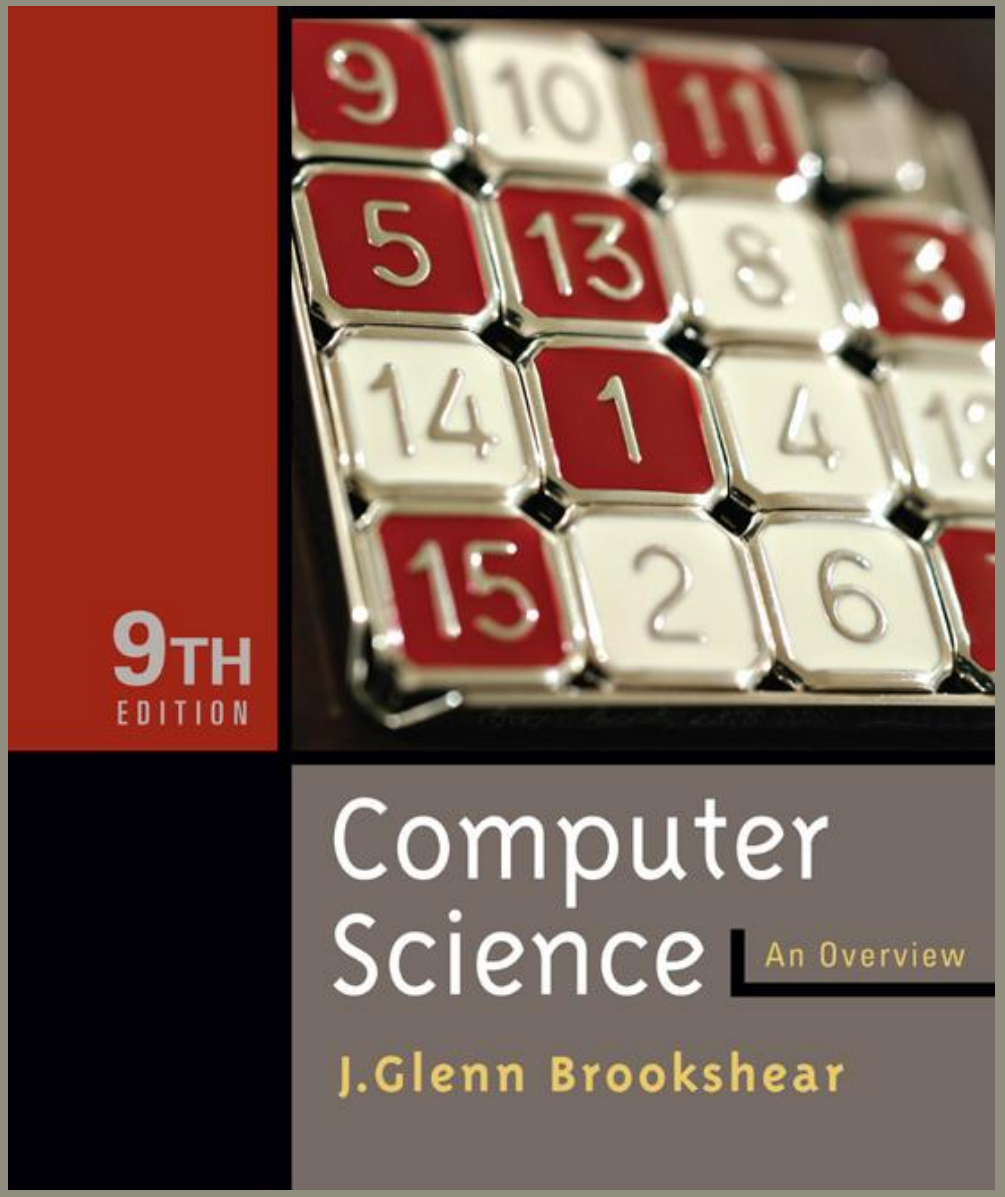
Chapter 1

Data Storage



Chapter 1: Data Storage

- 1.1 Bits and Their Storage
- 1.2 Main Memory
- 1.3 Mass Storage
- 1.4 Representing Information as Bit Patterns
- 1.5 The Binary System
- 1.6 Storing Integers

Chapter 1: Data Storage (continued)

- 1.7 Storing Fractions
- 1.8 Data Compression
- 1.9 Communications Errors

Bits and Bit Patterns

- **Bit:** Binary Digit (0 or 1)
- Bit Patterns are used to represent information.
  - Numbers
  - Text characters
  - Images
  - Sound
  - And others

Boolean Operations

- **Boolean Operation:** An operation that manipulates one or more true/false values
- Specific operations
  - AND
  - OR
  - XOR (exclusive or)
  - NOT

Figure 1.1 The Boolean operations AND, OR, and XOR (exclusive or)

The AND operation

```
  0     0     1     1
AND 0 AND 1 AND 0 AND 1
  0     0     0     1
```

The OR operation

```
  0     0     1     1
OR  0 OR  1 OR  0 OR  1
  0     1     1     1
```

The XOR operation

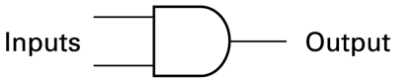
```
  0     0     1     1
XOR 0 XOR 1 XOR 0 XOR 1
  0     1     1     0
```

Gates

- **Gate:** A device that computes a Boolean operation
  - Often implemented as (small) electronic circuits
  - Provide the building blocks from which computers are constructed

Figure 1.2 A pictorial representation of AND, OR, XOR, and NOT gates as well as their input and output values

AND



Inputs	Output
0 0	0
0 1	0
1 0	0
1 1	1

OR

Inputs	Output
0 0	0
0 1	1
1 0	1
1 1	1

XOR

Inputs	Output
0 0	0
0 1	1
1 0	1
1 1	0

NOT

Inputs	Output
0	1
1	0

Flip-flops

- **Flip-flop:** A circuit built from gates that can store one bit.
  - Has an input line which sets its stored value to 1
  - Has an input line which sets its stored value to 0
  - While both input lines are 0, the most recently stored value is preserved

Figure 1.3 A simple flip-flop circuit

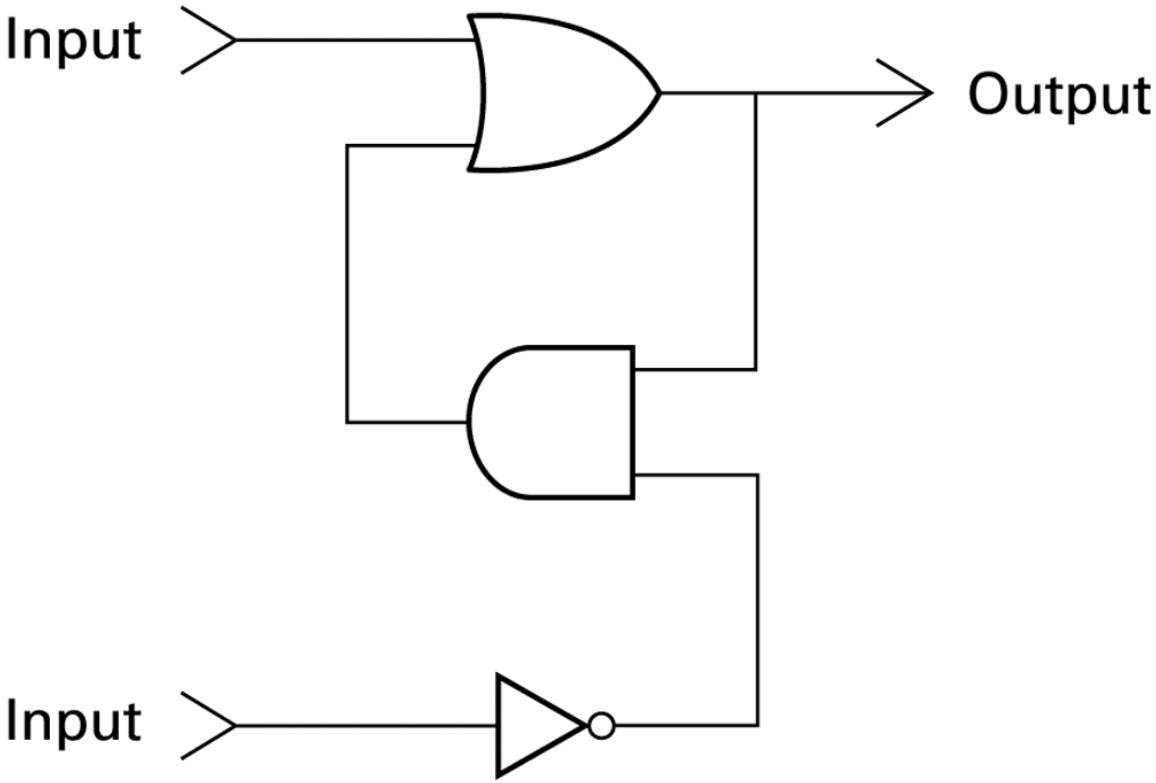


Figure 1.4 Setting the output of a flip-flop to 1

a. 1 is placed on the upper input.

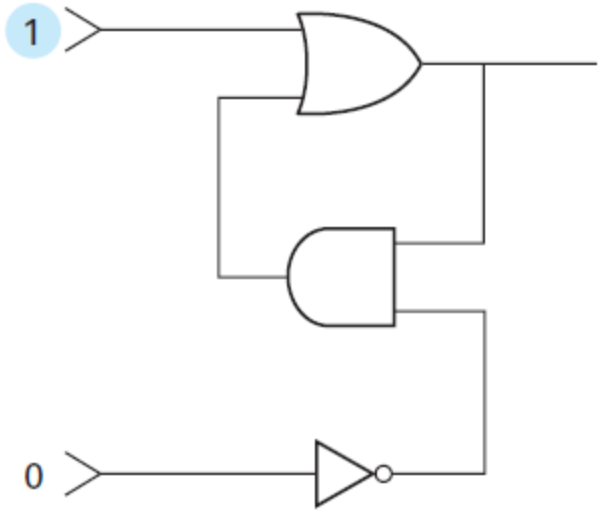


Figure 1.4 Setting the output of a flip-flop to 1 (continued)

b. This causes the output of the OR gate to be 1 and, in turn, the output of the AND gate to be 1.

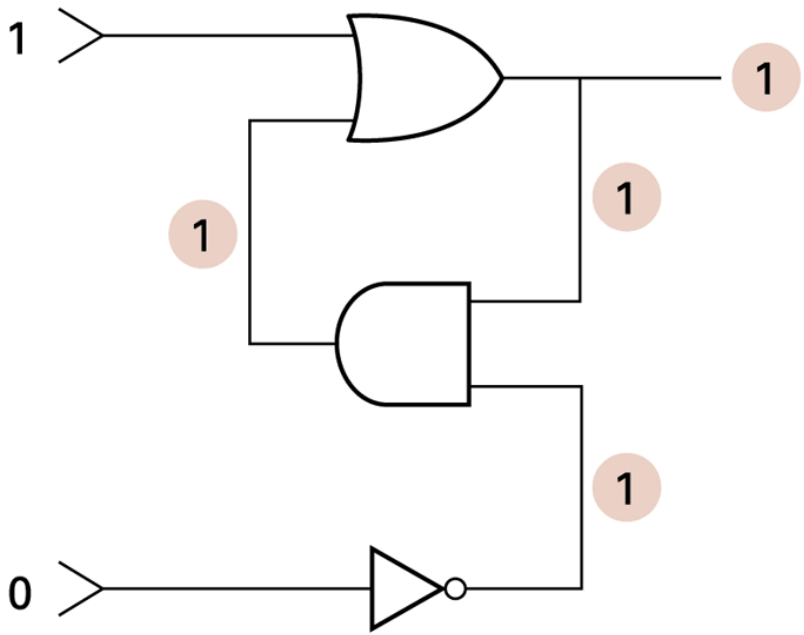


Figure 1.4 Setting the output of a flip-flop to 1 (continued)

c. The 1 from the AND gate keeps the OR gate from changing after the upper input returns to 0.

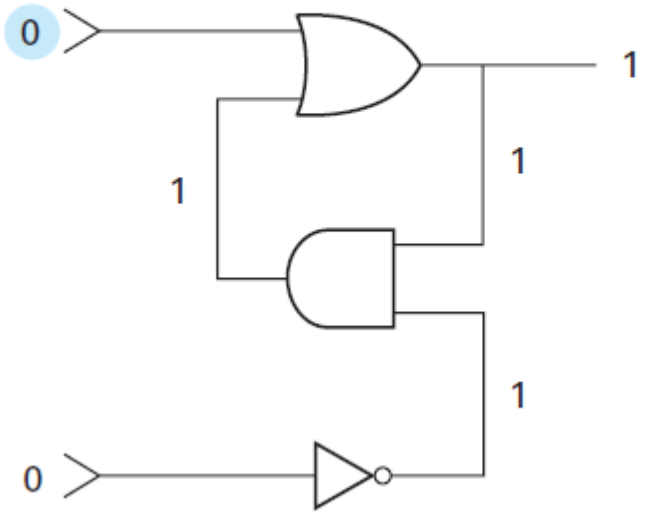
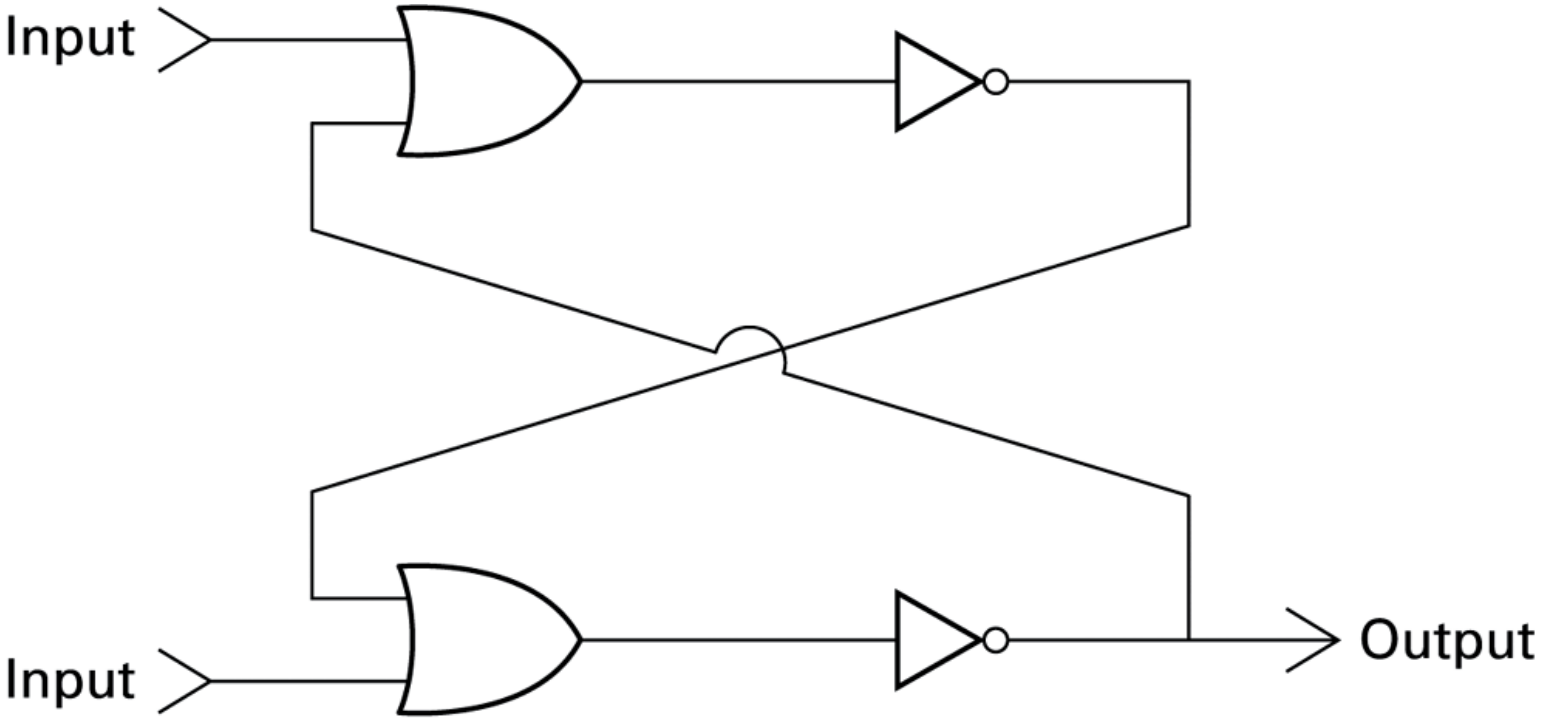


Figure 1.5 Another way of constructing a flip-flop



Hexadecimal Notation

- **Hexadecimal notation:** A shorthand notation for long bit patterns
  - Divides a pattern into groups of four bits each
  - Represents each group by a single symbol
- Example: 10100011 becomes A3

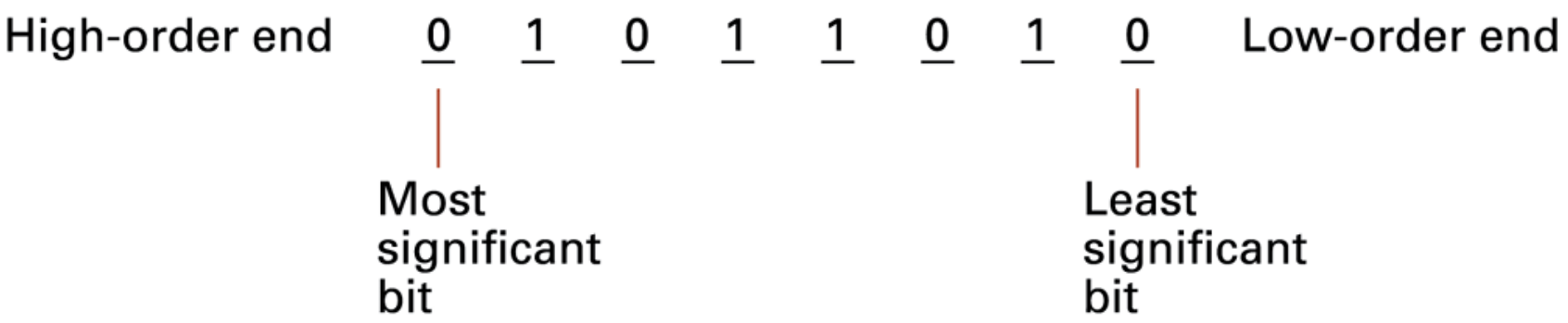
Figure 1.6 The hexadecimal coding system

Bit pattern	Hexadecimal representation
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

Main Memory Cells

- **Cell:** A unit of main memory (typically 8 bits which is one **byte**)
  - **Most significant bit:** the bit at the left (high-order) end of the conceptual row of bits in a memory cell
  - **Least significant bit:** the bit at the right (low-order) end of the conceptual row of bits in a memory cell

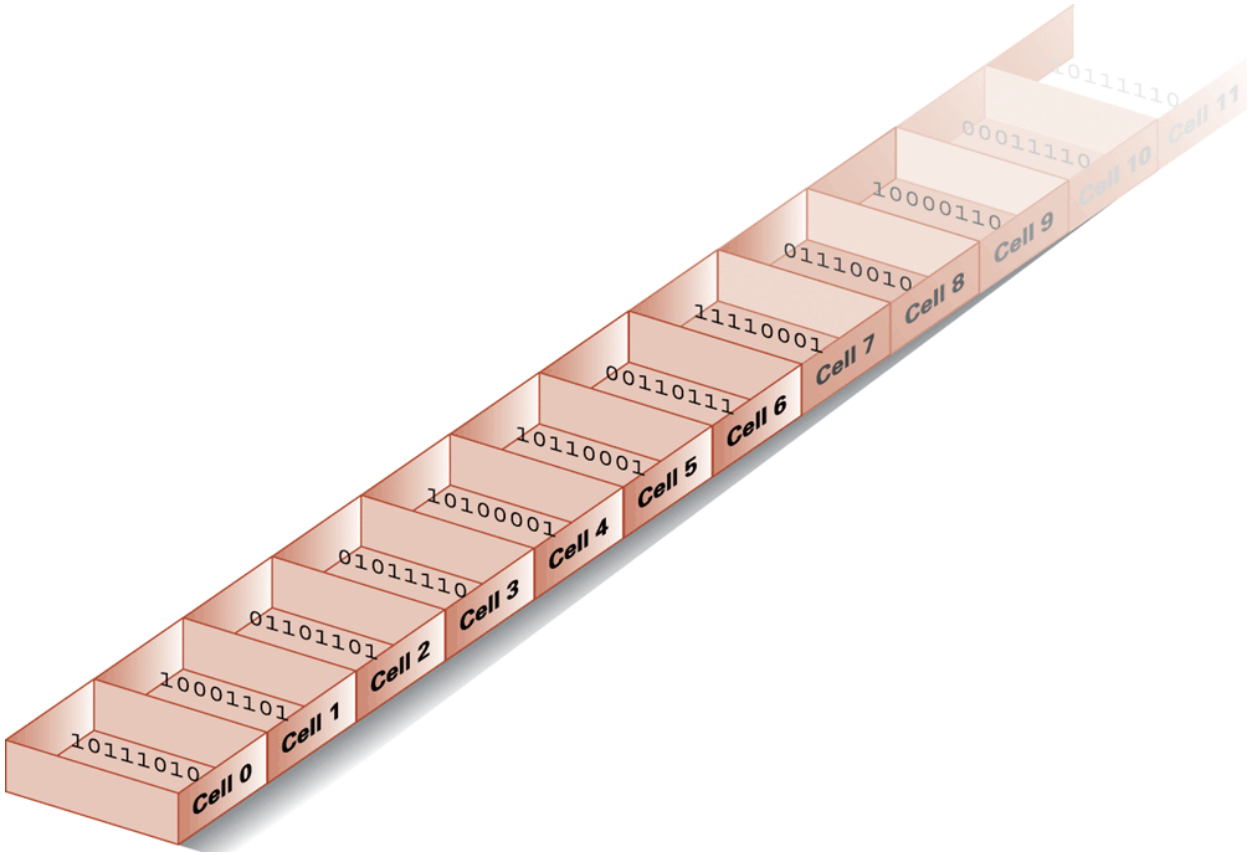
Figure 1.7 The organization of a byte-size memory cell



Main Memory Addresses

- **Address:** A "name" that uniquely identifies one cell in the computer's main memory
  - The names are actually numbers.
  - These numbers are assigned consecutively starting at zero.
  - Numbering the cells in this manner associates an order with the memory cells.

Figure 1.8 Memory cells arranged by address



Memory Terminology

- **Random Access Memory (RAM):** Memory in which individual cells can be easily accessed in any order
- **Dynamic Memory (DRAM):** RAM composed of volatile memory *(faster transfer circuitry needs periodic refresh per sec, SDRAM → synchronousDRAM additional circuitry for faster transfer)*

Measuring Memory Capacity

- **Kilobyte:** 2^{10} bytes = 1024 bytes
  - Example: 3 KB = 3 × 1024 bytes
  - Sometimes “kibi” rather than “kilo”
- **Megabyte:** 2^{20} bytes = 1,048,576 bytes
  - Example: 3 MB = 3 × 1,048,576 bytes
  - Sometimes “megi” rather than “mega”
- **Gigabyte:** 2^{30} bytes = 1,073,741,824 bytes
  - Example: 3 GB = 3 × 1,073,741,824 bytes
  - Sometimes “gigi” rather than “giga”

Mass Storage

- On-line versus off-line *(able to remove)*
- Typically larger than main memory
- Typically less volatile than main memory
- Typically slower than main memory

Mass Storage Systems

- Magnetic Systems
  - Disk
  - Tape
- Optical Systems
  - CD
  - DVD
- Flash Drives

Figure 1.9 A magnetic disk storage system

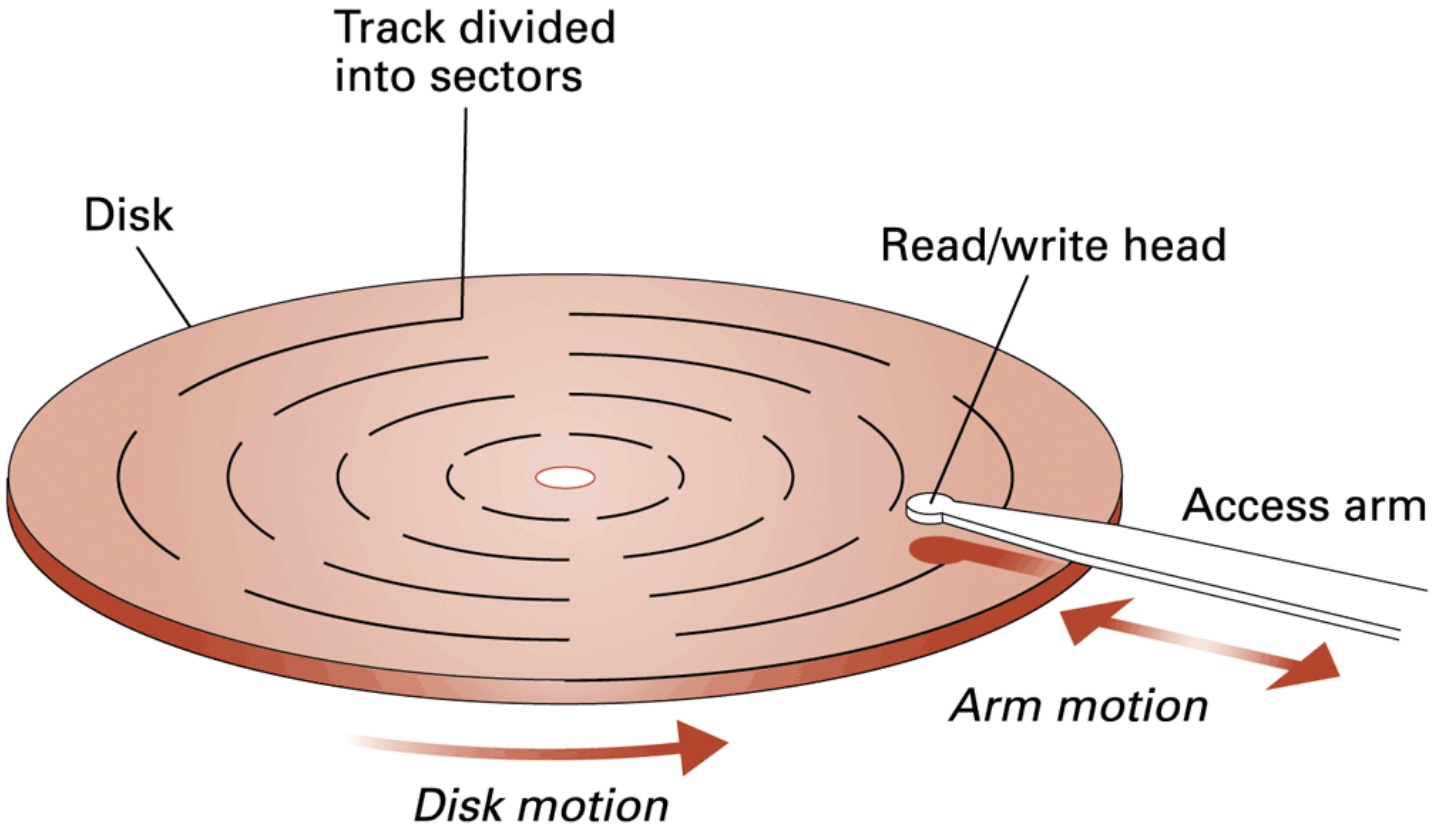


Figure 1.10 Magnetic tape storage *(mostly reliability)*

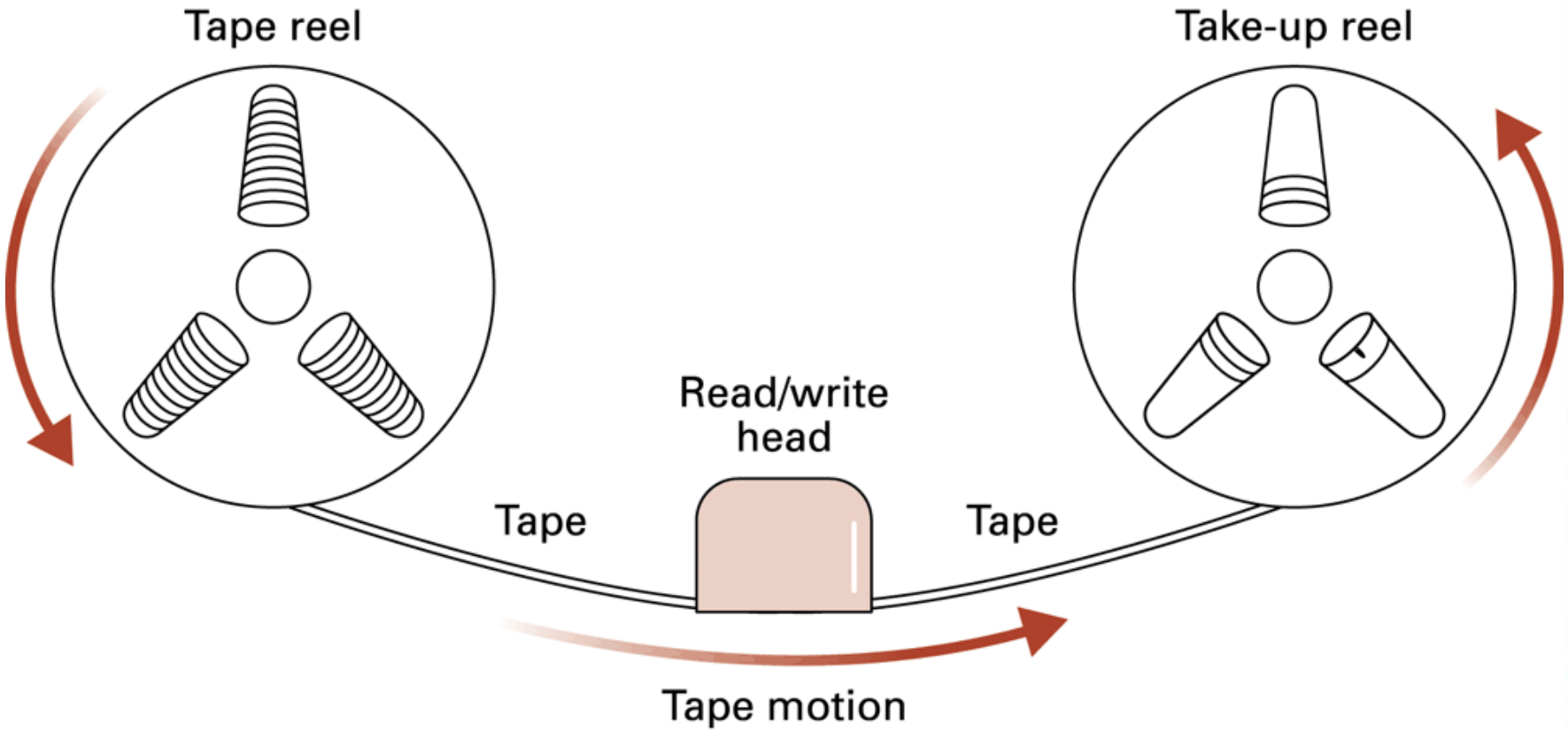
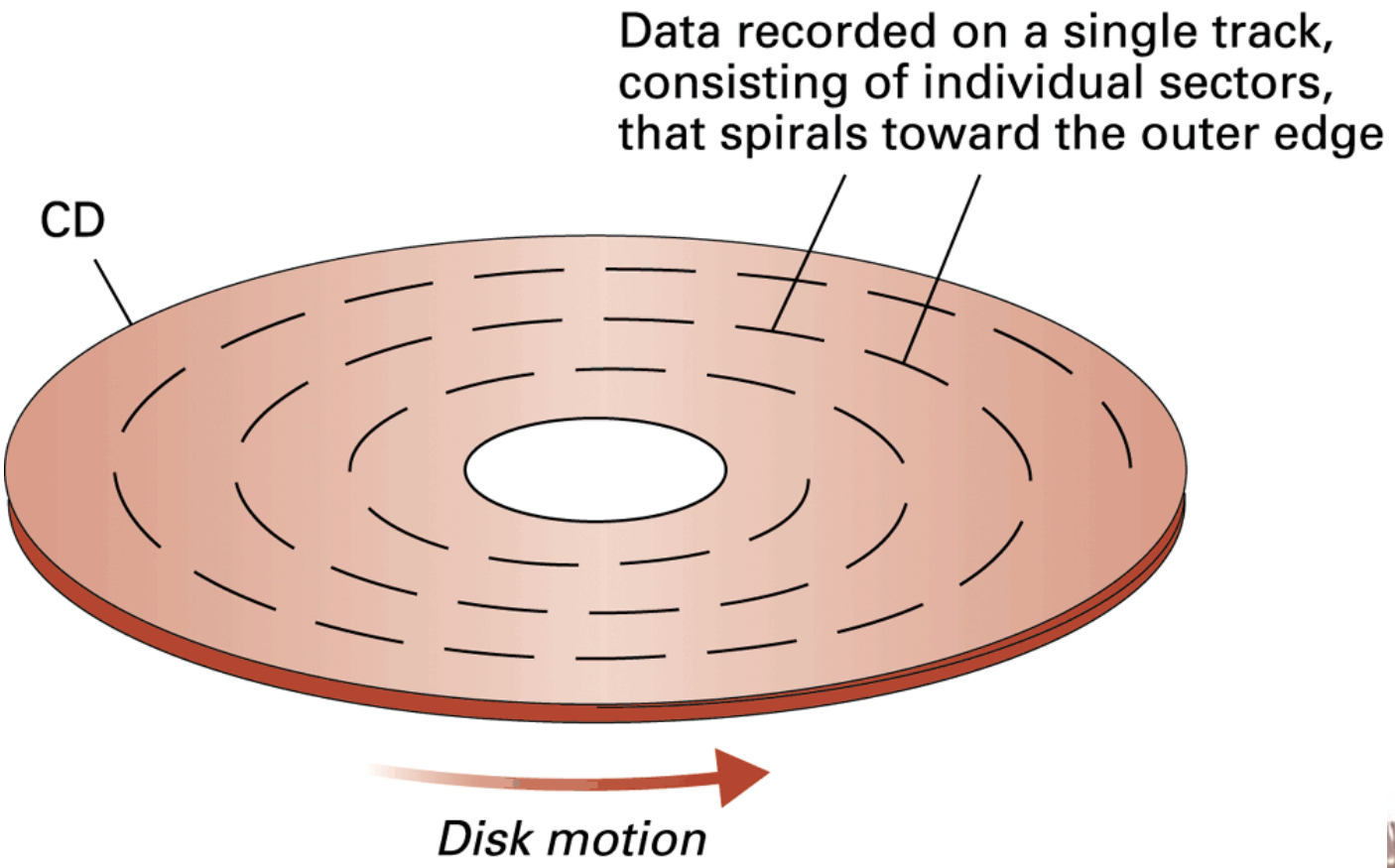


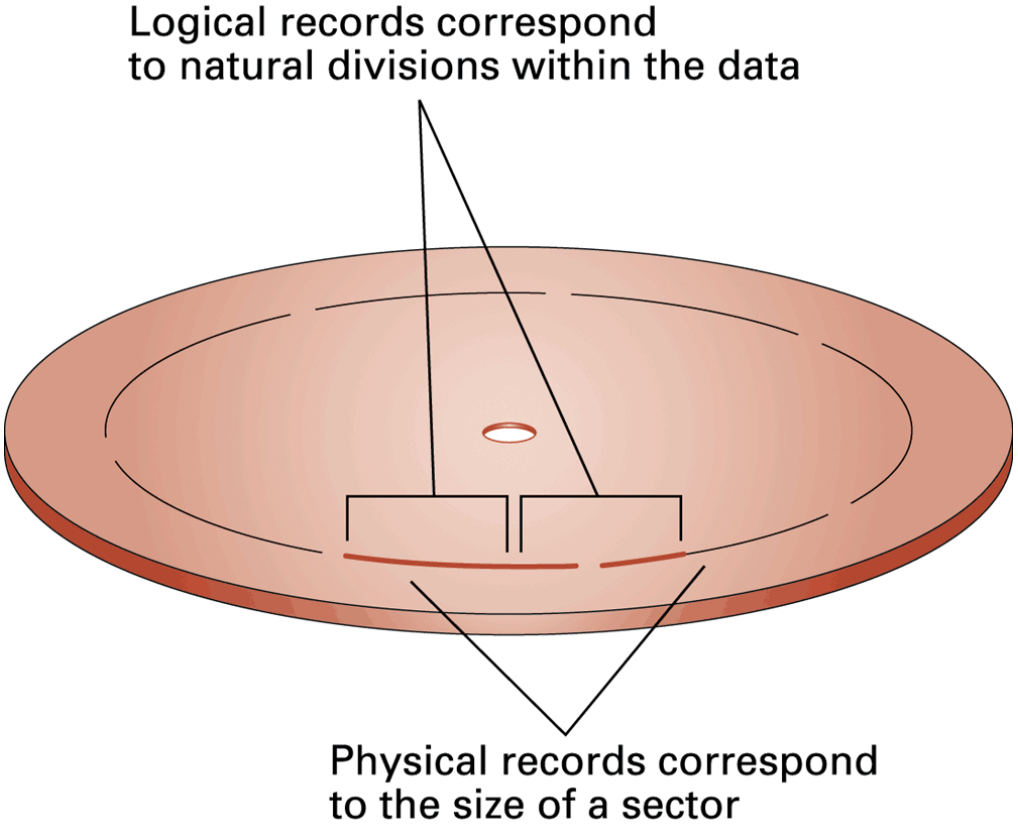
Figure 1.11 CD storage



Files

- **File:** A unit of data stored in mass storage system
  - **Fields** and **keyfields** for logical records (many units)
- Physical record versus Logical record
- **Buffer:** A memory area used for the temporary storage of data (usually as a step in transferring the data)

Figure 1.12 Logical records versus physical records on a disk



Representing Text

- Each character (letter, punctuation, etc.) is assigned a unique bit pattern.
  - ASCII: Uses patterns of 7-bits to represent most symbols used in written English text
  - Unicode: Uses patterns of 16-bits to represent the major symbols used in languages world side
  - ISO standard: Uses patterns of 32-bits to represent most symbols used in languages world wide

Figure 1.13 The message “Hello.” in ASCII

01001000	01100101	01101100	01101100	01101111	00101110
H	e	l	l	o	.

Representing Numeric Values

- Binary notation: Uses bits to represent a number in base two
- Limitations of computer representations of numeric values
  - Overflow – happens when a value is too big to be represented *(w.r.t. cell block size)*
  - Truncation – happens when a value is between two representable values *(w.r.t. cell block size again – i.e. sensitivity?)*

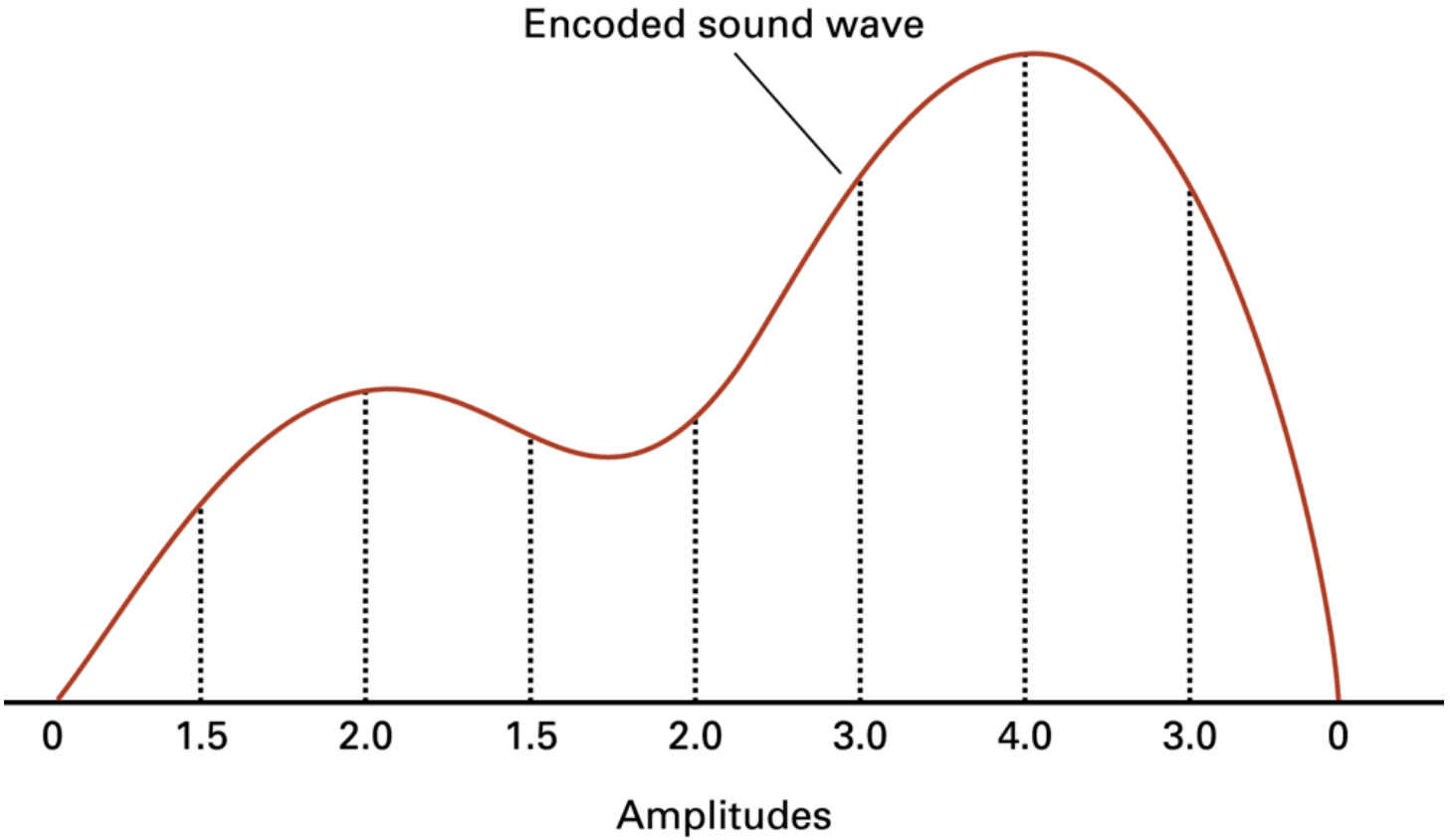
Representing Images

- Bit map techniques *(scalability problem)*
  - Pixel: short for "picture element"
  - RGB
  - Luminance *(brightness r+g+b)* and chrominance *(blue diff. and red diff. from luminance)*
- Vector techniques *(using analytic geometry tech.)*
  - Scalable
  - TrueType *(MS and Apple)* and PostScript *(Adobe)*
  - *Also popular in CAD systems*

Representing Sound

- Sampling techniques *(e.g. 44100 samples/sec CD)*
  - Used for high quality recordings
  - Records actual audio *(16 bits mono, 32 bits stereo)*
- MIDI
  - Used in music synthesizers
  - Records "musical score" *(notes and their durations are coded)*

Figure 1.14 The sound wave represented by the sequence 0, 1.5, 2.0, 1.5, 2.0, 3.0, 4.0, 3.0, 0



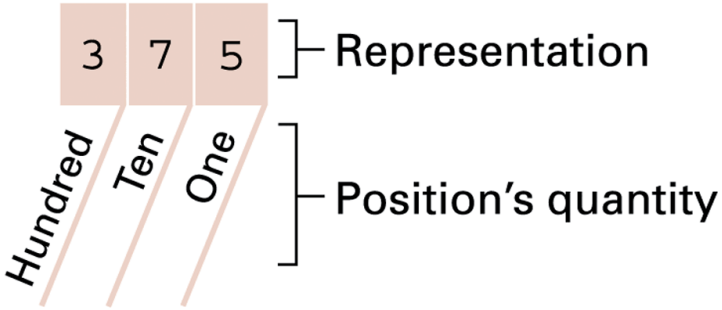
The Binary System

The traditional decimal system is based on powers of ten.

The Binary system is based on powers of two.

Figure 1.15 The base ten and binary systems

a. Base ten system



b. Base two system

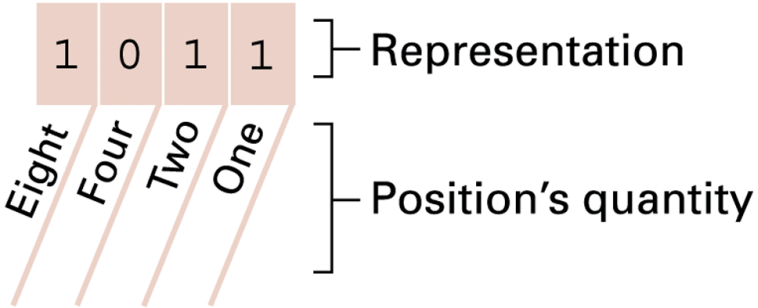


Figure 1.16 Decoding the binary representation 100101

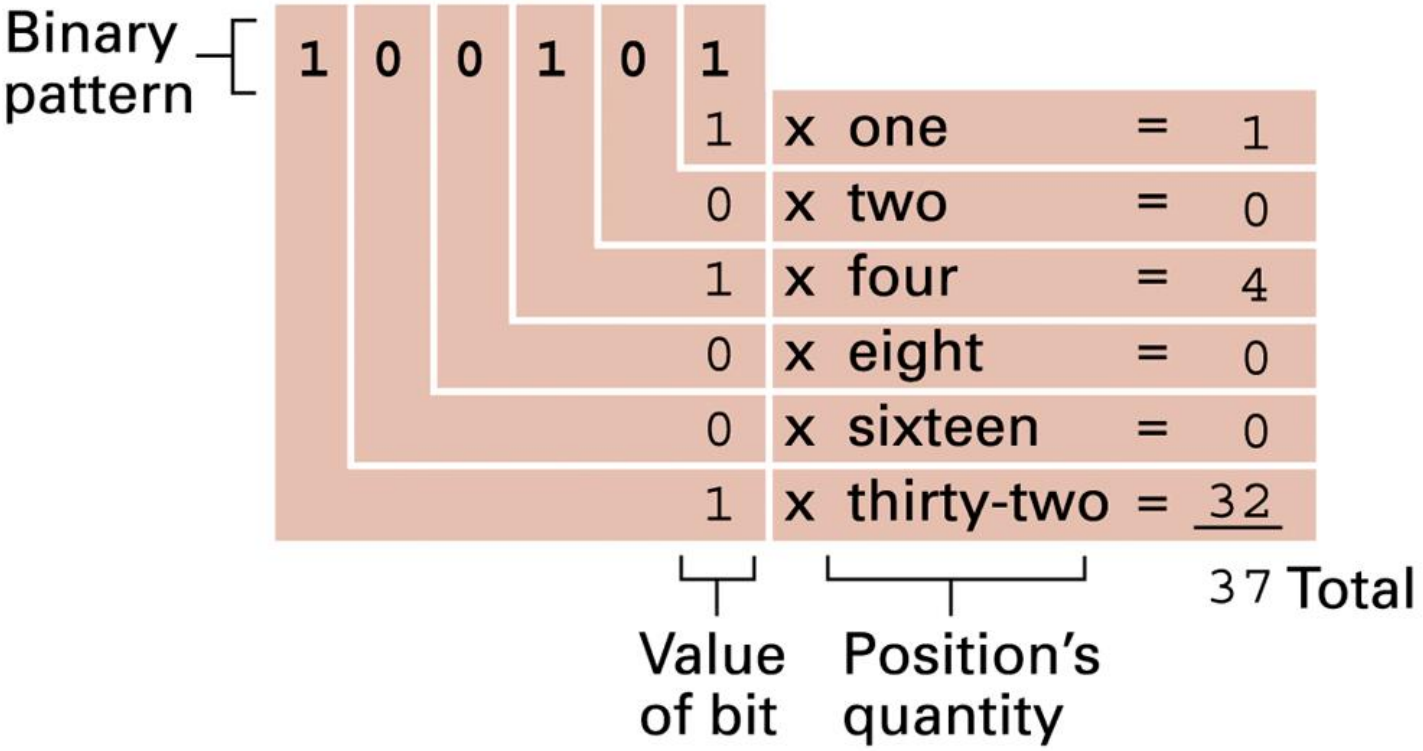


Figure 1.17 An algorithm for finding the binary representation of a positive integer

Step 1. Divide the value by two and record the remainder.

Step 2. As long as the quotient obtained is not zero, continue to divide the newest quotient by two and record the remainder.

Step 3. Now that a quotient of zero has been obtained, the binary representation of the original value consists of the remainders listed from right to left in the order they were recorded.

Figure 1.18 Applying the algorithm in Figure 1.15 to obtain the binary representation of thirteen

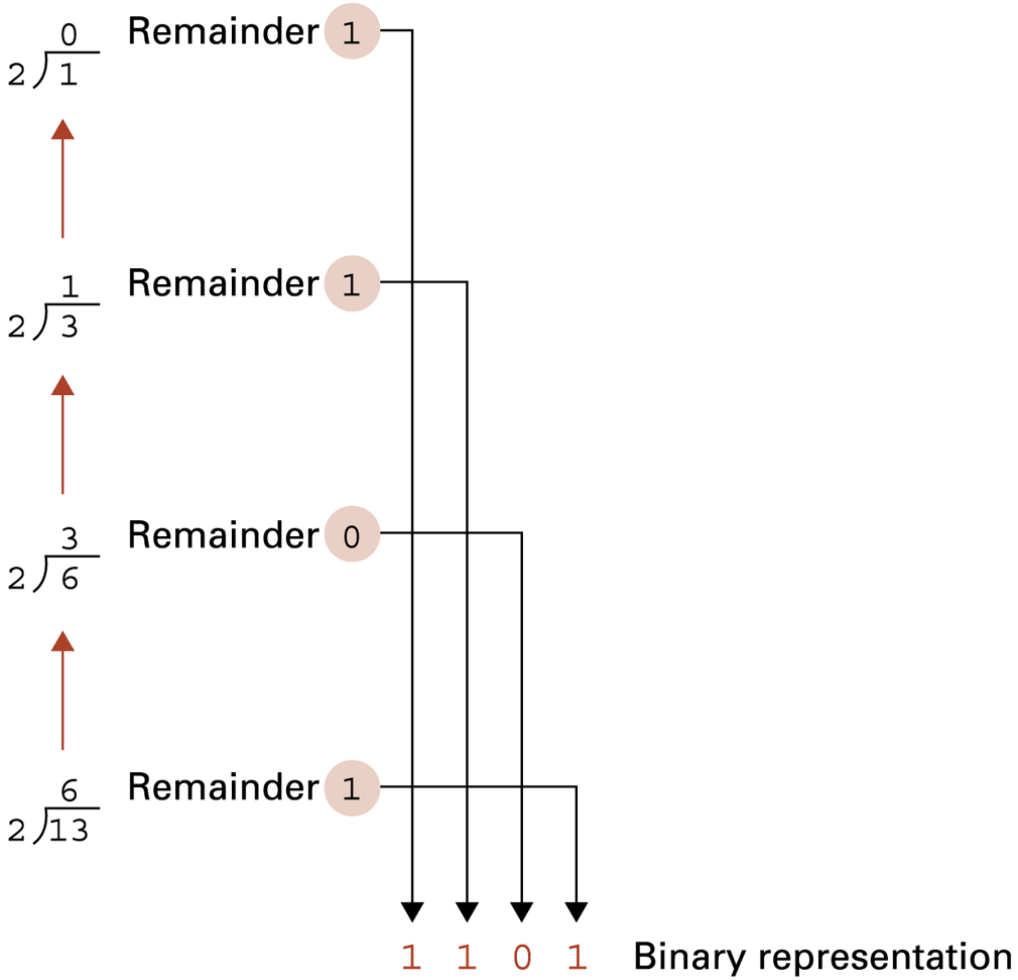
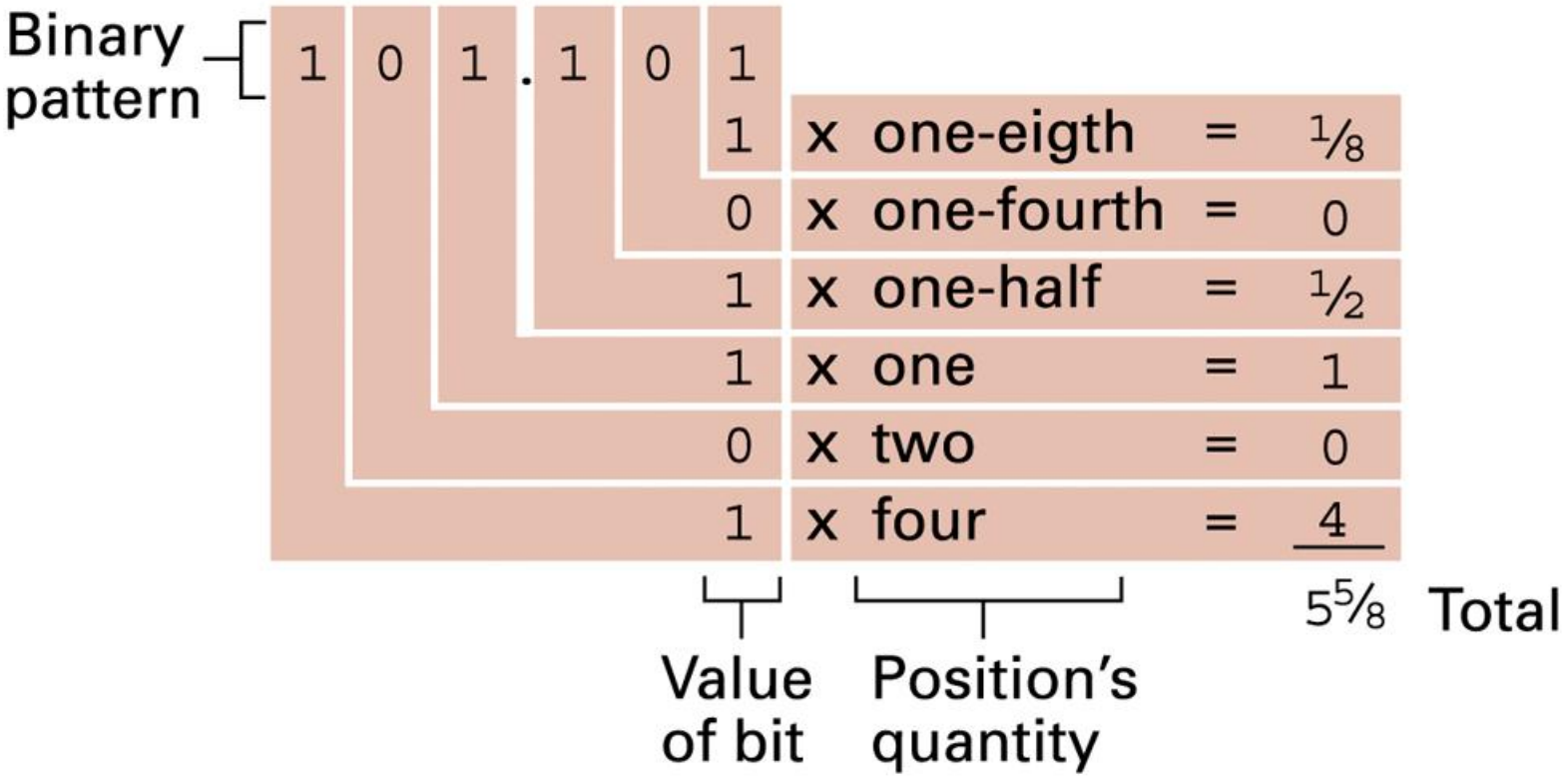


Figure 1.19 The binary addition facts

$$\begin{array}{r} 0 \\ +\,0 \\ \hline 0 \end{array} \qquad \begin{array}{r} 1 \\ +\,0 \\ \hline 1 \end{array} \qquad \begin{array}{r} 0 \\ +\,1 \\ \hline 1 \end{array} \qquad \begin{array}{r} 1 \\ +\,1 \\ \hline 10 \end{array}$$

Figure 1.20 Decoding the binary representation 101.101



Storing Integers

- **Two's complement notation:** The most popular means of representing integer values
- **Excess notation:** Another means of representing integer values
- Both can suffer from overflow errors.

Figure 1.21 Two's complement notation systems

a. Using patterns of length three

Bit pattern	Value represented
011	3
010	2
001	1
000	0
111	−1
110	−2
101	−3
100	−4

b. Using patterns of length four

Bit pattern	Value represented
0111	7
0110	6
0101	5
0100	4
0011	3
0010	2
0001	1
0000	0
1111	−1
1110	−2
1101	−3
1100	−4
1011	−5
1010	−6
1001	−7
1000	−8

Figure 1.22 Coding the value -6 in two's complement notation using four bits

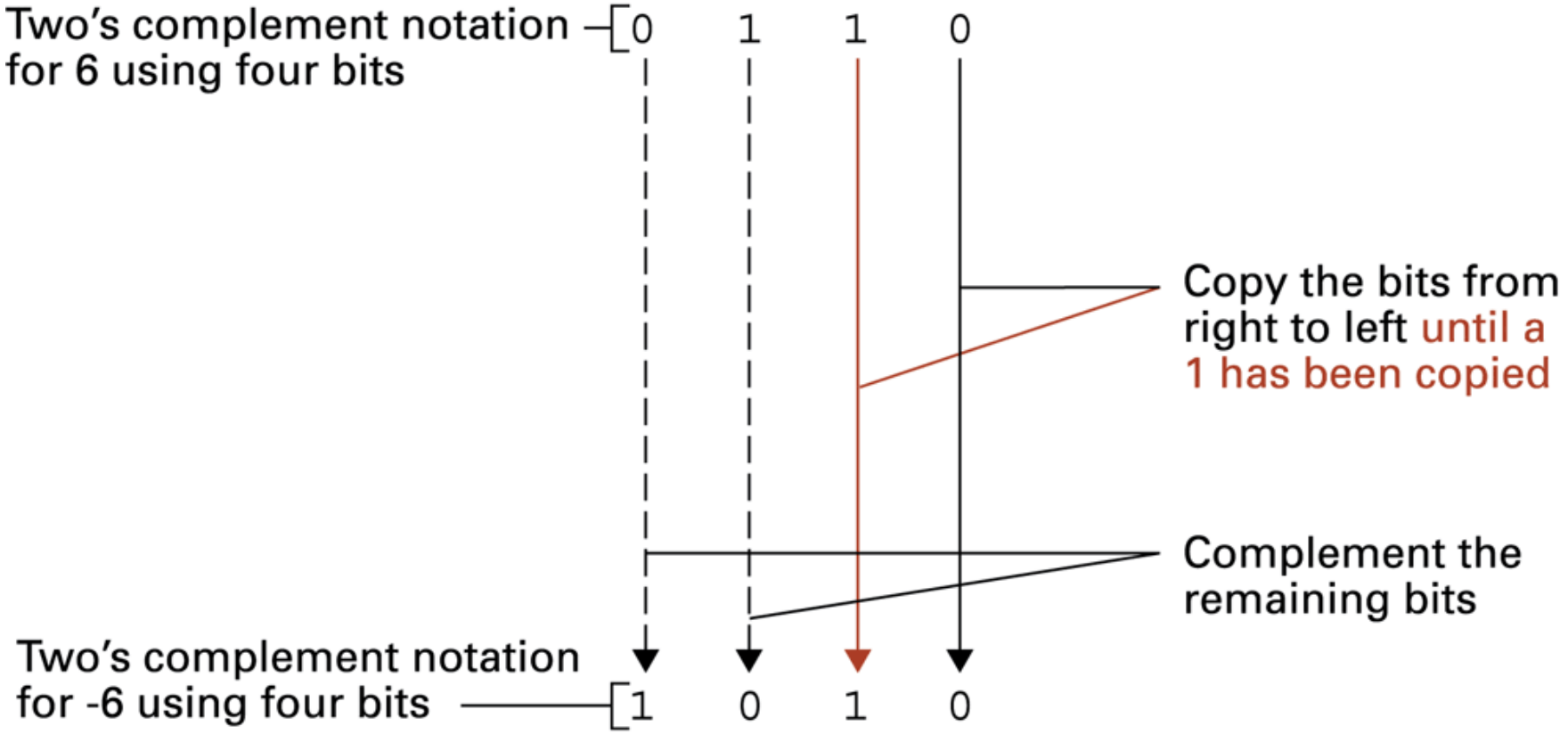


Figure 1.23 Addition problems converted to two's complement notation

Problem in base ten		Problem in two's complement		Answer in base ten
3 + 2	→	0011 + 0010 0101	→	5
−3 + −2	→	1101 + 1110 1011	→	−5
7 + −5	→	0111 + 1011 0010	→	2

Figure 1.24 An excess eight conversion table

Bit pattern	Value represented
1111	7
1110	6
1101	5
1100	4
1011	3
1010	2
1001	1
1000	0
0111	−1
0110	−2
0101	−3
0100	−4
0011	−5
0010	−6
0001	−7
0000	−8

Figure 1.25 An excess notation system using bit patterns of length three

Bit pattern	Value represented
111	3
110	2
101	1
100	0
011	−1
010	−2
001	−3
000	−4

Storing Fractions

- **Floating-point Notation:** Consists of a sign bit, a mantissa field, and an exponent field.
- Related topics include
  - Normalized form
  - Truncation errors

Figure 1.26 Floating-point notation components

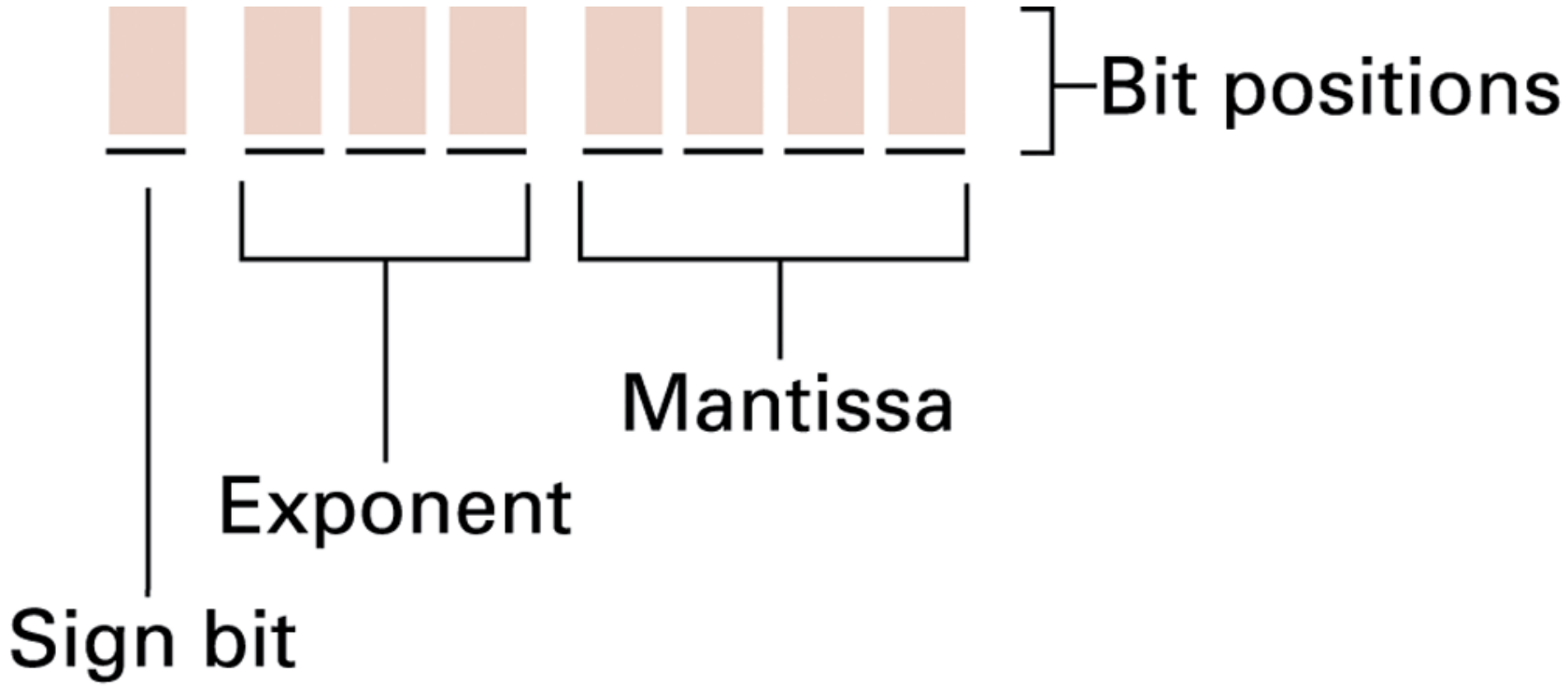
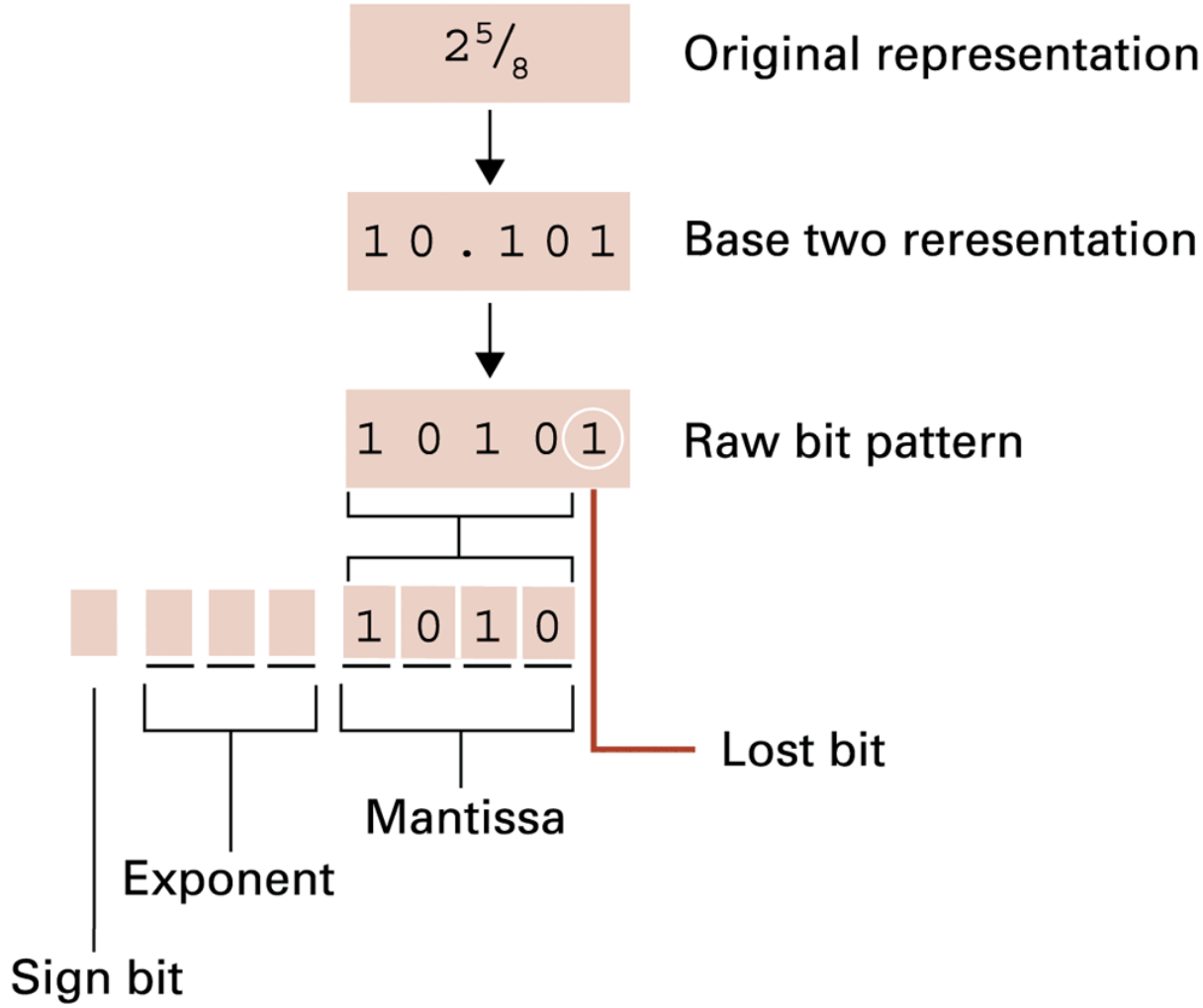


Figure 1.27 Encoding the value 2 5/8



Data Compression

- Lossy versus lossless
- Run-length encoding *(lossless - counting)*
- Frequency-dependent encoding

  (Huffman codes) *(lossless – symbol)*
- Relative encoding *(lossless or lossy – video?)*
- Dictionary encoding (Includes adaptive dictionary encoding such as LZW encoding.)
  (25k dict → 15bits vs. 6 letters → 48bits ascii)

(xyx xyx xyx xyx → 121343434 vs. 1213121312131213)

Compressing Images

- GIF: Good for cartoons *(Graphic Interchange Format – 256 colors can be lossy for real shots)*
- JPEG: Good for photographs *(Joint Photographic Experts Group – mostly lossy as standard – lossy sequential mode – exploting human eye's limitations)*
- TIFF: Good for image archiving *(Tagged Image File Format – also stores information – lossy or lossless – also .png too)*

Compressing Audio and Video

- MPEG *(Motion Picture Experts Group)*
  - High definition television broadcast
  - Video conferencing
- MP3 *(MPEG Layer 3 – exploiting human ear's limitations)*
  - Temporal masking *(softer sound after a loud sound)*
  - Frequency masking *(some frequencies are dominant and mask others)*

Communication Errors

- Parity bits (even versus odd)
- Checkbytes
- Error correcting codes

Figure 1.28 The ASCII codes for the letters A and F adjusted for odd parity

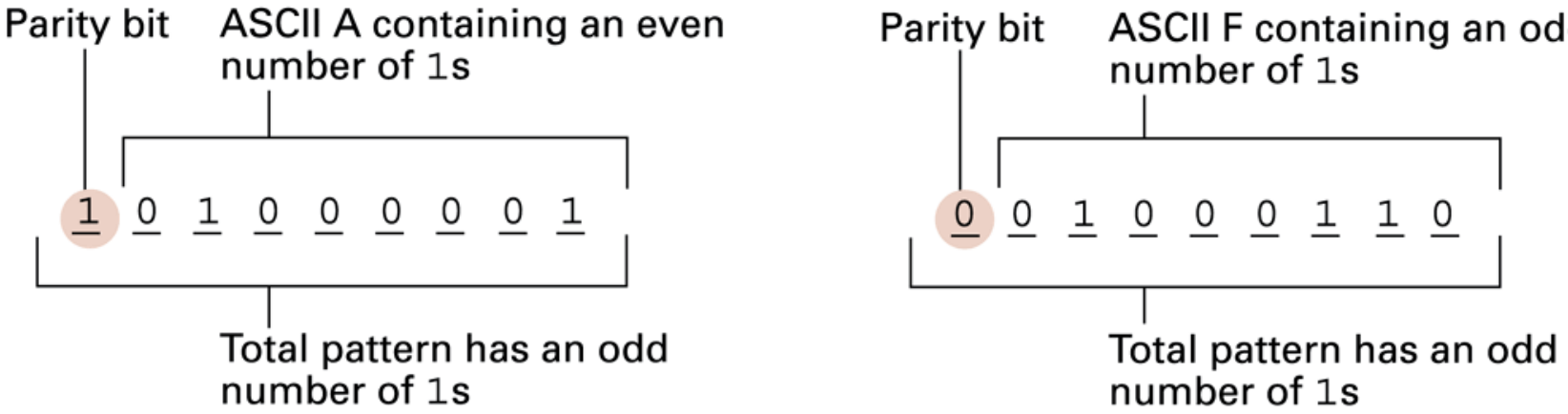


Figure 1.29 An error-correcting code

Hamming Distance

Symbol	Code
A	000000
B	001111
C	010011
D	011100
E	100110
F	101001
G	110101
H	111010

Figure 1.30 Decoding the pattern 010100 using the code in Figure 1.30

Character	Distance between the received pattern and the character being considered	
A	2	
B	4	
C	3	
D	1	*Smallest distance*
E	3	
F	5	
G	2	
H	4	