



Digital Image Processing

Image Compression

Relative Data Redundancy

- ▶ Let b and b' denote the number of bits in two representations of the same information, the relative data redundancy R is

$$R = 1 - 1/C$$

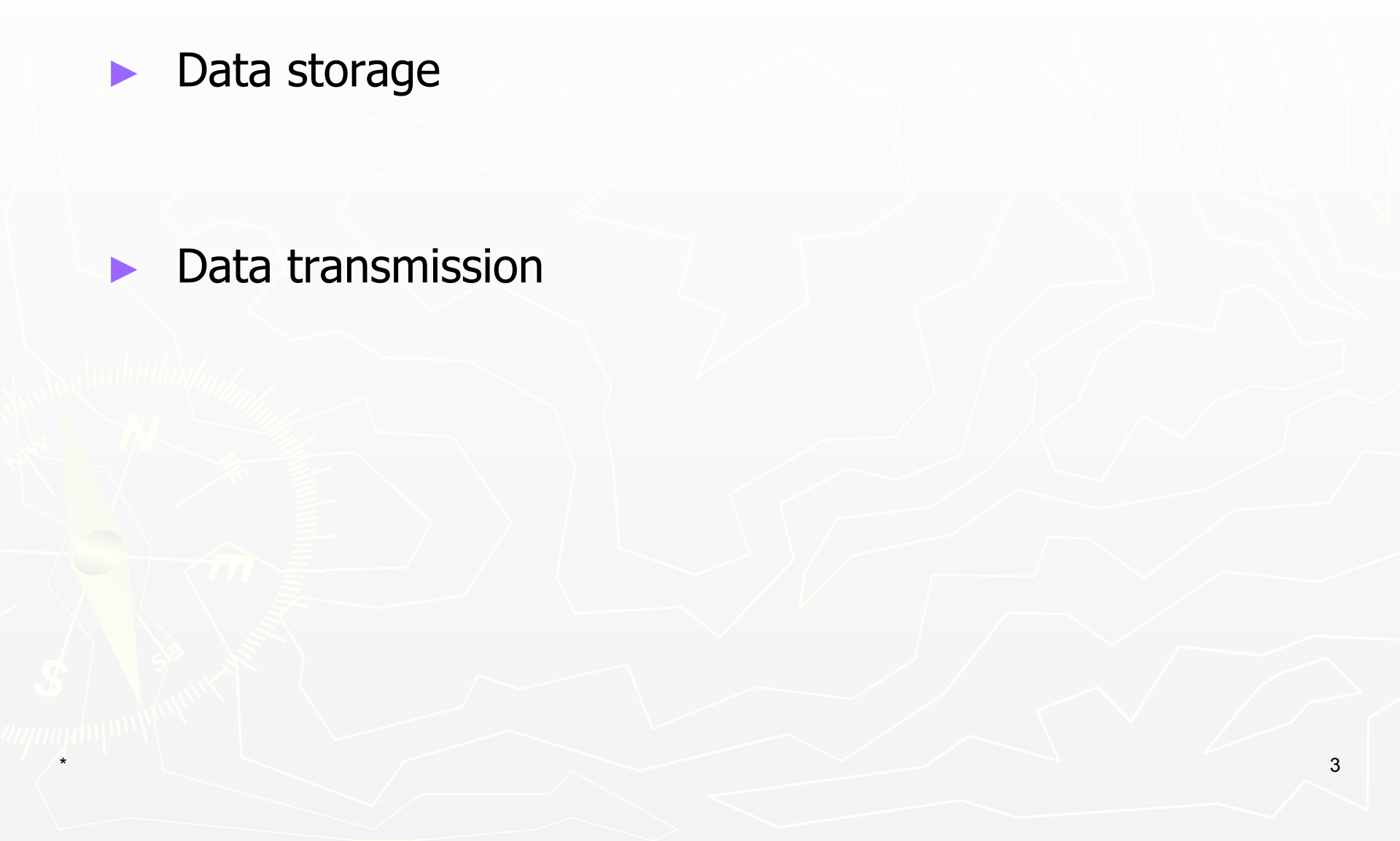
C is called the compression ratio, defined as

$$C = b/b'$$

e.g., $C = 10$, the corresponding relative data redundancy of the larger representation is 0.9, indicating that 90% of its data is redundant

Why do we need compression?

- ▶ Data storage
- ▶ Data transmission



How can we implement compression?

- ▶ **Coding redundancy**

Most 2-D intensity arrays contain more bits than are needed to represent the intensities

- ▶ **Spatial redundancy:** elements that are duplicated within a structure, such as pixels in a still image and bit patterns in a file. Exploiting spatial redundancy is how compression is performed.

- ▶ **Temporal redundancy:** pixels in two video frames that have the same values in the same location. Exploiting temporal redundancy is one of the primary techniques in video compression.

- ▶ **Irrelevant information**

Most 2-D intensity arrays contain information that is ignored by the human visual system

Examples of Redundancy

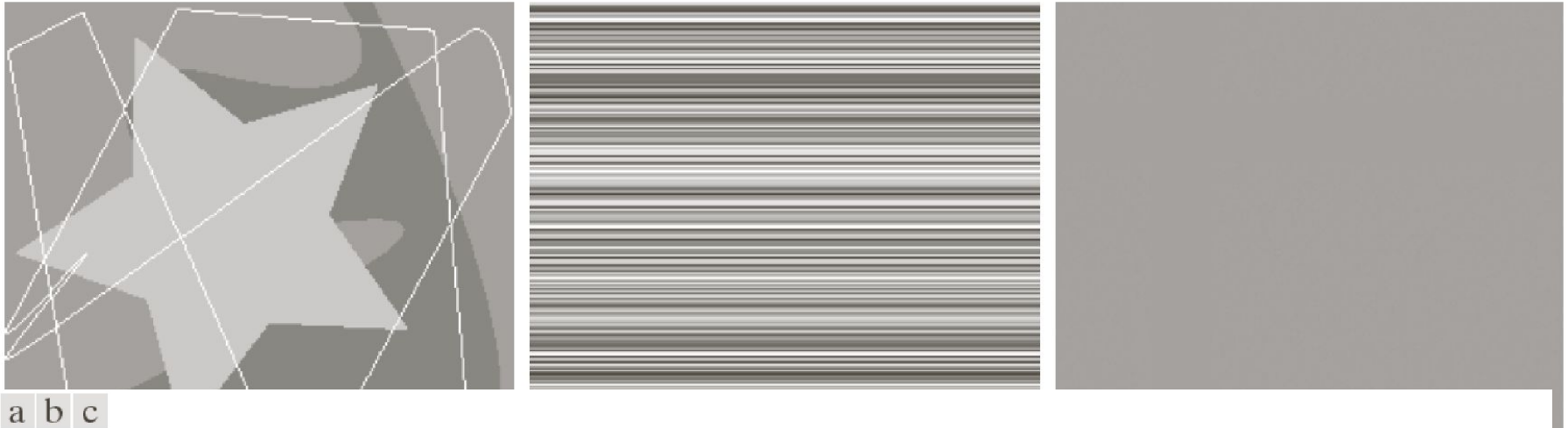


FIGURE 8.1 Computer generated $256 \times 256 \times 8$ bit images with (a) coding redundancy, (b) spatial redundancy, and (c) irrelevant information. (Each was designed to demonstrate one principal redundancy but may exhibit others as well.)

Coding Redundancy

TABLE 8.1
Example of
variable-length
coding.

r_k	$p_r(r_k)$	Code 1	$l_1(r_k)$	Code 2	$l_2(r_k)$
$r_{87} = 87$	0.25	01010111	8	01	2
$r_{128} = 128$	0.47	10000000	8	1	1
$r_{186} = 186$	0.25	11000100	8	000	3
$r_{255} = 255$	0.03	11111111	8	001	3
r_k for $k \neq 87, 128, 186, 255$	0	—	8	—	0

The average number of bits required to represent each pixel is

$$L_{avg} = \sum_{k=0}^{L-1} l(r_k) p_r(r_k) = 0.25(2) + 0.47(1) + 0.24(3) + 0.03(3) = 1.81 \text{ bits}$$

$$C = \frac{8}{1.81} \approx 4.42$$

$$R = 1 - 1/4.42 = 0.774$$

Spatial and Temporal Redundancy

1. All 256 intensities are equally probable.
2. The pixels along each line are identical.
3. The intensity of each line was selected randomly.

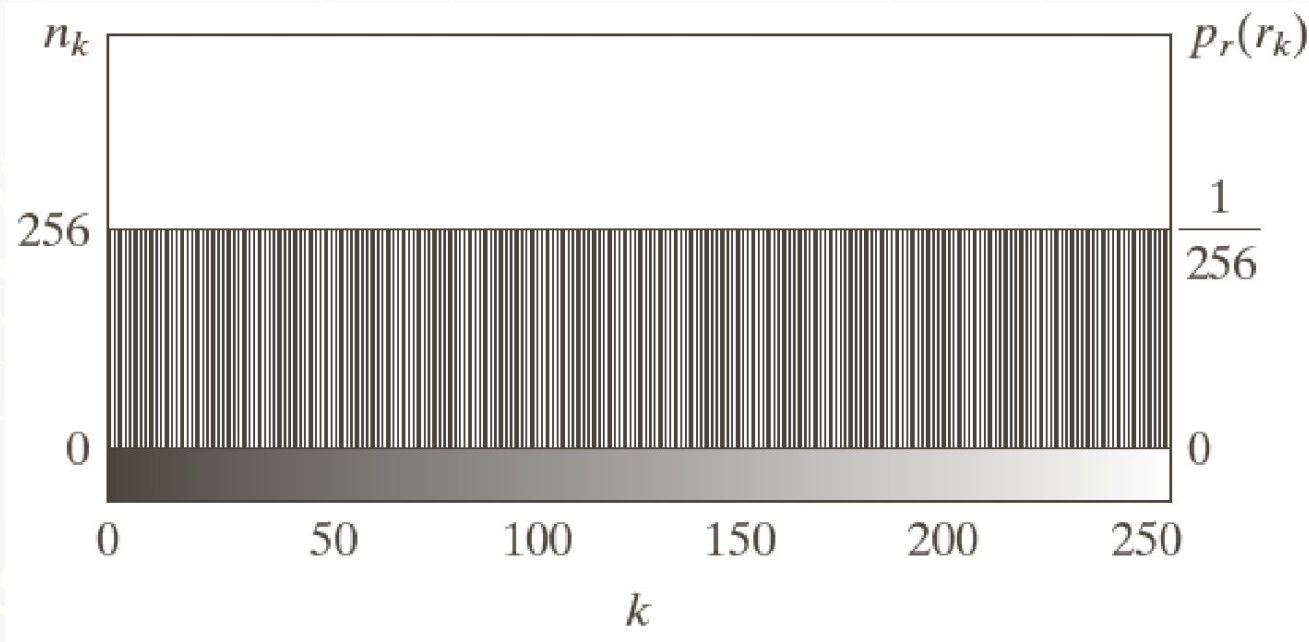


FIGURE 8.2 The intensity histogram of the image in Fig. 8.1(b).

Spatial and Temporal Redundancy

1. All 256 intensities are equally probable.
2. The pixels along each line are identical.
3. The intensity of each line was selected randomly.

Run-length pair specifies the start of a new intensity and the number of consecutive pixels that have that intensity.

Each 256-pixel line of the original representation is replaced by a single 8-bit intensity value and length 256 in the run-length representation.

The compression ratio is

$$\frac{256 \times 256 \times 8}{(256 + 256) \times 8} = 128 : 1$$

Measuring Image Information

Given a source of statistically independent random events from a discrete set of possible events $\{a_1, a_2, \dots, a_J\}$ with associated probabilities $\{P(a_1), P(a_2), \dots, P(a_J)\}$, the average information per source output, called the entropy of the source

$$H = -\sum_{j=1}^J P(a_j) \log P(a_j)$$

a_j is called source symbols. Because they are statistically independent, the source called *zero – memory source*.

Measuring Image Information

If an image is considered to be the output of an imaginary zero-memory "intensity source", we can use the histogram of the observed image to estimate the symbol probabilities of the source. The intensity source's entropy becomes

$$H = - \sum_{k=0}^{L-1} p_r(r_k) \log p_r(r_k)$$

$p_r(r_k)$ is the normalized histogram.

Measuring Image Information

For the fig.8.1(a),

$$\begin{aligned} H &= \\ & -[0.25 \log_2 0.25 + 0.47 \log_2 0.47 + 0.25 \log_2 0.25 + 0.03 \log_2 0.03] \\ & \approx 1.6614 \text{ bits/pixel} \end{aligned}$$

Image Compression Models

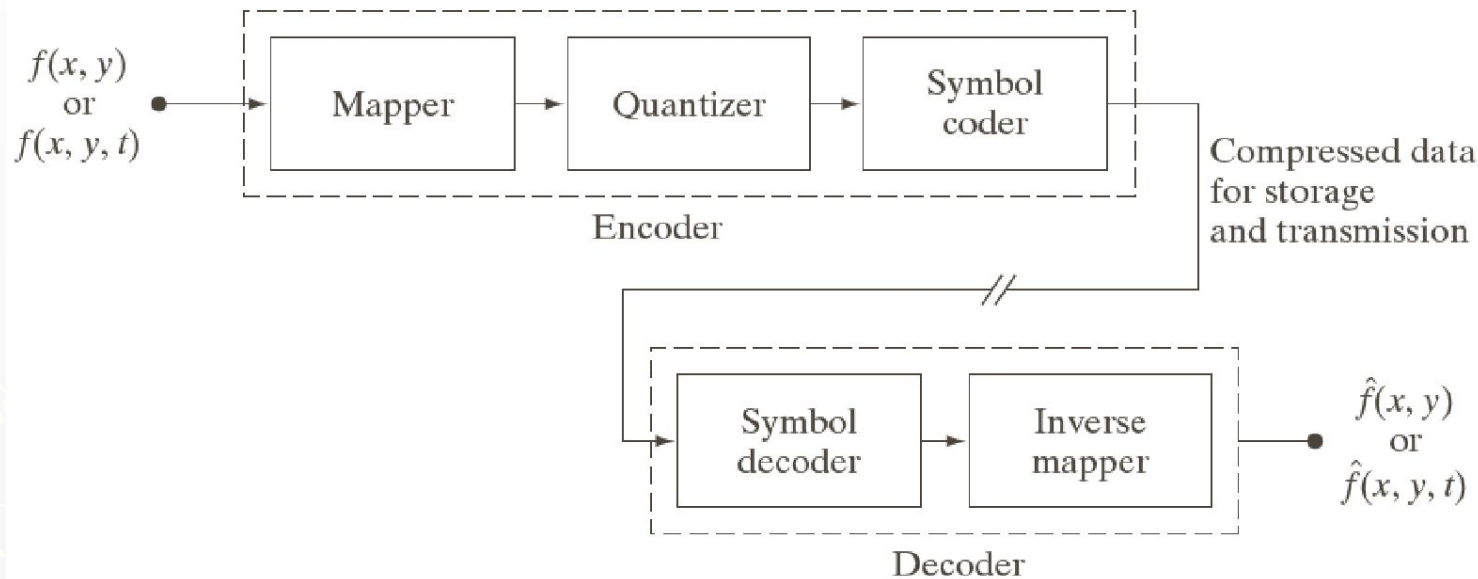


FIGURE 8.5
Functional block diagram of a general image compression system.

Mapper: Reduce spatial and temporal redundancy e.g. run-length coding

Quantizer: Reduces the quality in accord with predefined fidelity criteria (irreversible)

Symbol coder: Generates a fixed or variable length code to represent quantizer output.

Decoder, Inverse of Encoder's Mapper and coder.

Image Compression Standards

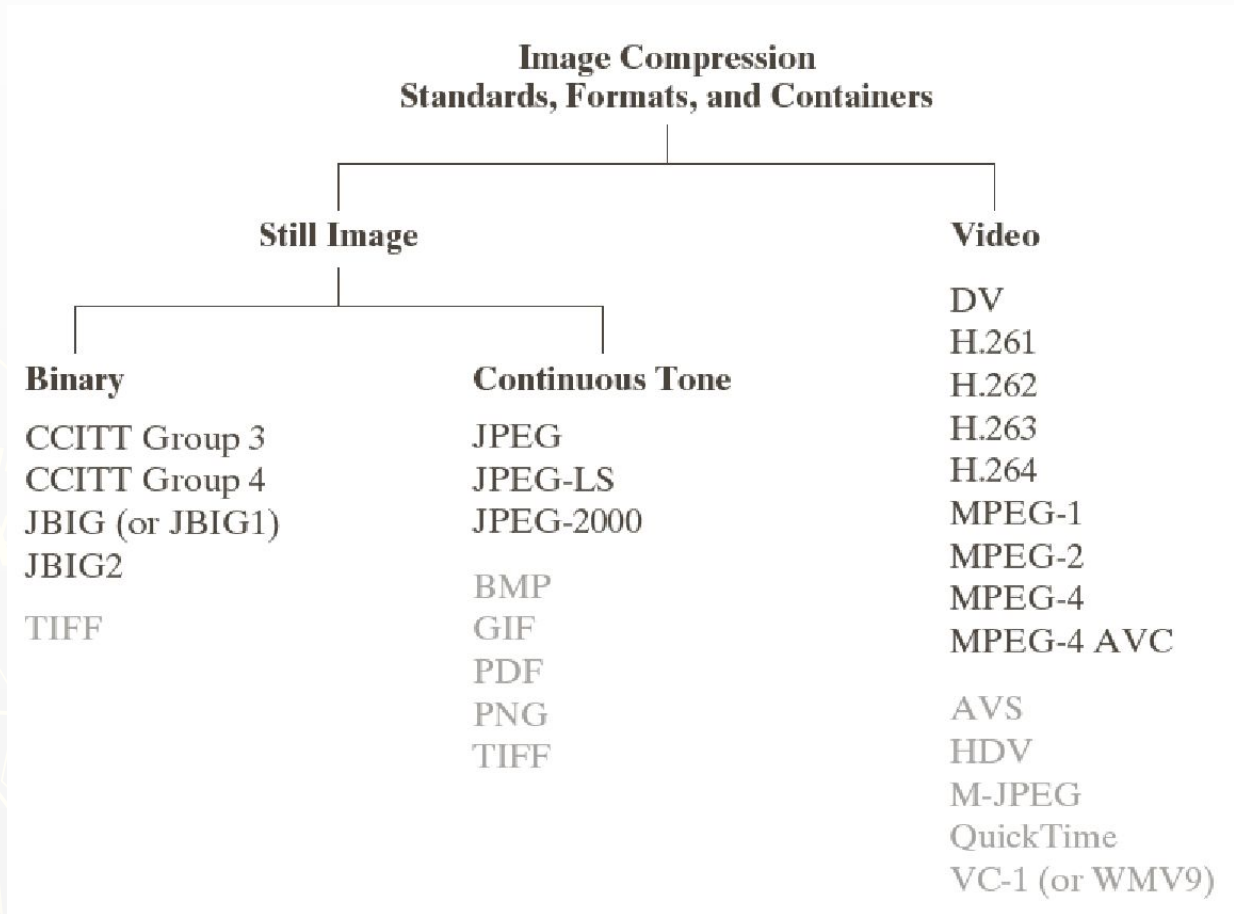


FIGURE 8.6 Some popular image compression standards, file formats, and containers. Internationally sanctioned entries are shown in black; all others are grayed.

Name	Organization	Description
<i>Bi-Level Still Images</i>		
CCITT Group 3	ITU-T	Designed as a facsimile (FAX) method for transmitting binary documents over telephone lines. Supports 1-D and 2-D run-length [8.2.5] and Huffman [8.2.1] coding.
CCITT Group 4	ITU-T	A simplified and streamlined version of the CCITT Group 3 standard supporting 2-D run-length coding only.
JBIG or JBIG1	ISO/IEC/ ITU-T	A <i>Joint Bi-level Image Experts Group</i> standard for progressive, lossless compression of bi-level images. Continuous-tone images of up to 6 bits/pixel can be coded on a bit-plane basis [8.2.7]. Context sensitive arithmetic coding [8.2.3] is used and an initial low resolution version of the image can be gradually enhanced with additional compressed data.
JBIG2	ISO/IEC/ ITU-T	A follow-on to JBIG1 for bi-level images in desktop, Internet, and FAX applications. The compression method used is content based, with dictionary based methods [8.2.6] for text and halftone regions, and Huffman [8.2.1] or arithmetic coding [8.2.3] for other image content. It can be lossy or lossless.
<i>Continuous-Tone Still Images</i>		
JPEG	ISO/IEC/ ITU-T	A <i>Joint Photographic Experts Group</i> standard for images of photographic quality. Its lossy <i>baseline coding system</i> (most commonly implemented) uses quantized discrete cosine transforms (DCT) on 8×8 image blocks [8.2.8], Huffman [8.2.1], and run-length [8.2.5] coding. It is one of the most popular methods for compressing images on the Internet.
JPEG-LS	ISO/IEC/ ITU-T	A lossless to near-lossless standard for continuous tone images based on adaptive prediction [8.2.9], context modeling [8.2.3], and Golomb coding [8.2.2].
JPEG-2000	ISO/IEC/ ITU-T	A follow-on to JPEG for increased compression of photographic quality images. Arithmetic coding [8.2.3] and quantized discrete wavelet transforms (DWT) [8.2.10] are used. The compression can be lossy or lossless.

TABLE 8.3
Internationally sanctioned image compression standards. The numbers in brackets refer to sections in this chapter.

(Continues)

Name	Organization	Description
<i>Video</i>		
DV	IEC	<i>Digital Video</i> . A video standard tailored to home and semiprofessional video production applications and equipment—like electronic news gathering and camcorders. Frames are compressed independently for uncomplicated editing using a DCT-based approach [8.2.8] similar to JPEG.
H.261	ITU-T	A two-way videoconferencing standard for ISDN (<i>integrated services digital network</i>) lines. It supports non-interlaced 352×288 and 176×144 resolution images, called CIF (<i>Common Intermediate Format</i>) and QCIF (<i>Quarter CIF</i>), respectively. A DCT-based compression approach [8.2.8] similar to JPEG is used, with frame-to-frame prediction differencing [8.2.9] to reduce temporal redundancy. A block-based technique is used to compensate for motion between frames.
H.262	ITU-T	See MPEG-2 below.
H.263	ITU-T	An enhanced version of H.261 designed for ordinary telephone modems (i.e., 28.8 Kb/s) with additional resolutions: SQCIF (<i>Sub-Quarter CIF</i> 128×96), 4CIF (704×576), and 16CIF (1408×512).
H.264	ITU-T	An extension of H.261–H.263 for videoconferencing, Internet streaming, and television broadcasting. It supports prediction differences within frames [8.2.9], variable block size integer transforms (rather than the DCT), and context adaptive arithmetic coding [8.2.3].
MPEG-1	ISO/IEC	A <i>Motion Pictures Expert Group</i> standard for CD-ROM applications with non-interlaced video at up to 1.5 Mb/s. It is similar to H.261 but frame predictions can be based on the previous frame, next frame, or an interpolation of both. It is supported by almost all computers and DVD players.
MPEG-2	ISO/IEC	An extension of MPEG-1 designed for DVDs with transfer rates to 15 Mb/s. Supports interlaced video and HDTV. It is the most successful video standard to date.
MPEG-4	ISO/IEC	An extension of MPEG-2 that supports variable block sizes and prediction differencing [8.2.9] within frames.
MPEG-4 AVC	ISO/IEC	MPEG-4 Part 10 <i>Advanced Video Coding</i> (AVC). Identical to H.264 above.

TABLE 8.3
(Continued)

Some Basic Compression Methods:

Huffman Coding

Original source		Source reduction			
Symbol	Probability	1	2	3	4
a_2	0.4	0.4	0.4	0.4	0.6
a_6	0.3	0.3	0.3	0.3	
a_1	0.1	0.1	0.2	0.3	0.4
a_4	0.1	0.1			
a_3	0.06	0.1	0.1	0.1	0.1
a_5	0.04				

FIGURE 8.7
Huffman source reductions.

Some Basic Compression Methods:

Huffman Coding

Original source			Source reduction			
Symbol	Probability	Code	1	2	3	4
a_2	0.4	1	0.4 1	0.4 1	0.4 1	0.6 0
a_6	0.3	00	0.3 00	0.3 00	0.3 00	0.4 1
a_1	0.1	011	0.1 011	0.2 010	0.3 01	
a_4	0.1	0100	0.1 0100	0.1 011		
a_3	0.06	01010	0.1 0101			
a_5	0.04	01011				

FIGURE 8.8
Huffman code
assignment
procedure.

The average length of this code is

$$\begin{aligned}
 L_{avg} &= 0.4 * 1 + 0.3 * 2 + 0.1 * 3 + 0.1 * 4 + 0.06 * 5 + 0.04 * 5 \\
 &= 2.2 \text{ bits/pixel}
 \end{aligned}$$