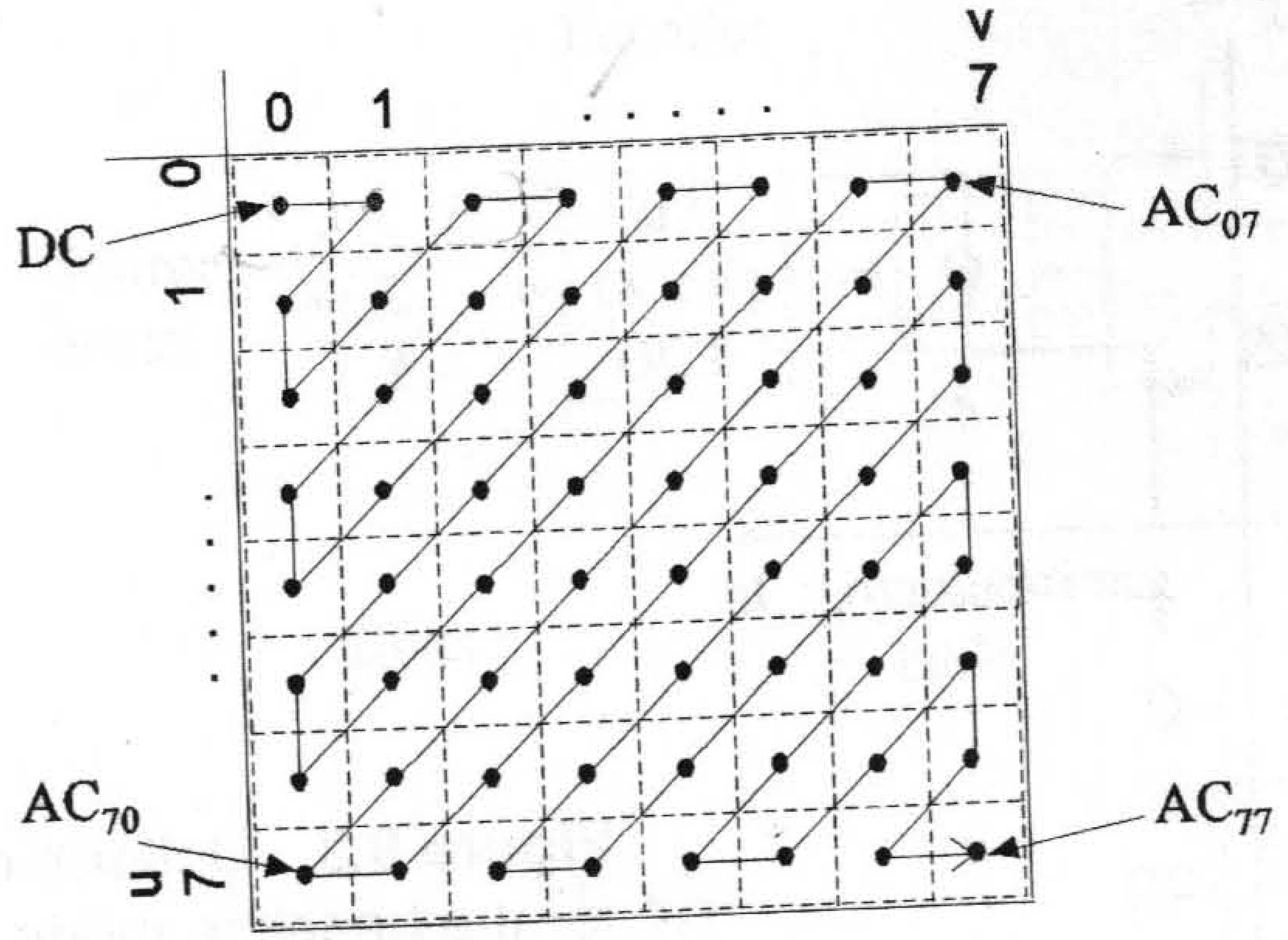


Figure 8.4 A zigzag scan of quantized DCT coefficients.

where R_{uv} is a dequantized DC or AC coefficient to be fed into the 2D (8×8) IDCT operation. It may be noted that Tables 8.1 and 8.2 are examples only. Any other custom-designed quantization matrices can be used as long as the receiver has knowledge of the same. 인공물, 가공품

Since a blocking artifact mainly from the DC coefficient is sensitive to 공간적인 spatial frequency response by the human visual system, the DC coefficient is treated separately from the 63 AC coefficients. It is differentially coded by the following first-order prediction

$$\mathrm{DIFF} = \mathrm{DC}_i - \mathrm{DC}_{i-1} \tag{8.3}$$

where DC_i and DC_{i-1} are the current (8 × 8) block and the previous (8 × 8) block DC coefficients, respectively.

The quantized 63 AC coefficients are formatted as per the zigzag scan shown in Fig. 8.4, in preparation for entropy coding. Along the zigzag scan the DCT coefficients represent increasing spatial frequencies and, in general, decreasing variances. Also, the HVS (human visual system) weighted quantization (Tables 8.1 and 8.2) results in many zero coefficients. An efficient VLC table can be developed that represents runs of zero coefficients along the zigzag scan followed by the size of the nonzero coefficient.

JPEG uses only Huffman coding for the baseline system. The encoder may employ two DC and two AC Huffman table lookups for luminance and chrominance DCT coefficients. It is suggested that all codes, for DC or AC, consist of a set of Huffman codes (maximum length 16 bits) followed by appended additional bits for representing the exact values.

Coding DC coefficients: The DIFF values as defined by Eq. (8.3) are classified into 12 categories (SSSS in Table 8.3) for 8-bit resolution. The dynamic range of DCT coefficients is 11 bits when source-image precision is 8 bits. Prediction based on the previous DC coefficient increases the prediction error by 1

Table 8.3 Difference categories for DC coding [367]

SSSS	DIFF values
0	0
1	$-1, 1$
2	$-3, -2, 2, 3$
3	$-7 \cdots -4, 4 \cdots 7$
4	$-15 \cdots -8, 8 \cdots 15$
5	$-31 \cdots -16, 16 \cdots 31$
6	$-63 \cdots -32, 32 \cdots 63$
7	$-127 \cdots -64, 64 \cdots 127$
8	$-255 \cdots -128, 128 \cdots 255$
9	$-511 \cdots -256, 256 \cdots 511$
10	$-1023 \cdots -512, 512 \cdots 1023$
11	$-2047 \cdots -1024, 1024 \cdots 2047$

Source: © 1993 ITU-T.

bit, resulting in 12 categories. Therefore, we have the difference categories written by two's complement expression. For the maximum source-image precision of 12 bits, 16 categories are defined in the same way.

The reader may generate Huffman tables for each category which has different probability distributions, or may employ informative JPEG Huffman tables as shown in Table 8.4 for luminance and chrominance components. Note that not a single code consists entirely of all 1 bits, since all-1s code would be difficult to decode.

In the case of SSSS = 0, i.e., the same value as the previous DC coefficient, additional bits are not required. For other categories, we need extra bits to express the exact value in the category, consisting of the sign and amplitude of the prediction error. When DIFF is positive, the sign bit is 1 and the SSSS low-order bits of DIFF are appended to the Huffman code. When DIFF is negative, the SSSS low-order bits of (DIFF − 1) are appended. The sign bit would be 0 and (DIFF − 1) operation implies one's complement representation to avoid all 1 bits of the two's complement operation. For example, the negative value -5 is represented as 010. This procedure for appending the additional bits is also applied to coding AC coefficients.

Coding AC coefficients

In general, because many of the AC coefficients become zero after quantization, runs of zeros along the zigzag scan are identified and compacted. Each nonzero AC coefficient is described by a composite R/S, where R is a 4-bit zero-run from the previous nonzero value and S represents the 10 (4-bit) categories, as shown in Table 8.5. If the zero-runs (the number of quantized zero coeffi-

Table 8.4 Huffman code table for luminance and chrominance DC difference [367]

	Luminance DC		Chrominance DC	
SSSS	Code length	Codeword	Code length	Codeword
0	2	00	2	00
1	3	010	2	01
2	3	011	2	10
3	3	100	3	110
4	3	101	4	1110
5	3	110	5	11110
6	4	1110	6	111110
7	5	11110	7	1111110
8	6	111110	8	11111110
9	7	1111110	9	111111110
10	8	11111110	10	1111111110
11	9	111111110	11	11111111110

Source: © 1993 ITU-T.

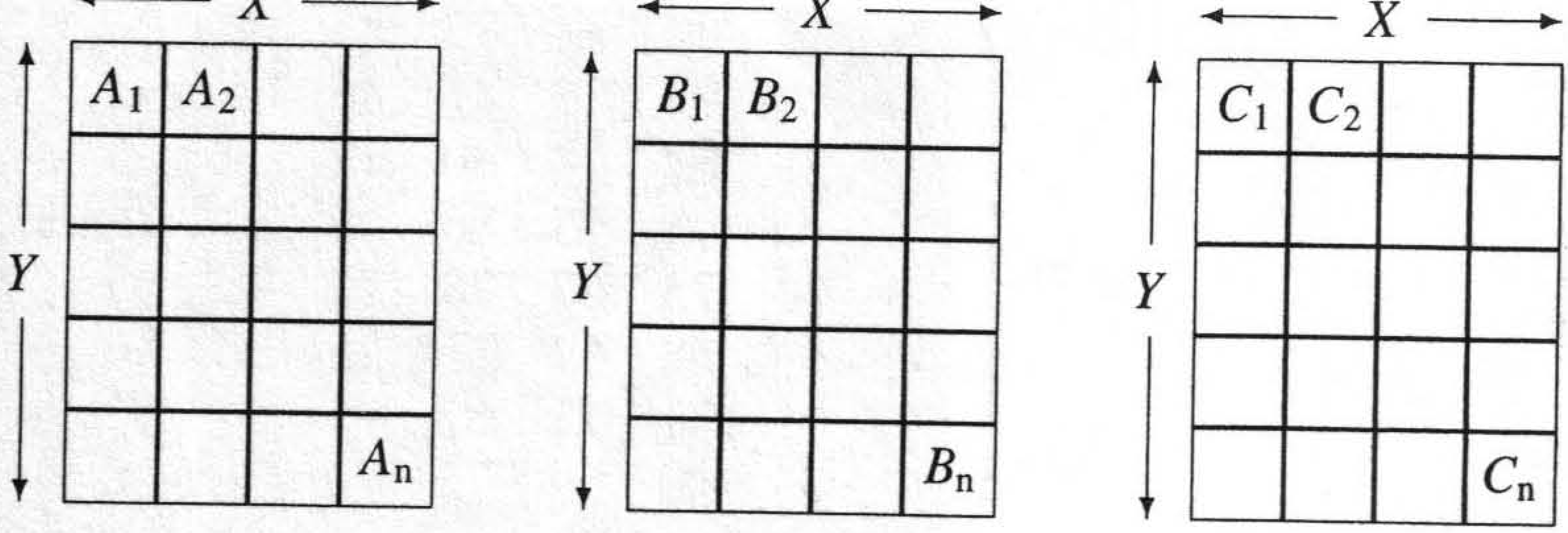
cients along the zigzag scan) are greater than 16, then R/S = x'F0' (15 zero-runs and 1 zero value) is coded by an 11-bit VLC as shown in Appendix C.1 and counted again. In addition, if all remaining coefficients along the zigzag scan are zero, a special value R/S = x'00' is coded as an EOB (end-of-block) code of 1010 (see Appendix C.1).

Huffman encoding and decoding tables are generated for each composite category R/S. We may use the informative tables that define the possible 162 codes in Appendix C.1 for luminance and in Appendix C.2 for chrominance. Here *Run* refers to the run length of the zero coefficients followed by the *Size* of the

Table 8.5 Categories assigned to AC coefficient values [367]

SSSS	AC coefficients
1	−1, 1
2	−3, −2, 2, 3
3	−7 · · · −4, 4 · · · 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

Source: © 1993 ITU-T.



(a) Data unit encoding order, *noninterleaved*

$$\underbrace{A_1, A_2, \cdots, A_n,}_{\text{Scan 1}} \qquad \underbrace{B_1, B_2, \cdots, B_n,}_{\text{Scan 2}} \qquad \underbrace{C_1, C_2, \cdots, C_n,}_{\text{Scan 3}}$$

(b) Data unit encoding order, *interleaved*

$$\underbrace{A_1, B_1, C_1, A_2, B_2, C_2, \cdots, A_n, B_n, C_n}_{\text{Scan 1}}$$

Figure 8.5 Interleaved and noninterleaved encoding order.

nonzero coefficient along the zigzag scan (Fig. 8.4). A similar VLC table is also developed for the chrominance [367]. Each of the codes is uniquely defined and the composite R/S information is decoded at the receiver, using the same VLC tables. The format and rules for the additional bits are the same as those for coding the prediction error of the DC coefficient. The encoding process is illustrated by an example in the next section. We have described baseline encoding-decoding processes for the luminance component, Y. Color image consists of Y and two chrominance components. The decoder is able to decode up to four components, such as CMY_eK (cyan, magenta, yellow, and black) in color print image coding. The three components of the color image can be interleaved, or noninterleaved as shown in Fig. 8.5. Subject to the interleave or noninterleave status, the MCU (minimum coded unit) components are varied. If it is interleaved, the first MCU becomes $A_1\ B_1\ C_1$ (Fig. 8.5).

8.4.2 Baseline coding example

We present an example of a baseline system reflecting the coding techniques described earlier. The following data block (marked by a squared block) is selected from the LENA image (Fig. 8.6):

$$x_{ij} = \begin{pmatrix} 79 & 75 & 79 & 82 & 82 & 86 & 94 & 94 \\ 76 & 78 & 76 & 82 & 83 & 86 & 85 & 94 \\ 72 & 75 & 67 & 78 & 80 & 78 & 74 & 82 \\ 74 & 76 & 75 & 75 & 86 & 80 & 81 & 79 \\ 73 & 70 & 75 & 67 & 78 & 78 & 79 & 85 \\ 69 & 63 & 68 & 69 & 75 & 78 & 82 & 80 \\ 76 & 76 & 71 & 71 & 67 & 79 & 80 & 83 \\ 72 & 77 & 78 & 69 & 75 & 75 & 78 & 78 \end{pmatrix} \tag{8.4}$$

Note the region is a very bright area, the data are 128 level-shifted, and we choose a relatively flat area for an easy example. This block, transformed by 2D (8×8) DCT, is given by

$$S_{uv} = \begin{pmatrix} 619 & -29 & 8 & 2 & 1 & -3 & 0 & 1 \\ 22 & -6 & -4 & 0 & 7 & 0 & -2 & -3 \\ 11 & 0 & 5 & -4 & -3 & 4 & 0 & -3 \\ 2 & -10 & 5 & 0 & 0 & 7 & 3 & 2 \\ 6 & 2 & -1 & -1 & -3 & 0 & 0 & 8 \\ 1 & 2 & 1 & 2 & 0 & 2 & -2 & -2 \\ -8 & -2 & -4 & 1 & 2 & 1 & -1 & 1 \\ -3 & 1 & 5 & -2 & 1 & -1 & 1 & -3 \end{pmatrix} \tag{8.5}$$

The DC coefficient value 619 is eight times the average gray-level of the block. The actual DC level without level-shifting is obtained by adding 1024 to 619, resulting in 1643. It is seen that the energy in the low-frequency band is greater than in the high-frequency band. This means that the spatial block is dominated by the low-frequency components, i.e., there is a high correlation between pixels.

A quanitized version of the transformed block is achieved by applying the luminance quantization matrix (Table 8.1), resulting in

$$S_{quv} = \begin{pmatrix} 39 & -3 & 1 & 0 & 0 & 0 & 0 & 0 \\ 2 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{8.6}$$

Note that each AC coefficient S_{uv} is uniformly quantized. The step size Q_{uv} is dependent on the corresponding coefficient S_{uv}. Table 8.1 shows that the low-frequency coefficients are finely quantized (smaller step sizes) whereas the

Figure 8.6 A selected (8×8) block (square on hat) in a LENA image.

high-frequency coefficients are coarsely quantized (larger step sizes). This process reflects the HVS.

There are only a few nonzero coefficients [see Eq. (8.6)]. Assuming the quantized DC coefficient of the previous block is 34, the prediction error is 5, which is entropy-coded. It belongs to category 3 in Table 8.4, and its Huffman code is 100. Additional bits of 101, representing the exact value of the prediction error in this category, are appended. The two-dimensional array is rearranged into a one-dimensional array based on the zigzag scan (see Fig. 8.4). It results in

$$(39 \quad -3 \quad 2 \quad 1 \quad -1 \quad 1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad -1 \quad \text{EOB}) \tag{8.7}$$

The first AC coefficient -3 belongs to category 0/2, which has codeword 01, in Appendix C.1. As previously discussed, the additional bits 00 are appended $(01 - 1 = 00)$. For the next coefficient we get the same category codeword 01 and extra bits 10. The last nonzero coefficient -1 belongs to category 5/1, which has codeword 1111010. This is followed by the EOB code 1010. The resulting bit stream is

$$(100101/0100/0110/001/000/001/11110100/1010) \tag{8.8}$$

A total of 35 bits are needed to transmit this block. Therefore the transmission bit rate is 0.55 bit/pel when we use 8-bit precision for the source image, and the compression ratio is about 15:1. The reconstructed block obtained by the operations VWL decoding, inverse quantization, and inverse DCT is given by

$$\hat{x}_{ij} = \begin{pmatrix} 74 & 75 & 77 & 80 & 85 & 91 & 95 & 98 \\ 77 & 77 & 78 & 79 & 82 & 86 & 89 & 91 \\ 78 & 77 & 77 & 77 & 78 & 81 & 83 & 84 \\ 74 & 74 & 74 & 74 & 76 & 78 & 81 & 82 \\ 69 & 69 & 70 & 72 & 75 & 78 & 82 & 84 \\ 68 & 68 & 69 & 71 & 75 & 79 & 82 & 85 \\ 73 & 73 & 72 & 73 & 75 & 77 & 80 & 81 \\ 78 & 77 & 76 & 75 & 74 & 75 & 76 & 77 \end{pmatrix} \tag{8.9}$$

The error block is given by

$$e_{ij} = \begin{pmatrix} 5 & 0 & 2 & 2 & -3 & -5 & -1 & -4 \\ -1 & 1 & -2 & 3 & 1 & 0 & -4 & 1 \\ -6 & -2 & -10 & 1 & 2 & -3 & -9 & -2 \\ 0 & 2 & 1 & 1 & 10 & 2 & 0 & -3 \\ 4 & 1 & 5 & -5 & 3 & 0 & -3 & 1 \\ 1 & -5 & -1 & -2 & 0 & -1 & 0 & -5 \\ 3 & 3 & -1 & -2 & -8 & 2 & 0 & 2 \\ -6 & 0 & 2 & -6 & 1 & 0 & 2 & 1 \end{pmatrix} \tag{8.10}$$

The errors due to the coarse quantization in the high-frequency area are greater in sharply changing areas. Since the selected block is a relatively flat area, the resulting normalized mean square error from Eq. (8.10) is 3.52 for the block, implying good performance. If we choose a block in the high-activity area, however, many coefficients become nonzero. The bit rate would be increased but greater errors due to larger quantization step sizes in high-frequency bands result in a blocking effect.

8.4.3 Simulation results

Using the coding procedures and informative tables, the resulting monochrome LENA image, which has (512 × 512) pixels, is presented in Fig. 8.7, at two average bit rates. The baseline system is quite efficient for most of the images, having moderately low complexity. The JPEG goal is to achieve moderate to good quality at 0.25 to 0.5 bpp [378]. We see in Fig. 8.7 that at 0.25 bpp, the lower bit rate, quality is quite degraded, but quality is very good at 0.5 bpp.

8.5 Progressive DCT-Based Process

For the sequential mode, (8 × 8) blocks from left to right and top to bottom are coded and decoded, i.e., FDCT, quantization, VWL coding, and corresponding inverse operations at the decoder. For the progressive mode, (8 × 8) blocks are also typically encoded in the same order as in the sequential mode, but in multiple scans through the image. As each transform block is quantized, its coefficients

C.1 VLC Table for Luminance AC Coefficients in JPEG

Run	Size	Code word	Run	Size	Code word
0	0	1010 (EOB)	3	5	1111 1111 1001 0000
0	1	00	3	6	1111 1111 1001 0001
0	2	01	3	7	1111 1111 1001 0010
0	3	100	3	8	1111 1111 1001 0011
0	4	1011	3	9	1111 1111 1001 0100
0	5	1101 0	3	A	1111 1111 1001 0101
0	6	1111 000	4	1	1110 11
0	7	1111 1000	4	2	1111 1110 00
0	8	1111 1101 10	4	3	1111 1111 1001 0110
0	9	1111 1111 1000 0010	4	4	1111 1111 1001 0111
0	A	1111 1111 1000 0011	4	5	1111 1111 1001 1000
1	1	1100	4	6	1111 1111 1001 1001
1	2	1101 1	4	7	1111 1111 1001 1010
1	3	1111 001	4	8	1111 1111 1001 1011
1	4	1111 1011 0	4	9	1111 1111 1001 1100
1	5	1111 1110 110	4	A	1111 1111 1001 1101
1	6	1111 1111 1000 0100	5	1	1111 010
1	7	1111 1111 1000 0101	5	2	1111 1110 111
1	8	1111 1111 1000 0110	5	3	1111 1111 1001 1110
1	9	1111 1111 1000 0111	5	4	1111 1111 1001 1111
1	A	1111 1111 1000 1000	5	5	1111 1111 1010 0000
2	1	1110 0	5	6	1111 1111 1010 0001
2	2	1111 1001	5	7	1111 1111 1010 0010
2	3	1111 1101 11	5	8	1111 1111 1010 0011
2	4	1111 1111 0100	5	9	1111 1111 1010 0100
2	5	1111 1111 1000 1001	5	A	1111 1111 1010 0101
2	6	1111 1111 1000 1010	6	1	1111 011
2	7	1111 1111 1000 1011	6	2	1111 1111 0110
2	8	1111 1111 1000 1100	6	3	1111 1111 1010 0110
2	9	1111 1111 1000 1101	6	4	1111 1111 1010 0111
2	A	1111 1111 1000 1110	6	5	1111 1111 1010 1000
3	1	1110 10	6	6	1111 1111 1010 1001
3	2	1111 1011 1	6	7	1111 1111 1010 1010
3	3	1111 1111 0101	6	8	1111 1111 1010 1011
3	4	1111 1111 1000 1111	6	9	1111 1111 1010 1100
6	A	1111 1111 1010 1101	A	6	1111 1111 1100 1011
7	1	1111 1010	A	7	1111 1111 1100 1100
7	2	1111 1111 0111	A	8	1111 1111 1100 1101
7	3	1111 1111 1010 1110	A	9	1111 1111 1100 1110
7	4	1111 1111 1010 1111	A	A	1111 1111 1100 1111
7	5	1111 1111 1011 0000	B	1	1111 1110 01
7	6	1111 1111 1011 0001	B	2	1111 1111 1101 0000

Run	Size	Code word	Run	Size	Code word
7	7	1111 1111 1011 0010	B	3	1111 1111 1101 0001
7	8	1111 1111 1011 0011	B	4	1111 1111 1101 0010
7	9	1111 1111 1011 0100	B	5	1111 1111 1101 0011
7	A	1111 1111 1011 0101	B	6	1111 1111 1101 0100
8	1	1111 1100 0	B	7	1111 1111 1101 0101
8	2	1111 1111 1000 000	B	8	1111 1111 1101 0110
8	3	1111 1111 1011 0110	B	9	1111 1111 1101 0111
8	4	1111 1111 1011 0111	B	A	1111 1111 1101 1000
8	5	1111 1111 1011 1000	C	1	1111 1110 10
8	6	1111 1111 1011 1001	C	2	1111 1111 1101 1001
8	7	1111 1111 1011 1010	C	3	1111 1111 1101 1010
8	8	1111 1111 1011 1011	C	4	1111 1111 1101 1011
8	9	1111 1111 1011 1100	C	5	1111 1111 1101 1100
8	A	1111 1111 1011 1101	C	6	1111 1111 1101 1101
9	1	1111 1100 1	C	7	1111 1111 1101 1110
9	2	1111 1111 1011 1110	C	8	1111 1111 1101 1111
9	3	1111 1111 1011 1111	C	9	1111 1111 1110 0000
9	4	1111 1111 1100 0000	C	A	1111 1111 1110 0001
9	5	1111 1111 1100 0001	D	1	1111 1111 000
9	6	1111 1111 1100 0010	D	2	1111 1111 1110 0010
9	7	1111 1111 1100 0011	D	3	1111 1111 1110 0011
9	8	1111 1111 1100 0100	D	4	1111 1111 1110 0100
9	9	1111 1111 1100 0101	D	5	1111 1111 1110 0101
9	A	1111 1111 1100 0110	D	6	1111 1111 1110 0110
A	1	1111 1101 0	D	7	1111 1111 1110 0111
A	2	1111 1111 1100 0111	D	8	1111 1111 1110 1000
A	3	1111 1111 1100 1000	D	9	1111 1111 1110 1001
A	4	1111 1111 1100 1001	D	A	1111 1111 1110 1010
A	5	1111 1111 1100 1010	E	1	1111 1111 1110 1011
E	2	1111 1111 1110 1100	F	1	1111 1111 1111 0101
E	3	1111 1111 1110 1101	F	2	1111 1111 1111 0110
E	4	1111 1111 1110 1110	F	3	1111 1111 1111 0111
E	5	1111 1111 1110 1111	F	4	1111 1111 1111 1000
E	6	1111 1111 1111 0000	F	5	1111 1111 1111 1001
E	7	1111 1111 1111 0001	F	6	1111 1111 1111 1010
E	8	1111 1111 1111 0010	F	7	1111 1111 1111 1011
E	9	1111 1111 1111 0011	F	8	1111 1111 1111 1100
E	A	1111 1111 1111 0100	F	9	1111 1111 1111 1101
F	0	1111 1111 001 (ZRL)	F	A	1111 1111 1111 1110

C.2 VLC Table for Chrominance AC Coefficients in JPEG

Run	Size	Code word	Run	Size	Code word
0	0	00 (EOB)	1	6	1111 1111 0101
0	1	01	1	7	1111 1111 1000 1000
0	2	100	1	8	1111 1111 1000 1001
0	3	1010	1	9	1111 1111 1000 1010
0	4	1100 0	1	A	1111 1111 1000 1011
0	5	1100 1	2	1	1101 0
0	6	1110 00	2	2	1111 0111
0	7	1111 000	2	3	1111 1101 11
0	8	1111 1010 0	2	4	1111 1111 0110
0	9	1111 1101 10	2	5	1111 1111 1000 010
0	A	1111 1111 0100	2	6	1111 1111 1000 1100
1	1	1011	2	7	1111 1111 1000 1101
1	2	1110 01	2	8	1111 1111 1000 1110
1	3	1111 0110	2	9	1111 1111 1000 1111
1	4	1111 1010 1	2	A	1111 1111 1001 0000
1	5	1111 1110 110	3	1	1101 1
3	2	1111 1000	6	8	1111 1111 1010 1100
3	3	1111 1110 00	6	9	1111 1111 1010 1101
3	4	1111 1111 0111	6	A	1111 1111 1010 1110
3	5	1111 1111 1001 0001	7	1	1111 010
3	6	1111 1111 1001 0010	7	2	1111 1111 000
3	7	1111 1111 1001 0011	7	3	1111 1111 1010 1111
3	8	1111 1111 1001 0100	7	4	1111 1111 1011 0000
3	9	1111 1111 1001 0101	7	5	1111 1111 1011 0001
3	A	1111 1111 1001 0110	7	6	1111 1111 1011 0010
4	1	1110 10	7	7	1111 1111 1011 0011
4	2	1111 1011 0	7	8	1111 1111 1011 0100
4	3	1111 1111 1001 0111	7	9	1111 1111 1011 0101
4	4	1111 1111 1001 1000	7	A	1111 1111 1011 0110
4	5	1111 1111 1001 1001	8	1	1111 1001
4	6	1111 1111 1001 1010	8	2	1111 1111 1011 0111
4	7	1111 1111 1001 1011	8	3	1111 1111 1011 1000
4	8	1111 1111 1001 1100	8	4	1111 1111 1011 1001
4	9	1111 1111 1001 1101	8	5	1111 1111 1011 1010
4	A	1111 1111 1001 1110	8	6	1111 1111 1011 1011
5	1	1110 11	8	7	1111 1111 1011 1100
5	2	1111 1110 01	8	8	1111 1111 1011 1101
5	3	1111 1111 1001 1111	8	9	1111 1111 1011 1110
5	4	1111 1111 1010 0000	8	A	1111 1111 1011 1111
5	5	1111 1111 1010 0001	9	1	1111 1011 1
5	6	1111 1111 1010 0010	9	2	1111 1111 1100 0000
5	7	1111 1111 1010 0011	9	3	1111 1111 1100 0001
5	8	1111 1111 1010 0100	9	4	1111 1111 1100 0010

Run	Size	Code word	Run	Size	Code word
5	9	1111 1111 1010 0101	9	5	1111 1111 1100 0011
5	A	1111 1111 1010 0110	9	6	1111 1111 1100 0100
6	1	1111 001	9	7	1111 1111 1100 0101
6	2	1111 1110 111	9	8	1111 1111 1100 0110
6	3	1111 1111 1010 0111	9	9	1111 1111 1100 0111
6	4	1111 1111 1010 1000	9	A	1111 1111 1100 1000
6	5	1111 1111 1010 1001	A	1	1111 1100 0
6	6	1111 1111 1010 1010	A	2	1111 1111 1100 1001
6	7	1111 1111 1010 1011	A	3	1111 1111 1100 1010
A	4	1111 1111 1100 1011	D	A	1111 1111 1110 1100
A	5	1111 1111 1100 1100	E	1	1111 1111 1000 00
A	6	1111 1111 1100 1101	E	2	1111 1111 1110 1101
A	7	1111 1111 1100 1110	E	3	1111 1111 1110 1110
A	8	1111 1111 1100 1111	E	4	1111 1111 1110 1111
A	9	1111 1111 1101 0000	E	5	1111 1111 1111 0000
A	A	1111 1111 1101 0001	E	6	1111 1111 1111 0001
B	1	1111 1100 1	E	7	1111 1111 1111 0010
B	2	1111 1111 1101 0010	E	8	1111 1111 1111 0011
B	3	1111 1111 1101 0011	E	9	1111 1111 1111 0100
B	4	1111 1111 1101 0100	E	A	1111 1111 1111 0101
B	5	1111 1111 1101 0101	F	0	1111 1110 10 (ZRL)
B	6	1111 1111 1101 0110	F	1	1111 1111 1000 011
B	7	1111 1111 1101 0111	F	2	1111 1111 1111 0110
B	8	1111 1111 1101 1000	F	3	1111 1111 1111 0111
B	9	1111 1111 1101 1001	F	4	1111 1111 1111 1000
B	A	1111 1111 1101 1010	F	5	1111 1111 1111 1001
C	1	1111 1101 0	F	6	1111 1111 1111 1010
C	2	1111 1111 1101 1011	F	7	1111 1111 1111 1011
C	3	1111 1111 1101 1100	F	8	1111 1111 1111 1100
C	4	1111 1111 1101 1101	F	9	1111 1111 1111 1101
C	5	1111 1111 1101 1110	F	A	1111 1111 1111 1110
C	6	1111 1111 1101 1111			
C	7	1111 1111 1110 0000			
C	8	1111 1111 1110 0001			
C	9	1111 1111 1110 0010			
C	A	1111 1111 1110 0011			
D	1	1111 1111 001			
D	2	1111 1111 1110 0100			
D	3	1111 1111 1110 0101			
D	4	1111 1111 1110 0110			
D	5	1111 1111 1110 0111			
D	6	1111 1111 1110 1000			
D	7	1111 1111 1110 1001			
D	8	1111 1111 1110 1010			
D	9	1111 1111 1110 1011			