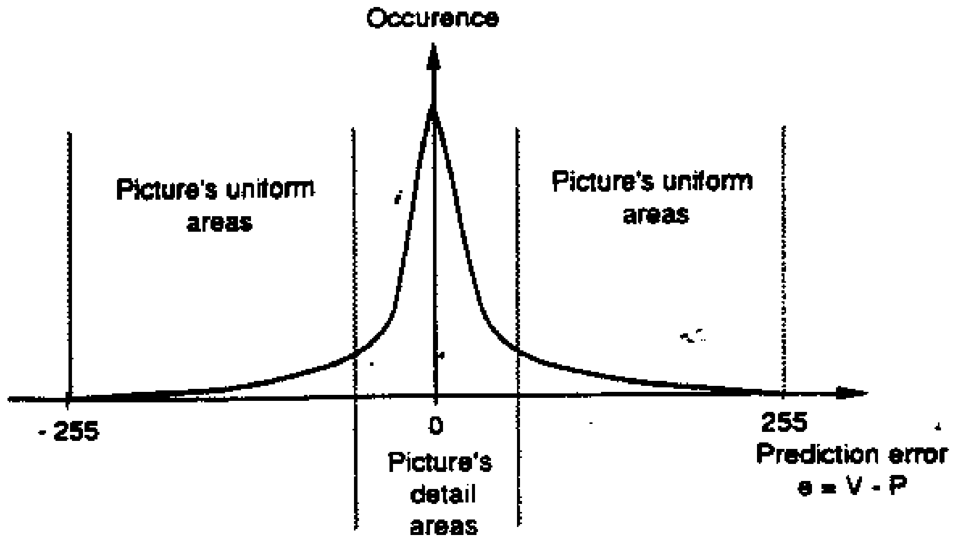



**Figure 8.6** DPCM encoder/decoder.



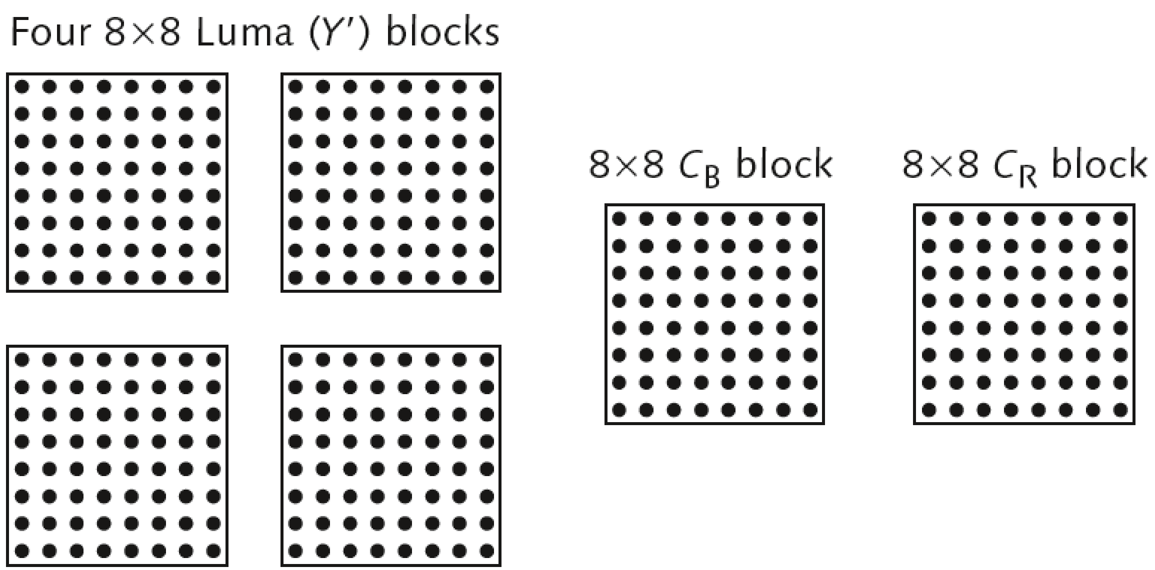

| Amplitude values | Probability of occurence | |
|---|---|---|
| | (a) | (b) |
| -6 | | 1 |
| -5 | | 0 |
| -4 | | 0 |
| -3 | | 0 |
| -2 | | 2 |
| -1 | | 2 |
| 0 | 2 | 12 |
| 1 | 2 | 1 |
| 2 | 4 | 2 |
| 3 | 3 | 1 |
| 4 | 5 | 1 |
| 5 | 1 | 0 |
| 6 | 2 | 0 |
| 7 | 4 | 0 |
| 8 | 1 | 0 |




(c) Prediction error histogram based on a long term average of TV pictures.

**Figure 8.7** DPCM encoding and entropy reduction.

Figure 45.1 **A JPEG 4:2:0 minimum coded unit** (MCU) comprises six 8×8 blocks: four luma blocks, a block of $C_B$, and a block of $C_R$. The six constituent blocks result from nonlinear $R'G'B'$ data being matrixed to $Y'C_BC_R$, then subsampled according to the 4:2:0 scheme; chroma subsampling is effectively the first stage of compression. The blocks are processed independently.

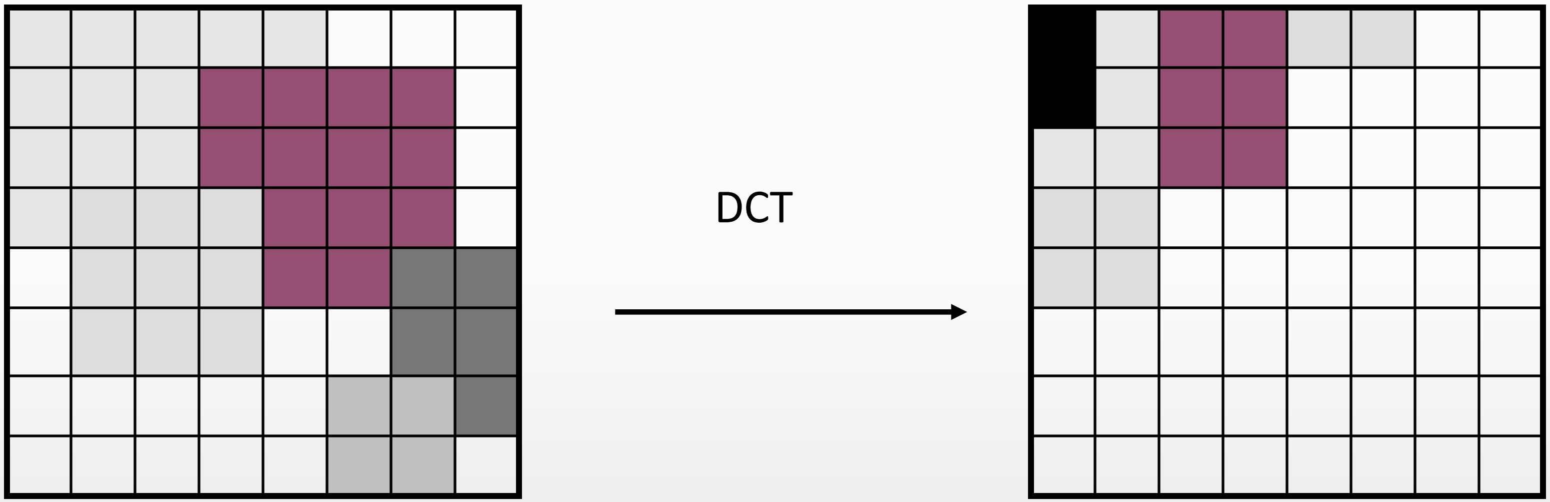


# Transformada de coseno discreta - DCT

$$F_{u,v} = \frac{1}{4}C(u)C(v)\sum_{i=0}^{7}\sum_{j=0}^{7} f_{i,j}\cos\left[\frac{(2i+1)u\pi}{16}\right]\cos\left[\frac{(2j+1)v\pi}{16}\right];$$

$$C(w) = \begin{cases} \dfrac{1}{\sqrt{2}}; & w = 0 \\ 1; & w = 1, 2, \ldots, 7 \end{cases}$$

# Transformada de Coseno Discreta (DCT)




*f(x,y)* = 64 elementos de imagen (8x8 pixels)

*F(u,v)* = 64 componentes de frecuencias especiales

# Transformada de coseno discreta - DCT

$$F(u,v) = \frac{C(u)C(v)}{4} \sum_{j=0}^{7} \sum_{k=0}^{7} f(j,k) \cos\left(\frac{(2j+1)u\pi}{16}\right) \cos\left(\frac{(2k+1)v\pi}{16}\right) \quad \text{(Eq. 8.1)}$$

where $f(j,k)$ = the original samples in the 8×8 luminance pixel block.
$F(u,v)$ = coefficients of the 8×8 DCT block.
$u$ = the normalized horizontal frequency ($0<u<7$).
$v$ = the normalized vertical frequency ($0<v<7$).

$$C(u), C(v) = 1/\sqrt{2} \qquad \text{if } u,v = 0$$

$$C(u), C(v) = 1 \qquad \text{if } u, v = 1, 2, \ldots, 7$$

For the first coefficient, the normalized frequencies $u$ and $v$ are equal to 0. Then, this coefficient is called the DC coefficient.

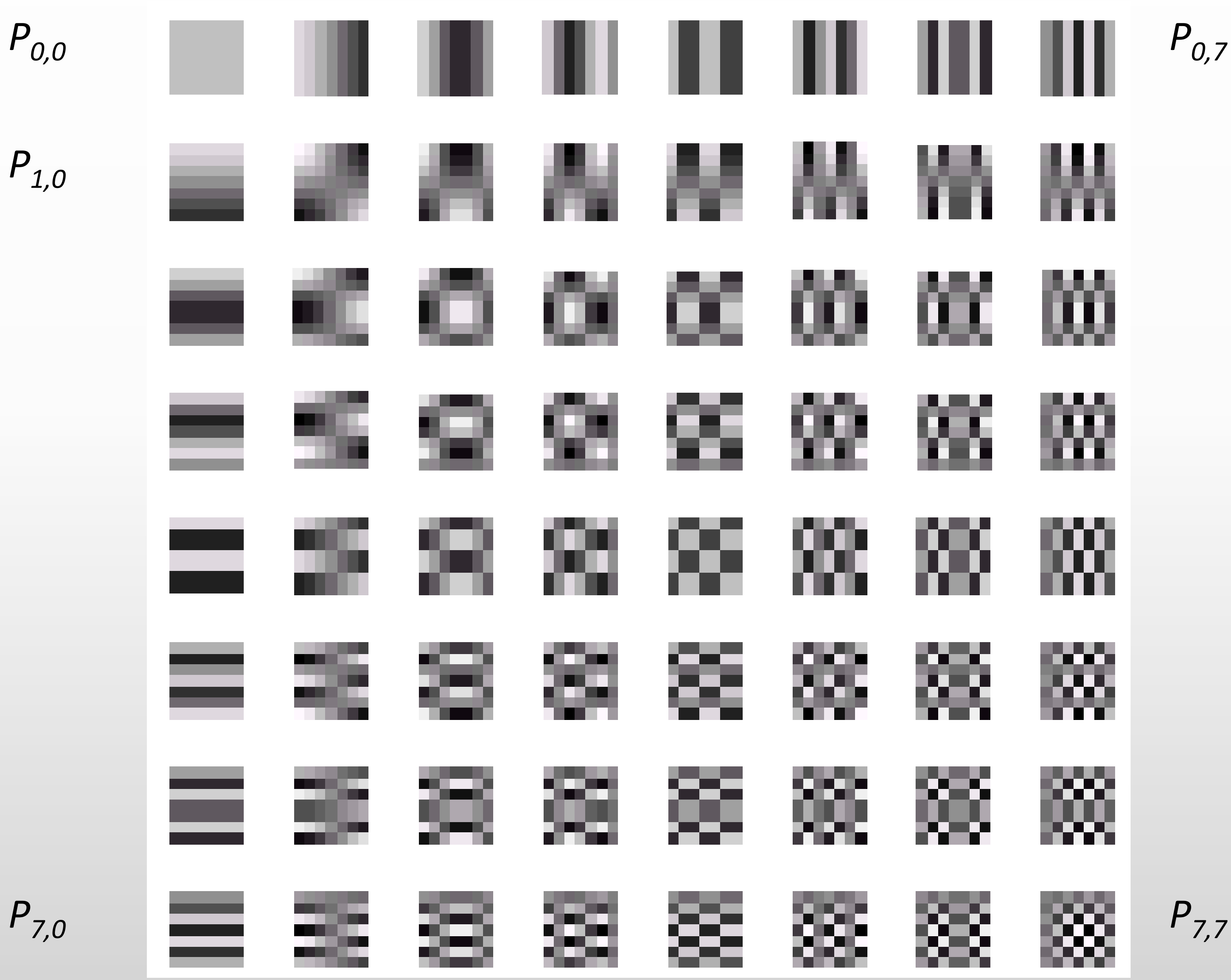
$$F(0,0) = \frac{1}{8} \sum_{j=0}^{7} \sum_{k=0}^{7} f(j,k) \quad \text{(Eq. 8.2)}$$

# Transformada de Coseno Discreta (DCT)

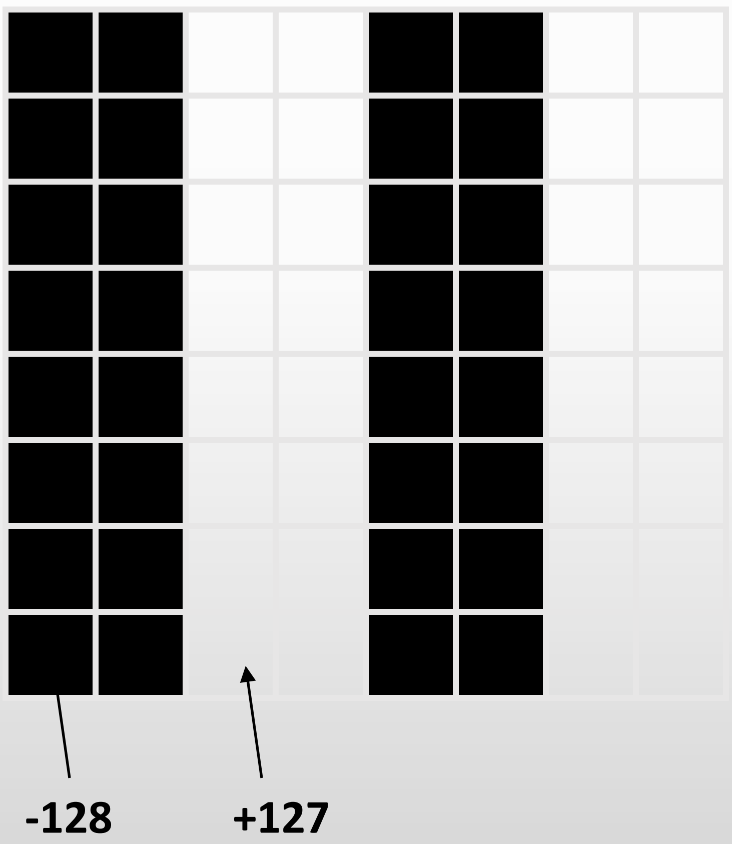
- Cada coeficiente *F(u,v)* expresa la semejanza (correlación) entre el bloque de 8x8 pixels y una determinada función primitiva correspondiente:

$$P_{u,v}(x,y) = \cos\left(\frac{(2x+1)u\pi}{16}\right) \times \cos\left(\frac{(2x+1)v\pi}{16}\right)$$

# Primitivas de la Transformada de Coseno Discreta (DCT)

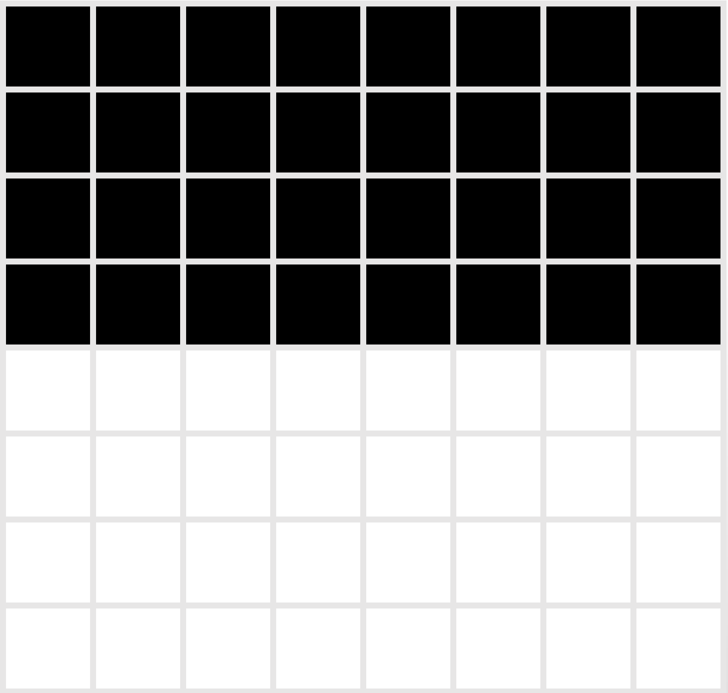


# Ejemplo de Transformada DCT



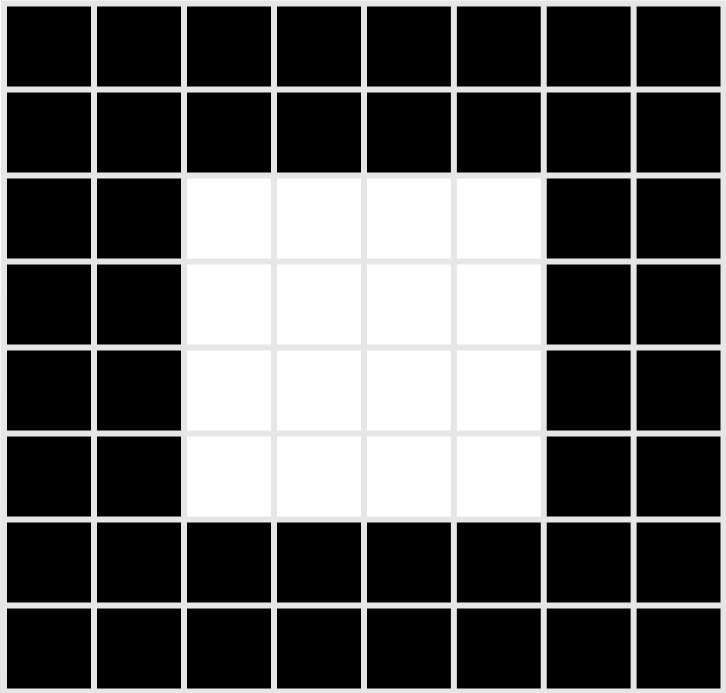

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -4 | -383 | 0 | -784 | 0 | 524 | 0 | 76 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Ejemplo de Transformada DCT



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 325 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -217 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 184 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Ejemplo de Transformada DCT



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -514 | 0 | -471 | 0 | 0 | 0 | 195 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -471 | 0 | 435 | 0 | 0 | 0 | -180 | 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 |
| 195 | 0 | 0 | 0 | 0 | 0 | 75 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

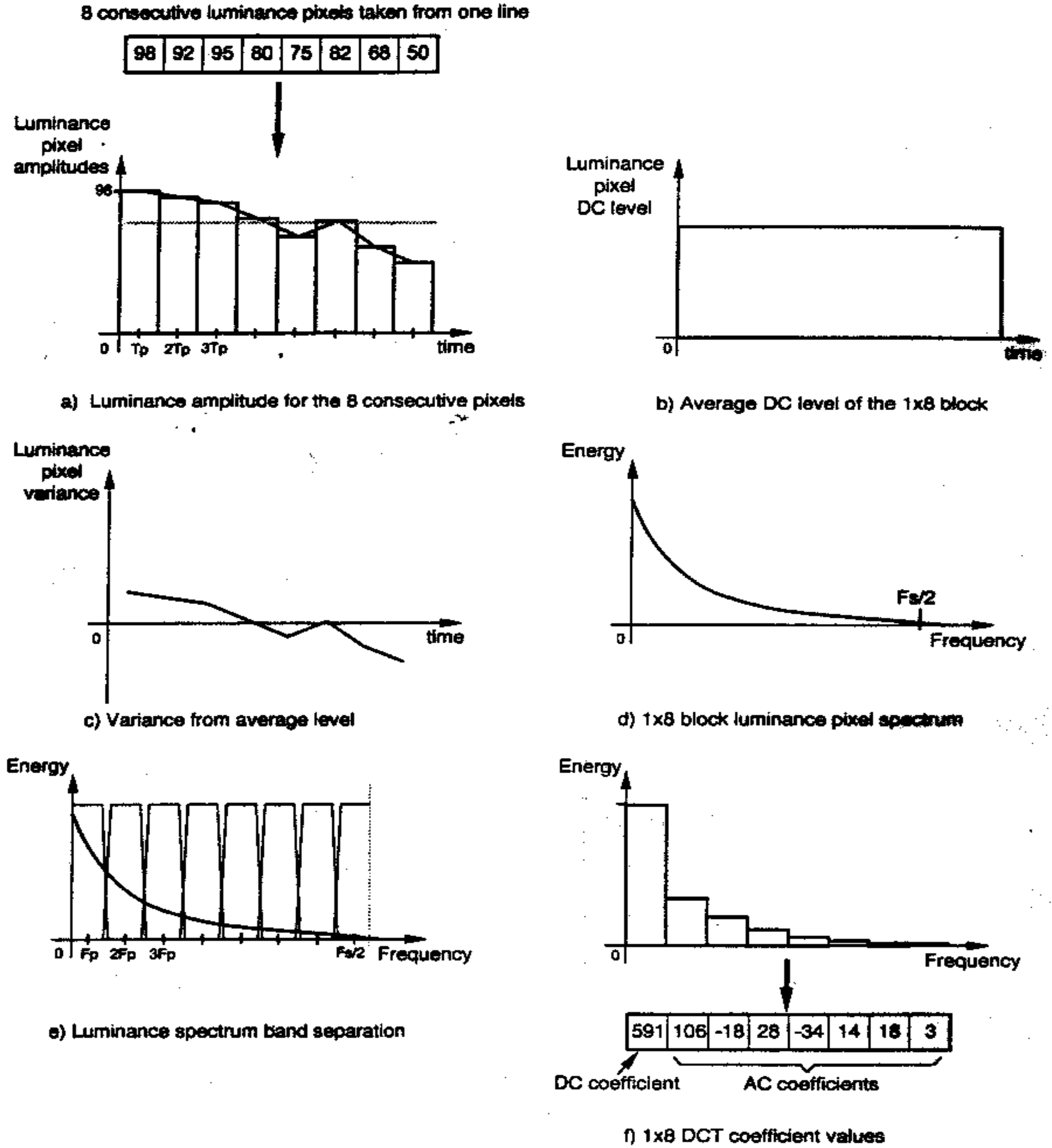
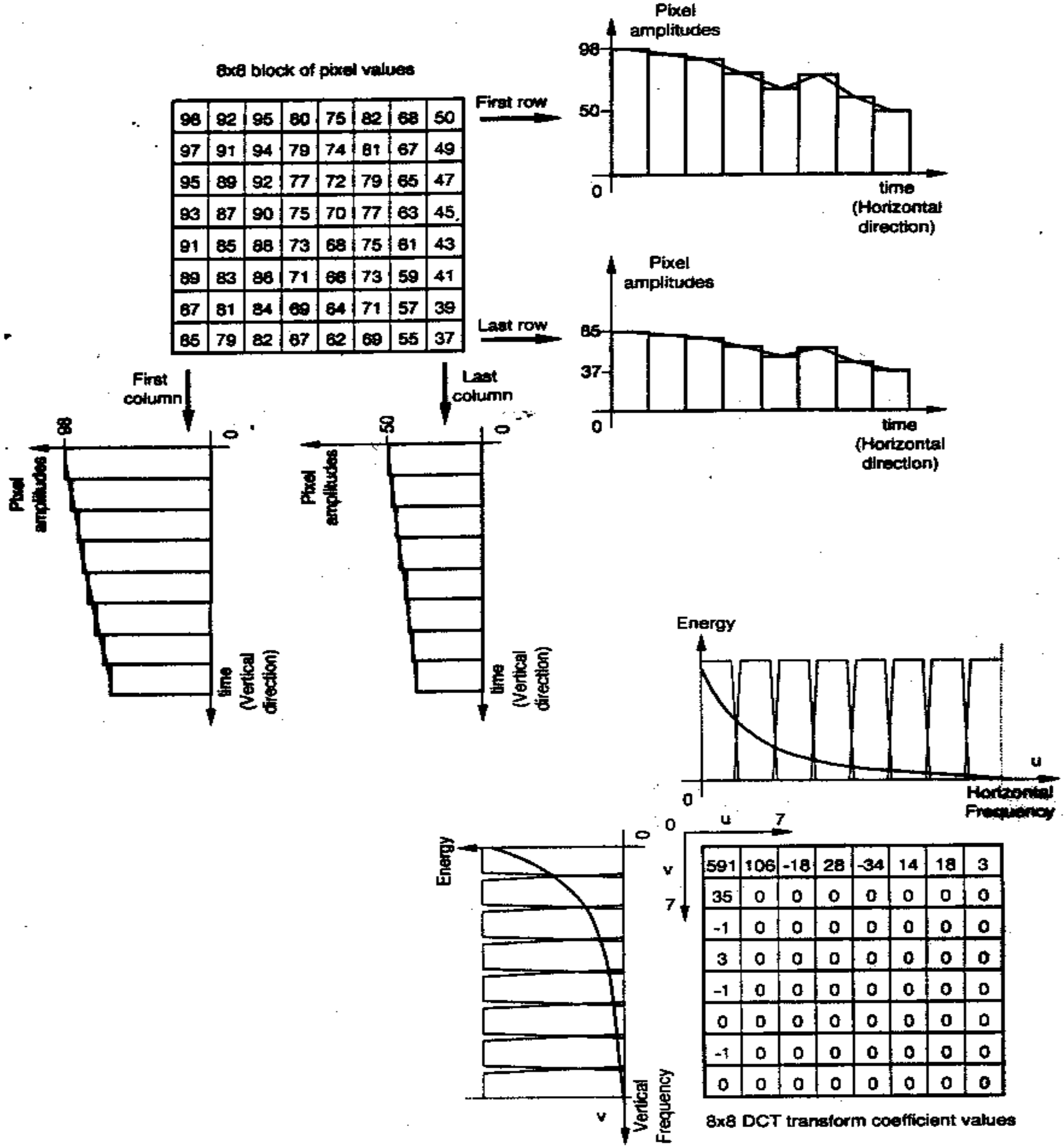



**Figure 8.8** Summary of 1-Dimensional DCT coding (*Courtesy of Sony Corporation*).




8x8 block of pixel values

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 98 | 92 | 95 | 80 | 75 | 82 | 68 | 50 |
| 97 | 91 | 94 | 79 | 74 | 81 | 67 | 49 |
| 95 | 89 | 92 | 77 | 72 | 79 | 65 | 47 |
| 93 | 87 | 90 | 75 | 70 | 77 | 63 | 45 |
| 91 | 85 | 88 | 73 | 68 | 75 | 61 | 43 |
| 89 | 83 | 86 | 71 | 66 | 73 | 59 | 41 |
| 87 | 81 | 84 | 69 | 64 | 71 | 57 | 39 |
| 85 | 79 | 82 | 67 | 62 | 69 | 55 | 37 |

8x8 DCT transform coefficient values

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 591 | 106 | -18 | 28 | -34 | 14 | 18 | 3 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Figure 8.9** Summary of 2-Dimensional DCT block coding (*Courtesy of Sony Corporation*).

a) An 8x8 block of luminance pixel values.
f(j, k)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 98 | 92 | 95 | 80 | 75 | 82 | 68 | 50 |
| 97 | 91 | 94 | 79 | 74 | 81 | 67 | 49 |
| 95 | 89 | 92 | 77 | 72 | 79 | 65 | 47 |
| 93 | 87 | 90 | 75 | 70 | 77 | 63 | 45 |
| 91 | 85 | 88 | 73 | 68 | 75 | 61 | 43 |
| 89 | 83 | 86 | 71 | 66 | 73 | 59 | 41 |
| 87 | 81 | 84 | 69 | 64 | 71 | 57 | 39 |
| 85 | 79 | 82 | 67 | 62 | 69 | 55 | 37 |

DCT process

b) The corresponding DCT coefficient values.
F(u, v)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 591 | 106 | -18 | 28 | -34 | 14 | 18 | 3 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

c) Weighting table (JPEG standard quantizing table for luminance samples)
Q (u, v)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 |

d) Normalized and quantized DCT coefficient values.
$F_q$(u, v)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 40 | 10 | -2 | 2 | -1 | 0 | 0 | 0 |
| 3 | 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 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Figure 8.10** 8×8 DCT block formatting, example #1.

a) An 8x8 block of luminance pixel values.
f(j, k)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 127 | -128 | 127 | -128 | 127 | -128 | 127 | -128 |
| -128 | 127 | -128 | 127 | -128 | 127 | -128 | 127 |
| 127 | -128 | 127 | -128 | 127 | -128 | 127 | -128 |
| -128 | 127 | -128 | 127 | -128 | 127 | -128 | 127 |
| 127 | -128 | 127 | -128 | 127 | -128 | 127 | -128 |
| -128 | 127 | -128 | 127 | -128 | 127 | -128 | 127 |
| 127 | -128 | 127 | -128 | 127 | -128 | 127 | -128 |
| -128 | 127 | -128 | 127 | -128 | 127 | -128 | 127 |

DCT process

b) The corresponding DCT coefficient values.
F(u, v)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 33 | 0 | 39 | 0 | 58 | 0 | 166 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 39 | 0 | 46 | 0 | 69 | 0 | 196 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 58 | 0 | 69 | 0 | 103 | 0 | 294 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 166 | 0 | 196 | 0 | 294 | 0 | 837 |

DCT block quantization

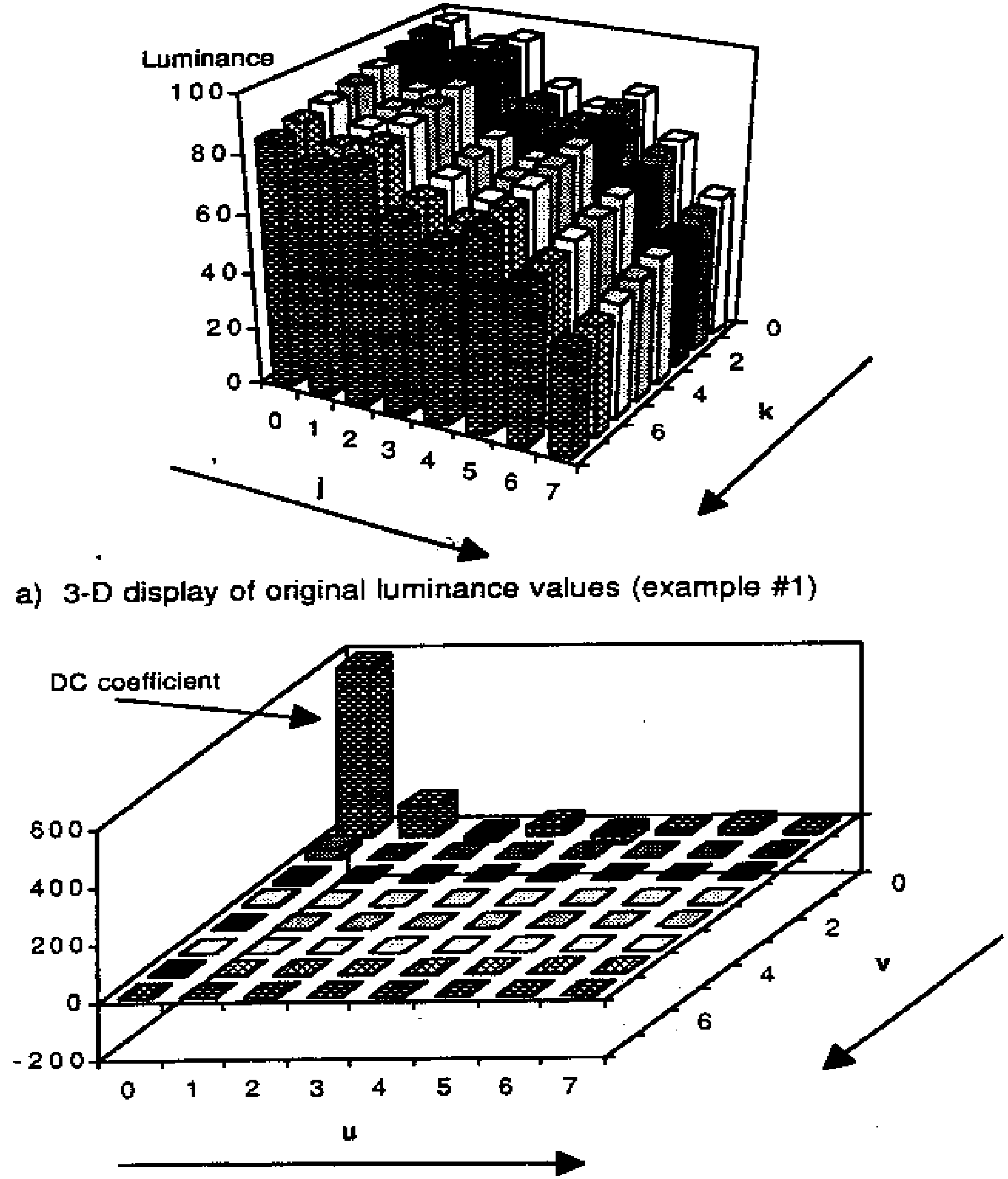
c) Weighting table
(JPEG standard quantizing table for luminance samples)
Q (u, v)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 |

d) Normalized and quantized DCT coefficient values.
$F_q(u, v)$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 3 | 0 | 2 | 0 | 1 | 0 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 0 | 2 | 0 | 1 | 0 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 0 | 1 | 0 | 1 | 0 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 0 | 2 | 0 | 3 | 0 | 8 |

**Figure 8.11** 8×8 DCT block formatting, example #2: checkerboard picture.

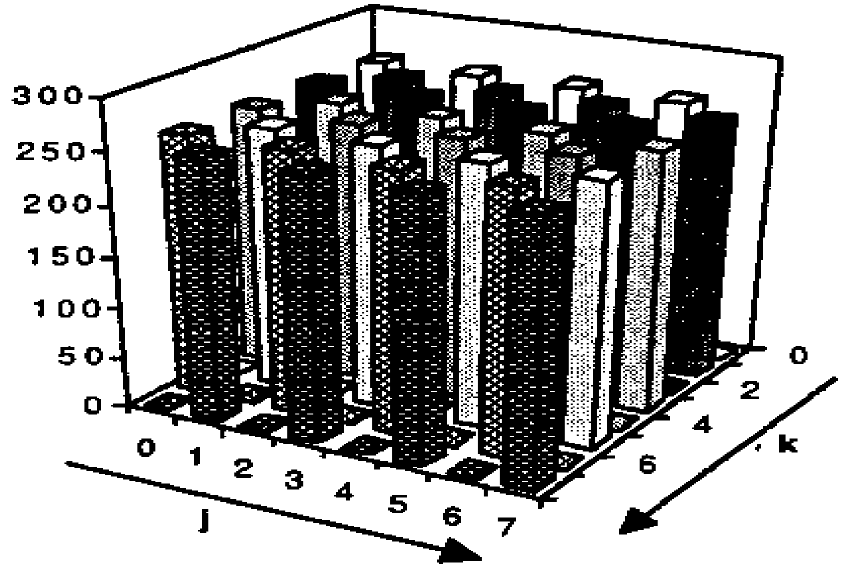



a) 3-D display of original luminance values (example #1)

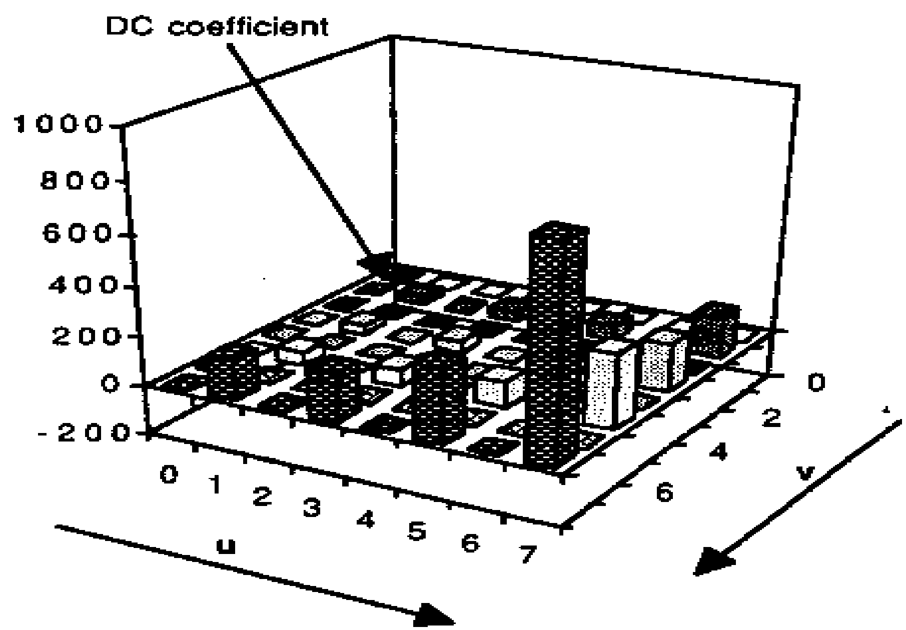


b) 3-D display of DCT coefficients (example #1)

**Figure 8.12** 3-D display of original luminance values and DCT coefficients (example #1).




a) 3-D display of original luminance values (example #2)



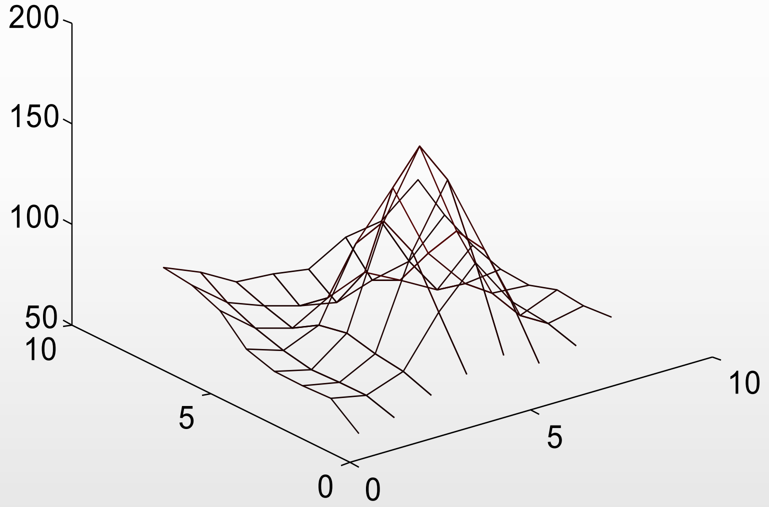

b) 3-D display of DCT coefficients (example #2)

**Figure 8.13** 3-D display of original luminance values and DCT coefficients (example #2).

# Ejemplo de Codificación DCT

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 52 | 55 | 61 | 66 | 70 | 61 | 64 | 73 |
| 63 | 59 | 66 | 90 | 109 | 85 | 69 | 72 |
| 62 | 59 | 68 | 113 | 144 | 104 | 66 | 73 |
| 63 | 58 | 71 | 122 | 154 | 106 | 70 | 69 |
| 67 | 61 | 68 | 104 | 126 | 88 | 68 | 70 |
| 79 | 65 | 60 | 70 | 77 | 68 | 58 | 75 |
| 85 | 71 | 64 | 59 | 55 | 61 | 65 | 83 |
| 87 | 79 | 69 | 68 | 65 | 76 | 78 | 94 |

Bloque 8 x 8



# Coeficientes DCT

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -415 | -29 | -62 | 25 | 55 | -20 | -1 | 3 |
| 7 | -21 | -62 | 9 | 11 | -7 | -6 | 6 |
| -46 | 8 | 77 | -25 | -30 | 10 | 7 | -5 |
| -50 | 13 | 35 | -15 | -9 | 6 | 0 | 3 |
| 11 | -8 | -13 | -2 | -1 | 1 | -4 | 1 |
| -10 | 1 | 3 | -3 | -1 | 0 | 2 | -1 |
| -4 | -1 | 2 | -1 | 2 | -3 | 1 | -2 |
| -1 | -1 | -1 | -2 | -1 | -1 | 0 | -1 |

# Coeficientes DCT Cuantizados

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -26 | -3 | -6 | 2 | 2 | 0 | 0 | 0 |
| 1 | -2 | -4 | 0 | 0 | 0 | 0 | 0 |
| -3 | 1 | 5 | -1 | -1 | 0 | 0 | 0 |
| -4 | 1 | 2 | -1 | 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 |

# Imagen Reconstruida

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 58 | 64 | 67 | 64 | 59 | 62 | 70 | 78 |
| 56 | 55 | 67 | 89 | 98 | 88 | 74 | 69 |
| 60 | 50 | 70 | 119 | 141 | 116 | 80 | 64 |
| 69 | 51 | 71 | 128 | 149 | 115 | 77 | 68 |
| 74 | 53 | 64 | 105 | 115 | 84 | 65 | 72 |
| 76 | 57 | 56 | 74 | 75 | 57 | 57 | 74 |
| 83 | 69 | 59 | 60 | 61 | 61 | 67 | 78 |
| 93 | 81 | 67 | 62 | 69 | 80 | 84 | 84 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -6 | -9 | -6 | 2 | 11 | -1 | -6 | -5 |
| 7 | 4 | -1 | 1 | 11 | -3 | -5 | 3 |
| 2 | 9 | -2 | -6 | -3 | -12 | -14 | 9 |
| -6 | 7 | 0 | -4 | -5 | -9 | -7 | 1 |
| -7 | 8 | 4 | -1 | 11 | 4 | 3 | -2 |
| 3 | 8 | 4 | -4 | 2 | 11 | 1 | 1 |
| 2 | 2 | 5 | -1 | -6 | 0 | -2 | 5 |
| -6 | -2 | 2 | 6 | -4 | -4 | -6 | 10 |

Error de Reconstrucción

# Reconstrucción de Imagen JPEG

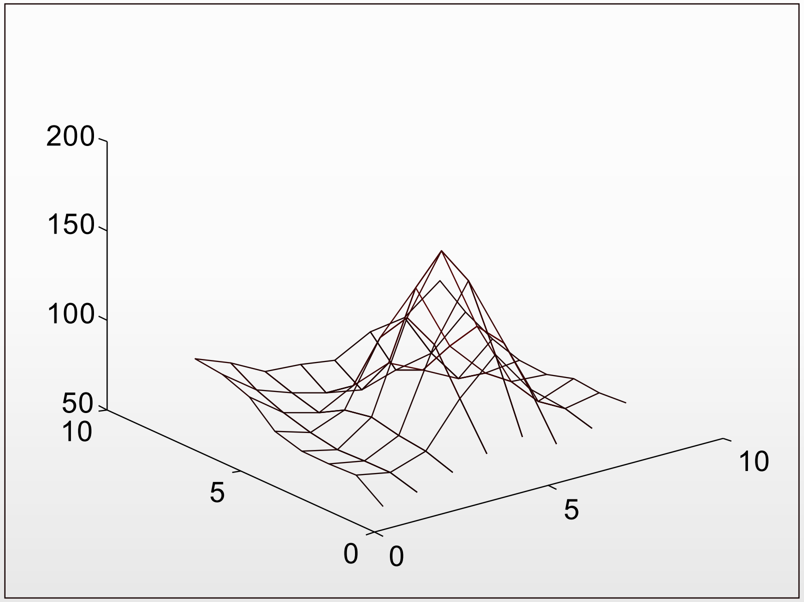



Imagen Original

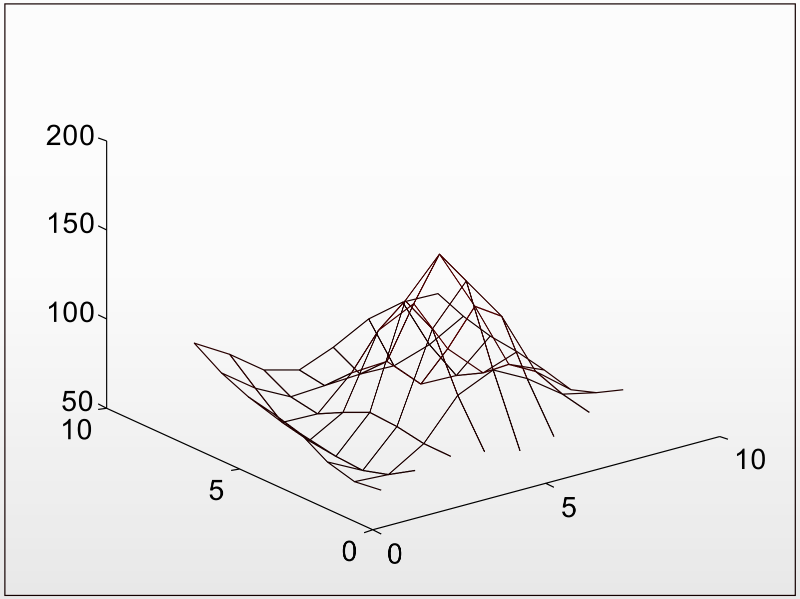



Imagen Reconstruida

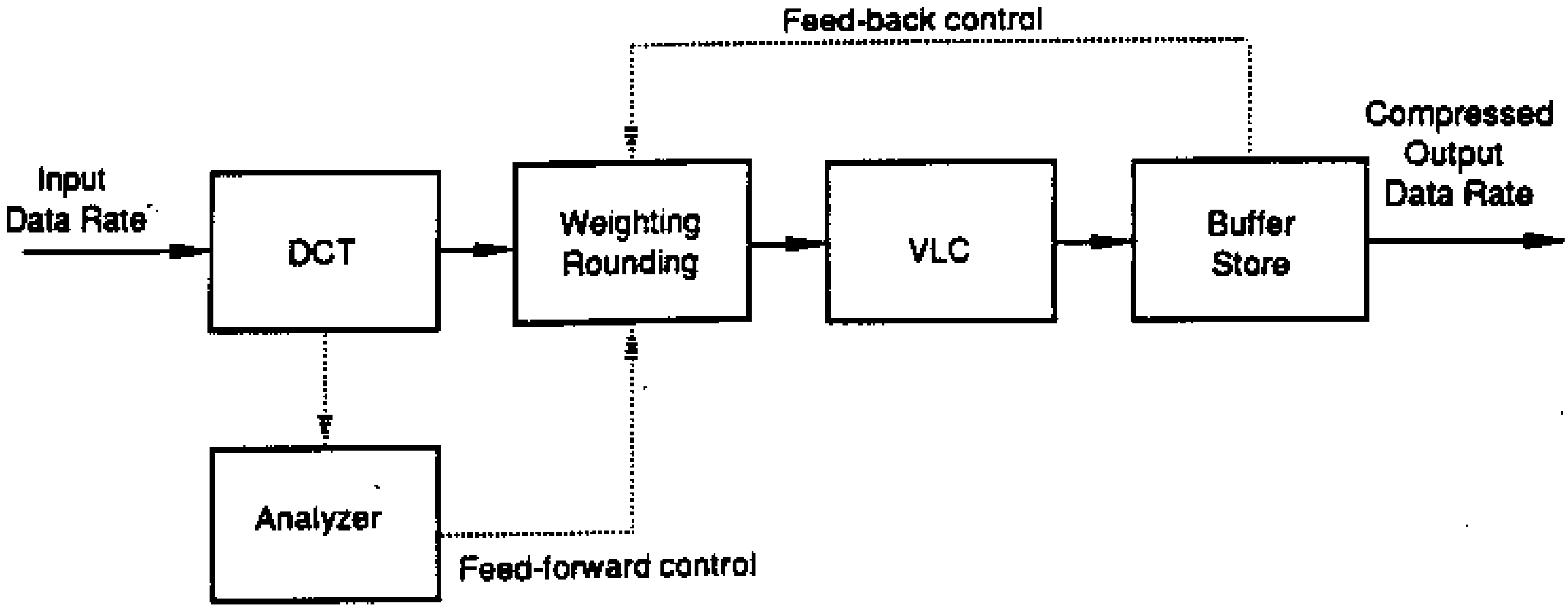



**Figure 8.14** Simplified video data reduction process using a DCT scheme.

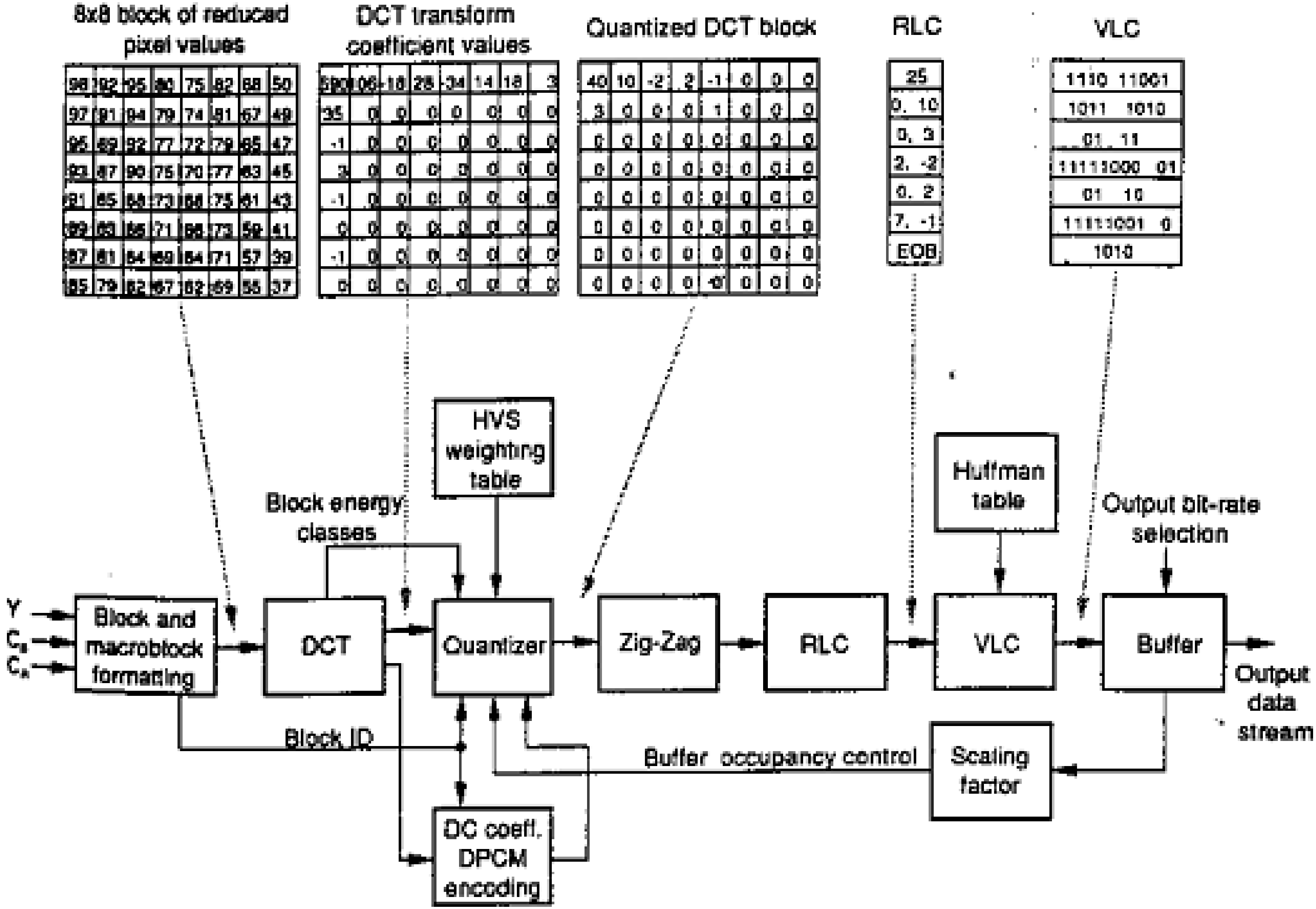



Figure 8.16 Basic picture data reduction process made with a DCT coding scheme.

- Matriz de cuantificación

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 |

**Weighting table**
**(JPEG standard quantizing table for luminance samples)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 17 | 18 | 24 | 47 | 99 | 99 | 99 | 99 |
| 18 | 21 | 26 | 66 | 99 | 99 | 99 | 99 |
| 24 | 26 | 56 | 99 | 99 | 99 | 99 | 99 |
| 47 | 66 | 99 | 99 | 99 | 99 | 99 | 99 |
| 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 |

**Weighting table**
**(JPEG standard quantizing table for chrominance samples)**

**Figure 8.17** JPEG standard quantization tables for luminance and chrominance signals.

• Zigzag scanning

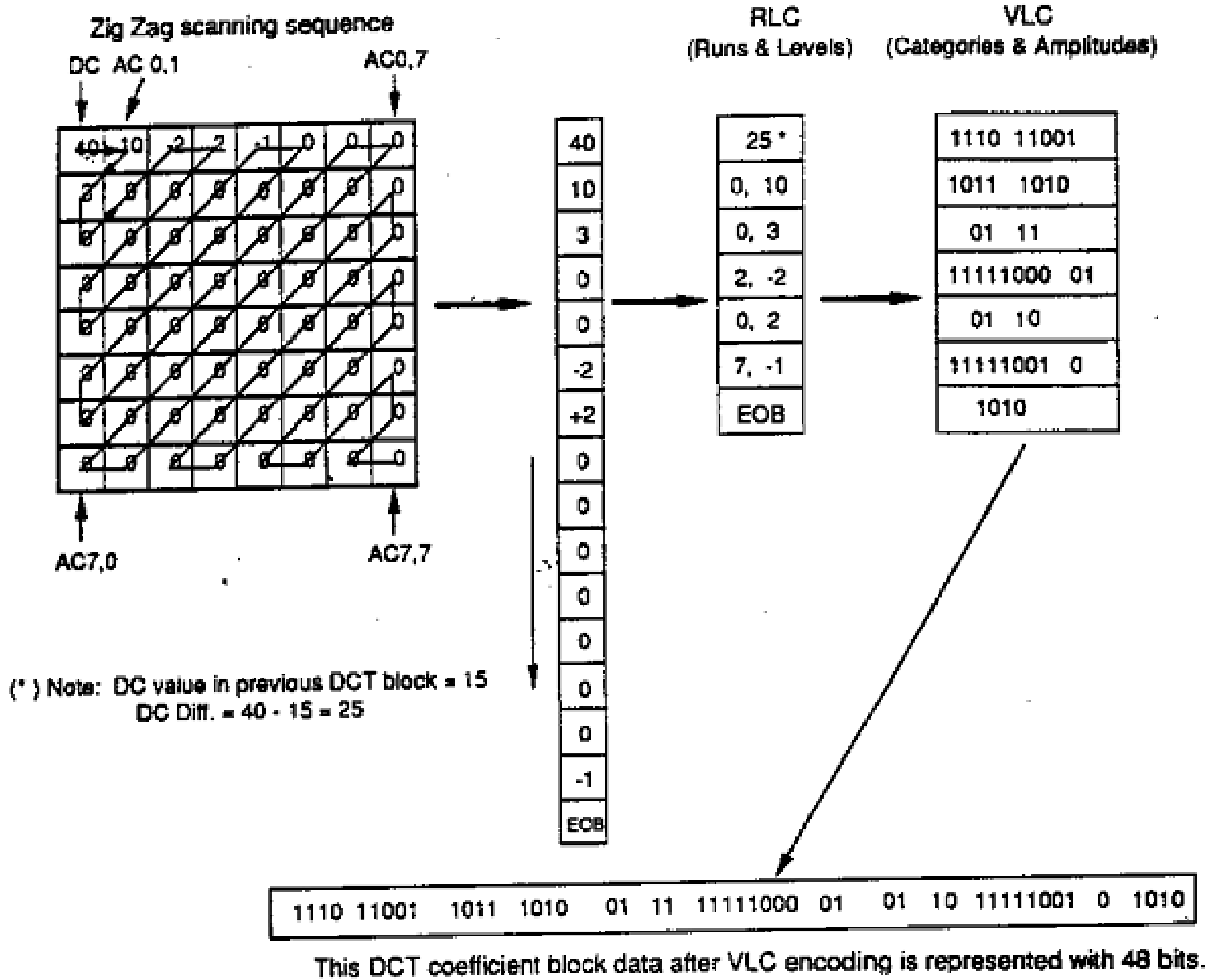



**Figure 8.18** Zigzag scanning and Huffman encoding.

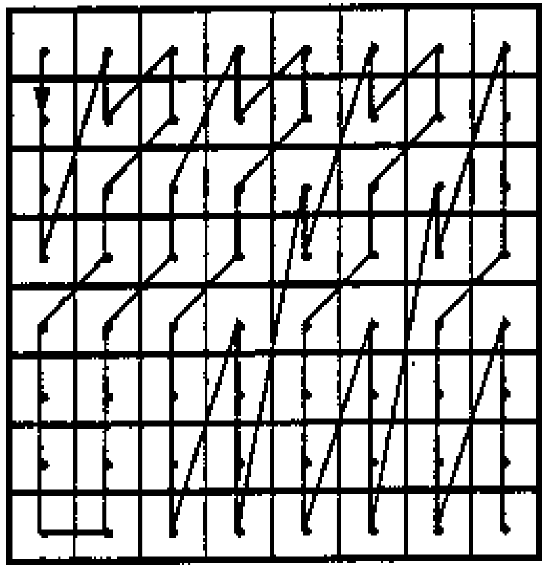


Figure 8.19 Other possible DCT coefficient block scanning process (MPEG-2 Standard).

**TABLE 8.1 AC Coefficient Ranges and Categories**

| Category | Coefficient range |
|---|---|
| NA | 0 |
| 1 | −1, 1 |
| 2 | −3, −2, 2, 3 |
| 3 | −7, −6, −5, −4, 4, 5, 6, 7 |
| 4 | −15,.......,−8, 8,.......,15 |
| 5 | −31,........,−16, 16,........,31 |
| 6 | −63,.........,−32, 32,.........,63 |
| 7 | −127,...........,−64, 64,...........,127 |
| 8 | −255,...........,−128, 128,...........,255 |
| 9 | −511,...........,−256, 256,...........,511 |
| 10 | −1023,...........,−512, 512,...........,1023 |
| 11 | −2047,...........,−1024, 1024,...........,2047 |
| ⋮ | ⋮ |

• Codificación de largo variable (VLC)

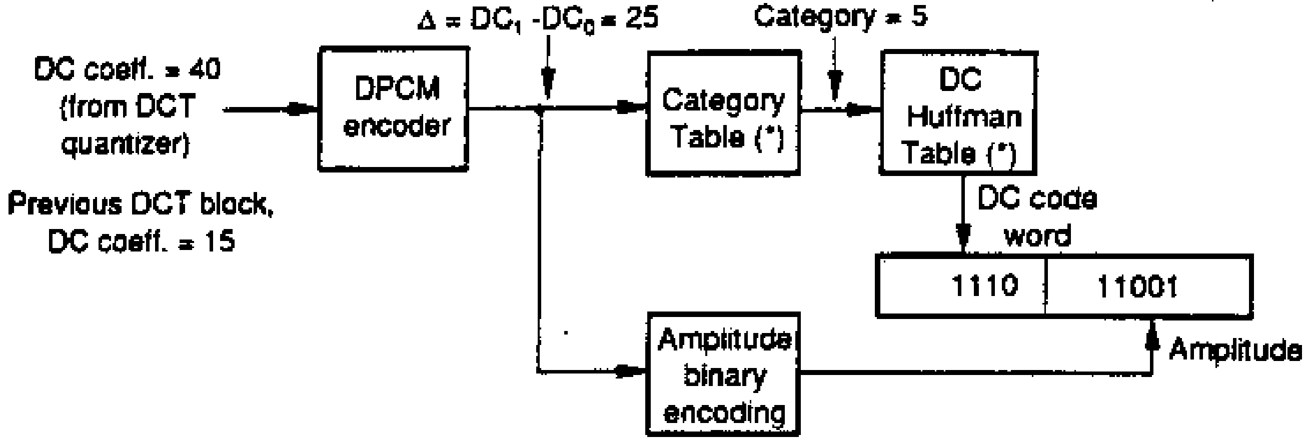
**TABLE 8.2 Example of an AC Coefficient Huffman Code Table (JPEG Default Table)**

| Zero run | Category | Code length | Code word |
|---|---|---|---|
| 0 | 1 | 2 | 00 |
| 0 | 2 | 2 | 01 |
| 0 | 3 | 3 | 100 |
| 0 | 4 | 4 | 1011 |
| 0 | 5 | 5 | 11010 |
| 0 | 6 | 6 | 111000 |
| 0 | 7 | 7 | 1111000 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| 1 | 1 | 4 | 1100 |
| 1 | 2 | 6 | 111001 |
| 1 | 3 | 7 | 1111001 |
| 1 | 4 | 9 | 111110110 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| 2 | 1 | 5 | 11011 |
| 2 | 2 | 8 | 11111000 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| 3 | 1 | 6 | 111010 |
| 3 | 2 | 9 | 111110111 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| 4 | 1 | 6 | 111011 |
| 5 | 1 | 7 | 1111010 |
| 6 | 1 | 7 | 1111011 |
| 7 | 1 | 8 | 11111001 |
| 8 | 1 | 8 | 11111010 |
| 9 | 1 | 9 | 111111000 |
| 10 | 1 | 9 | 111111001 |
| 11 | 1 | 9 | 111111010 |
| ⋮ | ⋮ | ⋮ | ⋮ |
| End of Block (EOB) | | 4 | 1010 |

**TABLE 8.3 Variable Length Codes for DC Coefficients**

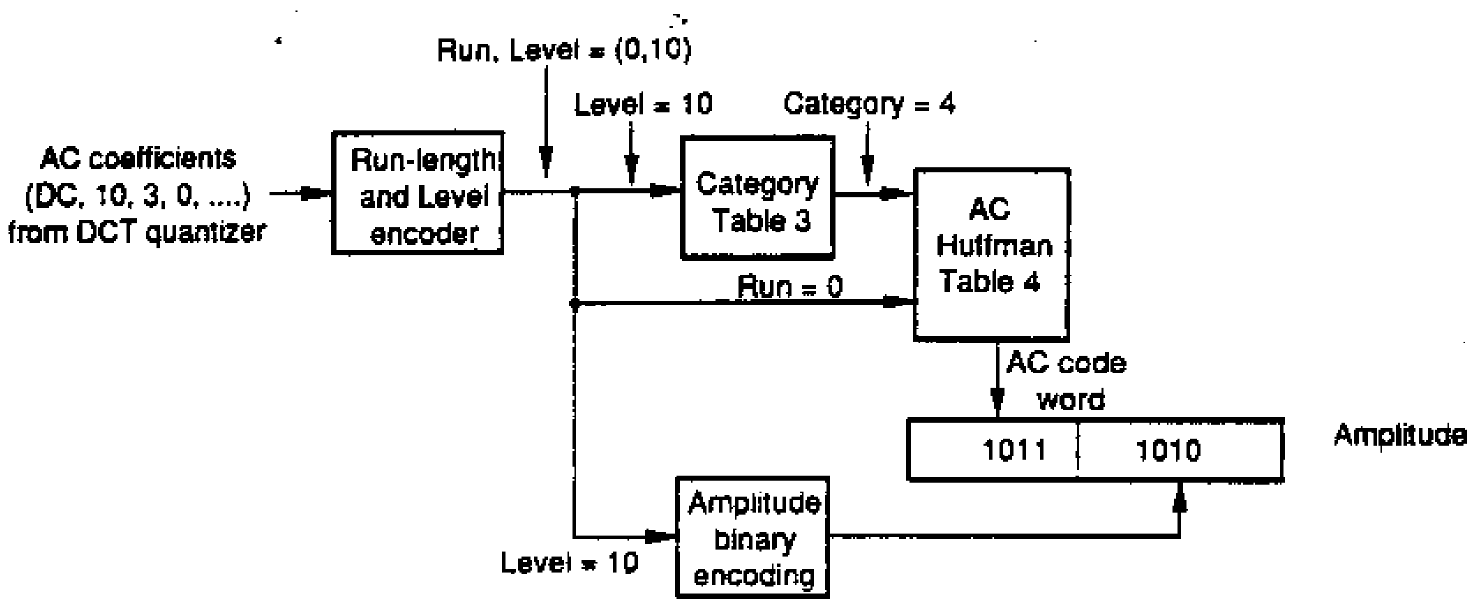
| Differential DC values | Categories | Code word for luminance | Code word for chrominance |
|---|---|---|---|
| −255 to −128 | 8 | 1111 110 | 1111 1110 |
| −127 to −64 | 7 | 1111 10 | 1111 110 |
| −63 to −32 | 6 | 1111 0 | 1111 10 |
| −31 to −16 | 5 | 1110 | 1111 0 |
| −15 to −8 | 4 | 110 | 1110 |
| −7 to −4 | 3 | 101 | 110 |
| −3 to −2 | 2 | 01 | 10 |
| −1 | 1 | 00 | 01 |
| 0 | 0 | 100 | 00 |
| 1 | 1 | 00 | 01 |
| 2 to 3 | 2 | 01 | 10 |
| 4 to 7 | 3 | 101 | 110 |
| 8 to 15 | 4 | 110 | 1110 |
| 16 to 31 | 5 | 1110 | 1111 0 |
| 32 to 63 | 6 | 1111 0 | 1111 10 |
| 64 to 127 | 7 | 1111 10 | 1111 110 |
| 128 to 255 | 8 | 1111 110 | 1111 1110 |

a) DC coefficient VLC encoding




(*) Category and DC Huffman binary numbers are shown in Table 8-3.

b) AC coefficient VLC encoding




(*) Category/run and AC Huffman binary numbers are shown in Tables 8-1 and 8-2.

**Figure 8.20** DC and AC coefficient variable length/Huffman encoding (JPEG Baseline standard).

- Decodificador DCT - Transformada inversa

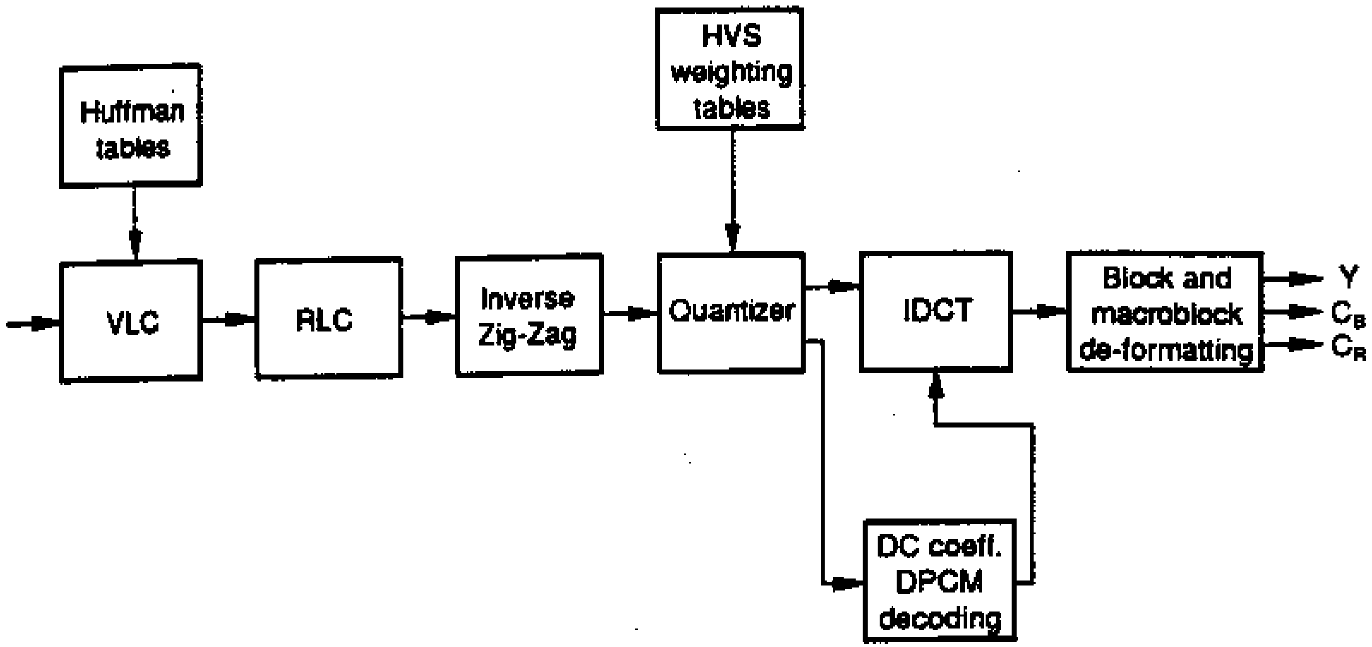



**Figure 8.21** Basic DCT decoder.

$$f*(j,k) = \frac{1}{4}\sum_{u=0}^{7}\sum_{v=0}^{7} C(u)C(v)F(u,v)\cos\left(\frac{(2j+1)u\pi}{16}\right)\cos\left(\frac{(2k+1)v\pi}{16}\right) \quad \text{(Eq. 8.5)}$$

0 $u_H$ 7
$u_V$ 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 40 | 10 | -2 | 2 | -1 | 0 | 0 | 0 |
| 3 | 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 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

a) VLC decoded and normalized DCT coefficient values $F_q(u, v)$

Inverse Quantization

0 $u_H$ 7
$u_V$ 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 |

b) Weighting table (JPEG quantizing table for luminance pixels) Q (u, v)

0 $u_H$ 7
$u_V$ 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 591 | 110 | -20 | 32 | -24 | 0 | 0 | 0 |
| 36 | 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 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

c) DCT coefficients after inverse quantization $R_q(u, v) = F_q(u, v) \times Q(u, v)$

0 j 7
k 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 98 | 97 | 90 | 81 | 80 | 79 | 67 | 50 |
| 97 | 96 | 89 | 80 | 79 | 78 | 66 | 49 |
| 95 | 94 | 87 | 78 | 77 | 77 | 64 | 47 |
| 93 | 92 | 85 | 76 | 75 | 74 | 62 | 45 |
| 90 | 89 | 82 | 74 | 72 | 72 | 59 | 43 |
| 88 | 87 | 80 | 71 | 70 | 69 | 57 | 40 |
| 86 | 85 | 78 | 70 | 68 | 68 | 55 | 39 |
| 85 | 84 | 77 | 69 | 67 | 67 | 54 | 38 |

d) Reconstructed block of luminance pixels after Inverse DCT $f^*(j, k)$

0 j 7
k 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | -5 | 5 | -1 | -5 | 3 | 1 | 0 |
| 0 | -5 | 5 | -1 | -5 | 3 | 1 | 0 |
| 0 | -5 | 5 | -1 | -5 | 2 | 1 | 0 |
| 0 | -5 | 5 | -1 | -5 | 3 | 1 | 0 |
| 1 | -4 | 6 | -1 | -4 | 3 | 2 | 0 |
| 1 | -4 | 6 | 0 | -4 | 4 | 2 | 1 |
| 1 | -4 | 6 | -1 | -4 | 3 | 2 | 0 |
| 0 | -5 | 5 | -2 | -5 | 2 | 1 | -1 |

e) Errors between original and reconstructed luminance values. $e(j,k) = f(j, k) - f^*(j, k)$

**Figure 8.22** Inverse 8×8 DCT block process and resulting data errors. (Example #1).

0 $u_H$ 7, $u_V$ 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 3 | 0 | 2 | 0 | 1 | 0 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 0 | 2 | 0 | 1 | 0 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 0 | 1 | 0 | 1 | 0 | 3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 2 | 0 | 2 | 0 | 3 | 0 | 8 |

a) VLC decoded and normalized DCT coefficient values $F_q(u, v)$

Inverse quantization

0 $u_H$ 7, $u_V$ 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 |

b) Weighting table (JPEG quantizing table for luminance pixels) $Q(u, v)$

0 $u_H$ 7, $u_V$ 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 36 | 0 | 38 | 0 | 58 | 0 | 165 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 34 | 0 | 58 | 0 | 87 | 0 | 186 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 70 | 0 | 64 | 0 | 104 | 0 | 276 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 184 | 0 | 196 | 0 | 300 | 0 | 792 |

c) DCT coefficients after inverse quantization $R_q(u, v) = F_q(u, v) \times Q(u, v)$

0 j 7, k 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 132 | -126 | 122 | -117 | 117 | -122 | 126 | -132 |
| -130 | 120 | -122 | 114 | -114 | 122 | -120 | 130 |
| 127 | -114 | 127 | -119 | 119 | -127 | 114 | -127 |
| -131 | 126 | -119 | 117 | -117 | 119 | -126 | 131 |
| 131 | -126 | 119 | -117 | 117 | -119 | 126 | -131 |
| -127 | 114 | -127 | 119 | -119 | 127 | -114 | 127 |
| 130 | -120 | 122 | -114 | 114 | -122 | 120 | -130 |
| -132 | 126 | -122 | 117 | -117 | 122 | -126 | 132 |

d) Reconstructed block of luminance pixels after Inverse DCT $f^*(j, k)$

0 j 7, k 7

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -5 | -2 | 5 | -11 | 10 | -6 | 1 | 4 |
| 2 | 7 | -6 | 13 | -14 | 5 | -8 | -3 |
| 0 | -14 | 0 | -9 | 8 | -1 | 13 | -1 |
| 3 | 1 | -9 | 10 | -11 | 8 | -2 | -4 |
| -4 | -2 | 8 | -11 | 10 | -9 | 1 | 3 |
| -1 | 13 | -1 | 8 | -9 | 0 | -14 | 0 |
| -3 | -8 | 5 | -14 | 13 | -6 | 7 | 2 |
| 4 | 1 | -6 | 10 | -11 | 5 | -2 | -5 |

e) Errors between original and reconstructed luminance values. $e(j, k) = f(j, k) - f^*(j, k)$

**Figure 8.23** Inverse 8×8 DCT block process and resulting data errors. (Example #2: checkerboard picture).

# Medición de los errores

- *e( j,k ) = f( j,k ) – f*( j,k )*

$$RMSE = \sqrt{\frac{1}{64}\sum_{j=0}^{7}\sum_{k=0}^{7} e^2(j,k)}$$

Root-mean-squared error

$$PSNR = 20\log_{10}\left(\frac{255}{RMSE}\right)$$

Picture Signal Noise Ratio

- En los ejemplos anteriores
  - Ejemplo 1:
    - RMSE = 3.26
    - PSNR = 37.9 dB
  - Ejemplo 2:
    - RMSE = 7.47
    - PSNR = 30.66 dB

# Ejemplo de Codificación JPEG

# Imagen Reconstruida por JPEG (~20:1)

# Detalles de los Efectos de la Compresión

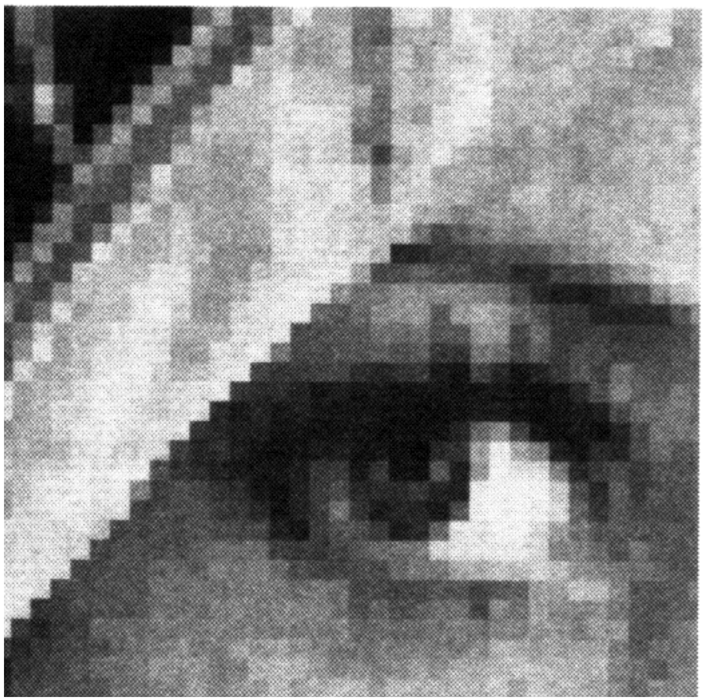


Imagen Original (40x40)

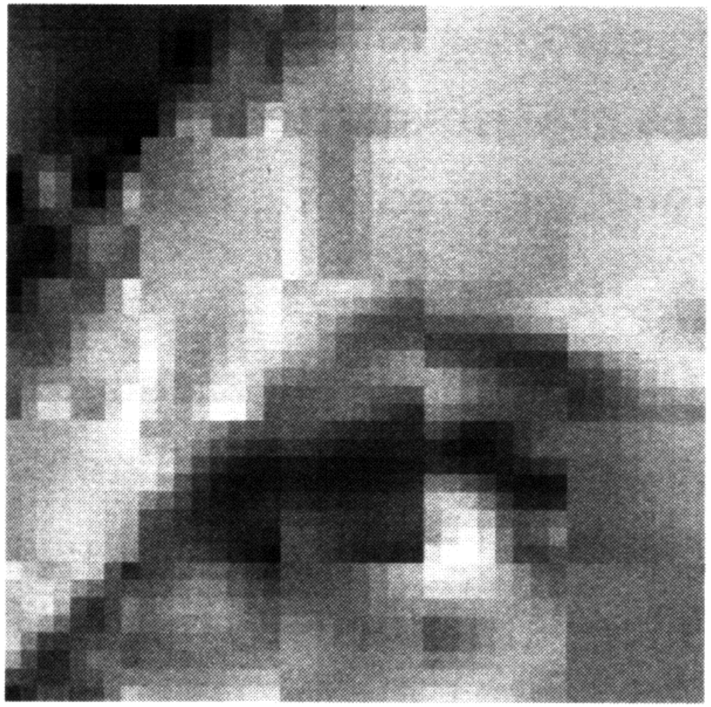
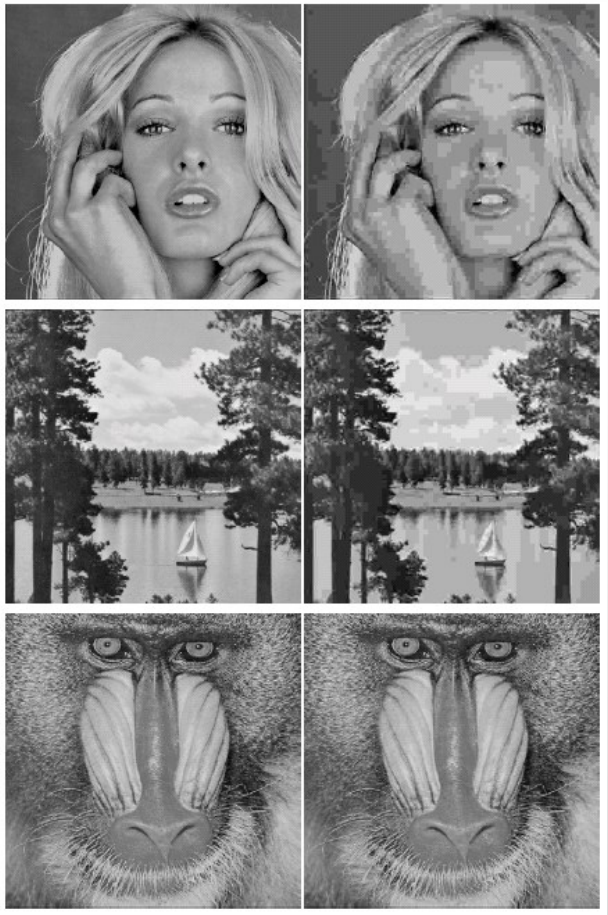


Imagen Comprimida ~20:1

# RMSE y PSNR no se co-relacionan con la percepción humana



Izquierda: imagen original. Derecha: imagen degradada
Arriba: “Tiffany”, MSE=165; Medio: “Lago”, MSE=167
Abajo: “Mandril”, MSE=163

(a) Original (b) PSNR = 32 dB (c) PSNR = 32 dB