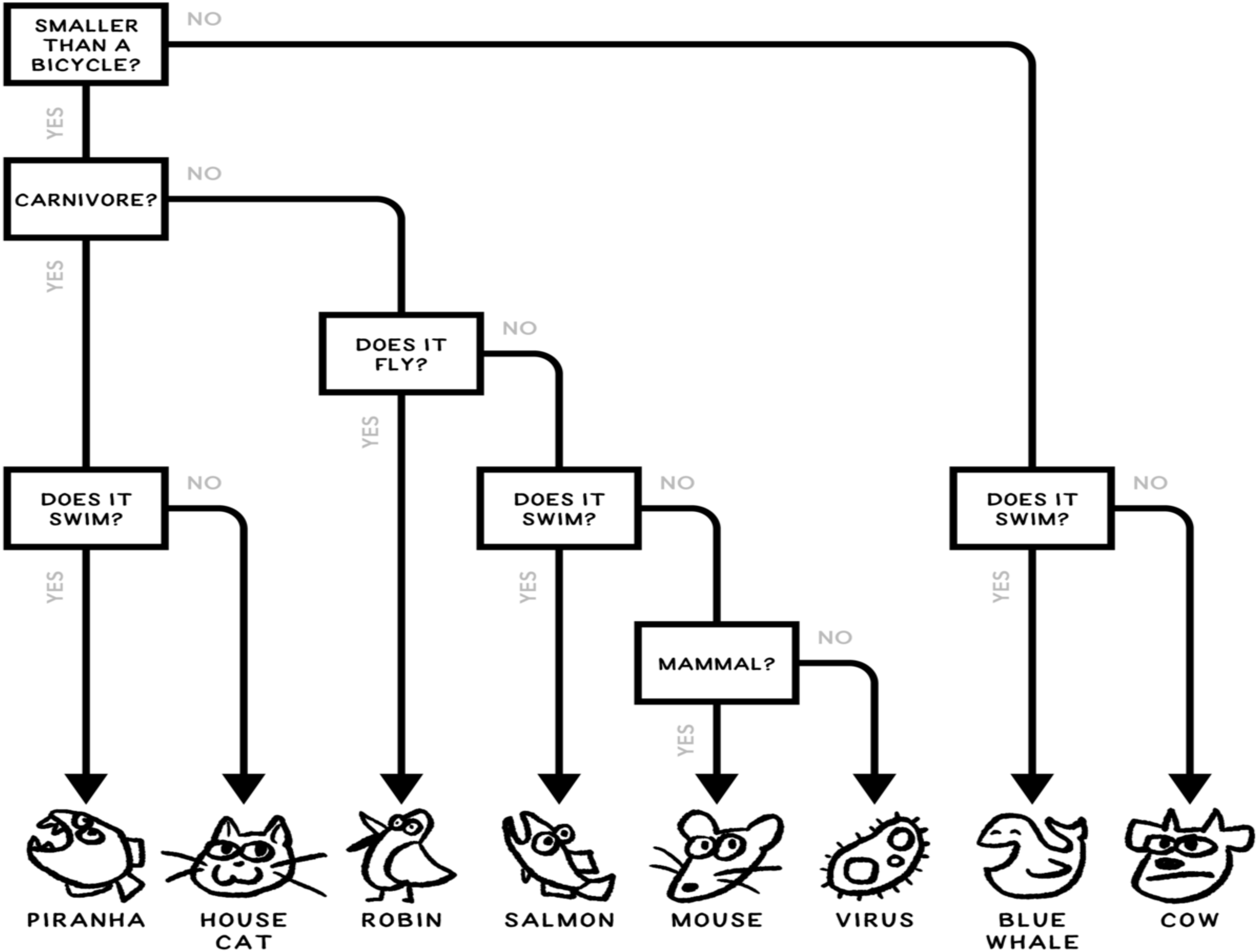
DECISION-MAKING

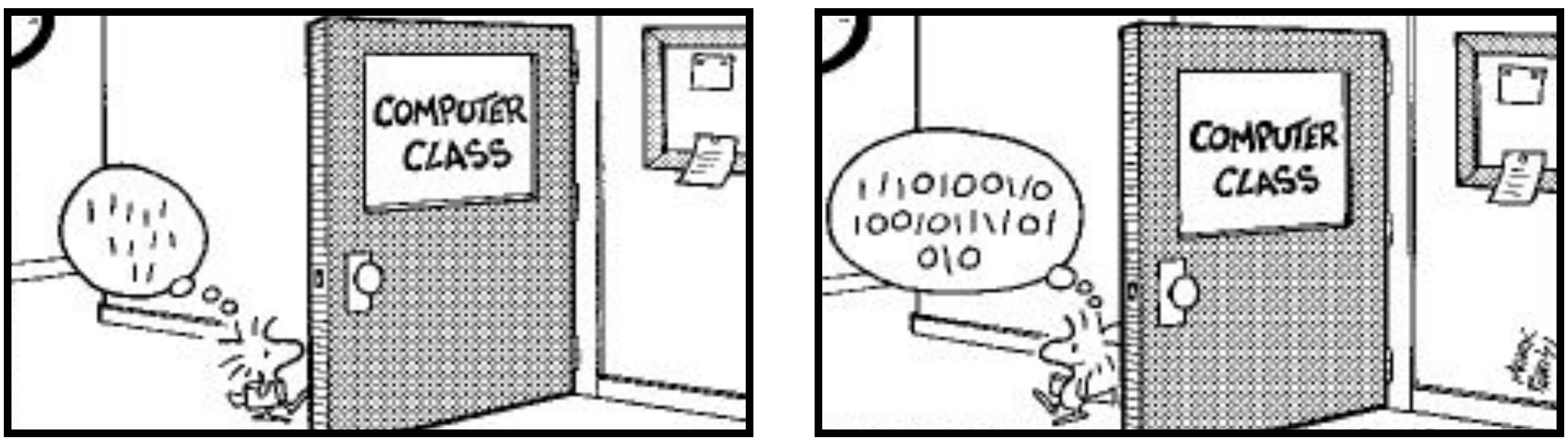
- **Computers can *make decisions*, and computers can do things *very very* fast.** Right now, a computer is deciding what the solution to a mathematical equation is. Somewhere else, a computer is deciding whether to suspend someone's credit card to protect them from fraud, and another computer is deciding whether an image represents a stop sign or a bird.
- **An important part of computer science is understanding how computers can make *the right decisions*, or at least pretty good ones.**

- One of the ways computers (and sometimes humans) make decisions is with a structure called a ***decision tree***. Decision trees encode a series of simple yes-or-no questions that you can follow in order to answer a **more complex question**. Here is a silly decision tree that helps you decide which of eight different creatures you're dealing with:


SMALLER THAN A BICYCLE?
NO
YES
CARNIVORE?
NO
YES
DOES IT FLY?
NO
YES
DOES IT SWIM?
NO
YES
DOES IT SWIM?
NO
YES
MAMMAL?
NO
YES
DOES IT SWIM?
NO
YES
PIRANHA
HOUSE CAT
ROBIN
SALMON
MOUSE
VIRUS
BLUE WHALE
COW

CHAPTER 1

Data Storage (& Representation)



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 possible input and output values of 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

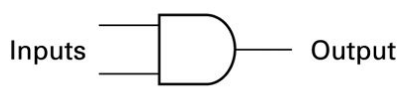
0	0	1	1
XOR 0	XOR 1	XOR 0	XOR 1
0	1	1	0

Gates

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

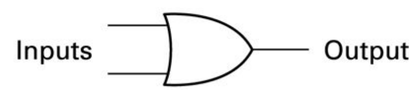
Figure 1.2 A pictorial representation of AND, OR, XOR, and NOT gates as well as their input and output values

AND



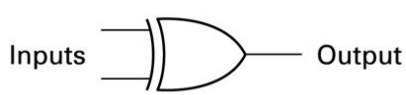
Inputs	Output
0 0	0
0 1	0
1 0	0
1 1	1

OR



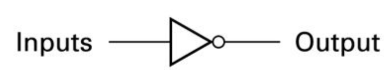
Inputs	Output
0 0	0
0 1	1
1 0	1
1 1	1

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.
  - One input line is used to set its stored value to 1
  - One input line is used to set 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

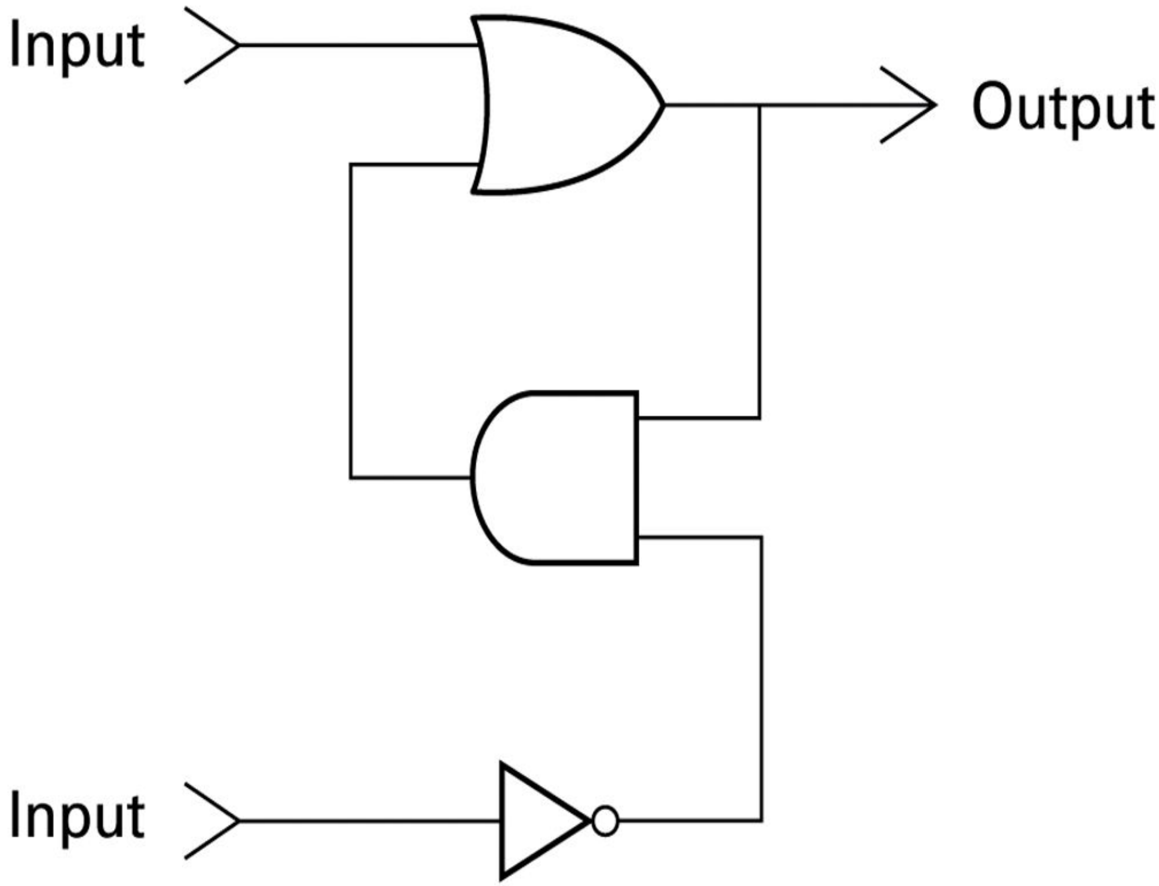


Figure 1.4 Setting the output of a flip-flop to 1

a. First, a 1 is placed on the upper input.

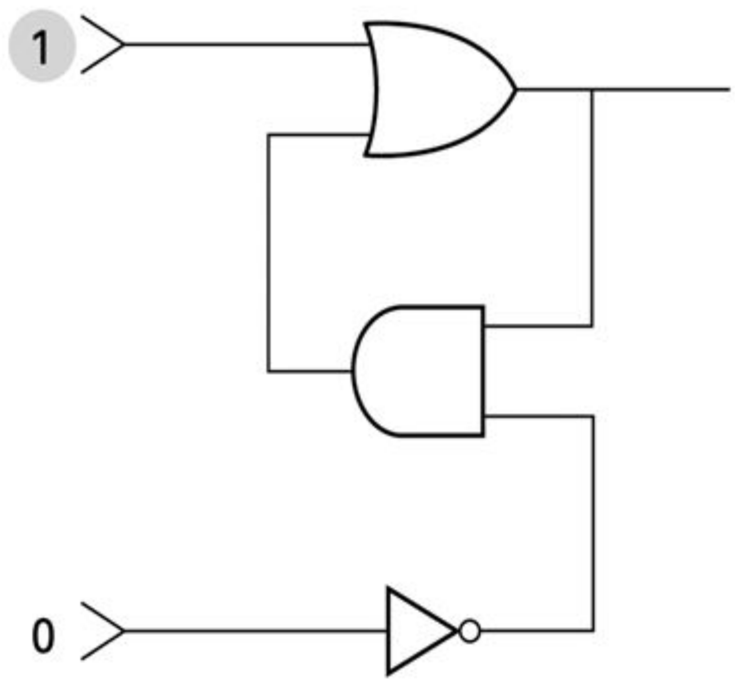


Figure 1.4 Setting the output of a flip-flop to 1 (continued)

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

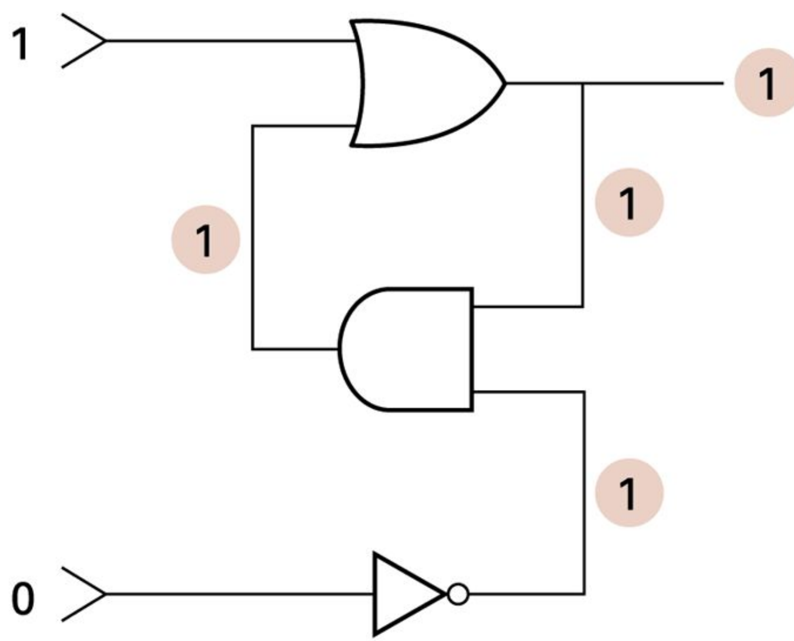


Figure 1.4 Setting the output of a flip-flop to 1 (continued)

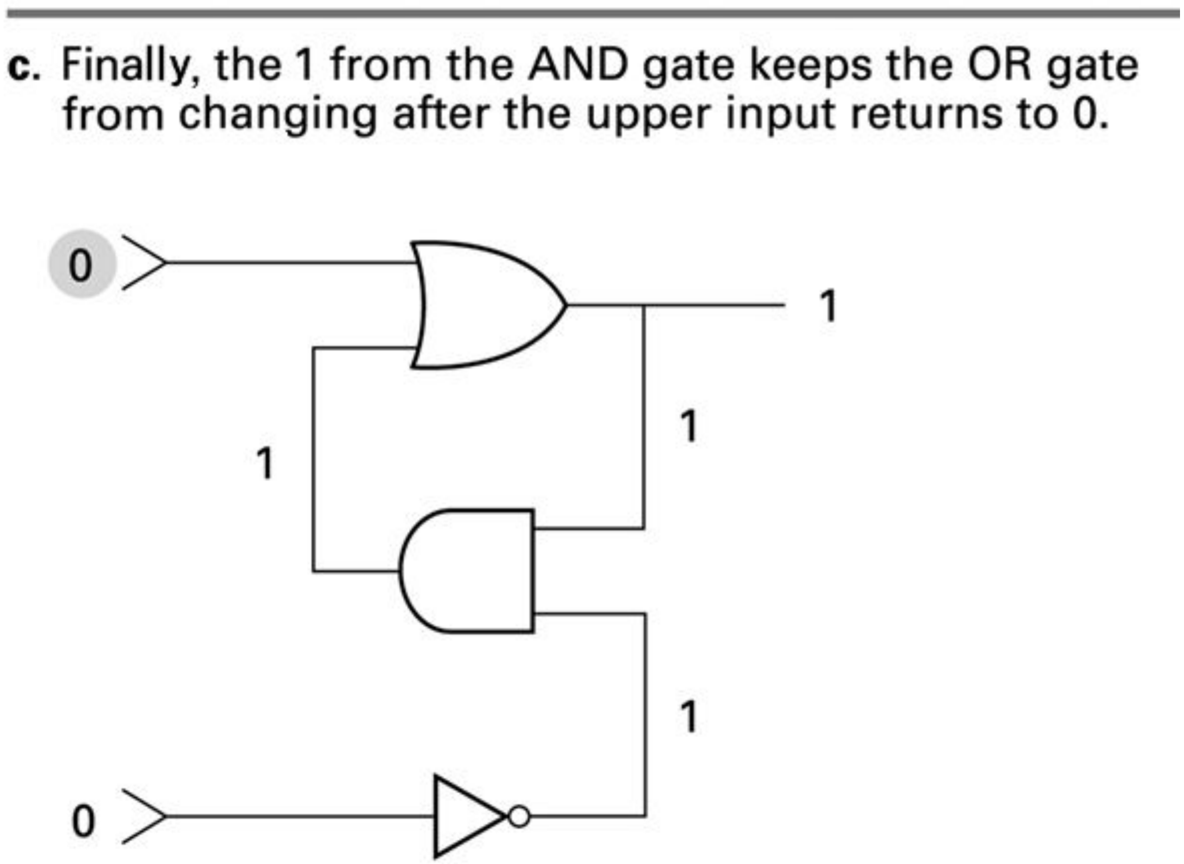
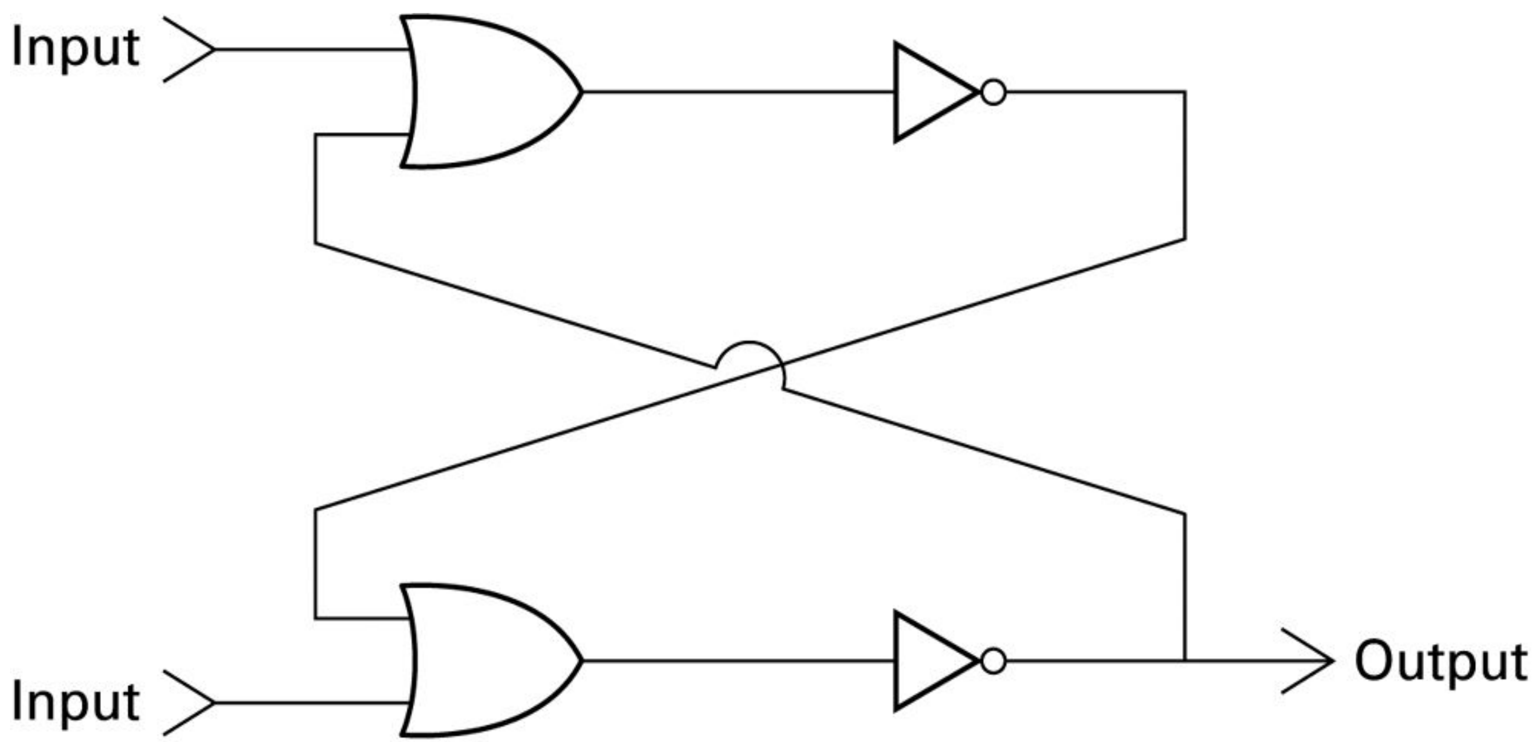


Figure 1.5 Another way of constructing a flip-flop



Hexadecimal Notation

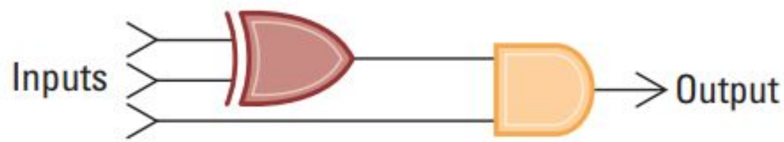
- **Hexadecimal notation:** A shorthand notation for long bit patterns
  - Divides a pattern into groups of four bits each
  - Represents each group by a single symbol
- Example: 10100011 becomes A3

Figure 1.6 The hexadecimal coding system

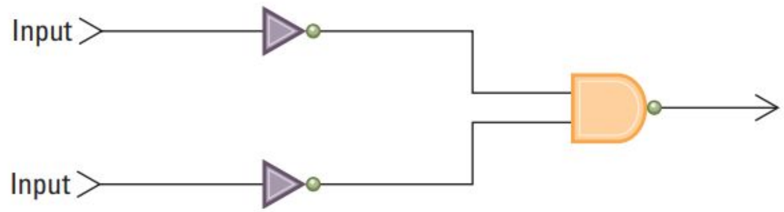
Bit pattern	Hexadecimal representation
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	A
1011	B
1100	C
1101	D
1110	E
1111	F

1.1 Questions & Exercises

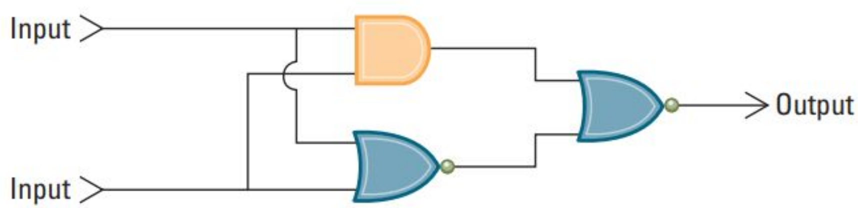
1. What input bit patterns will cause the following circuit to produce an output of 1?



2. In the text, we claimed that placing a 1 on the lower input of the flip-flop in Figure 1.3 (while holding the upper input at 0) will force the flip-flop's output to be 0. Describe the sequence of events that occurs within the flip-flop in this case.
3. Assuming that both inputs to the flip-flop in Figure 1.5 begin as 0, describe the sequence of events that occurs when the upper input is temporarily set to 1.
4. **a.** If the output of an AND gate is passed through a NOT gate, the combination computes the Boolean operation called NAND, which has an output of 0 only when both its inputs are 1. The symbol for a NAND gate is the same as an AND gate except that it has a circle at its output. The following is a circuit containing a NAND gate. What Boolean operation does the circuit compute?



b. If the output of an OR gate is passed through a NOT gate, the combination computes the Boolean operation called NOR that has an output of 1 only when both its inputs are 0. The symbol for a NOR gate is the same as an OR gate except that it has a circle at its output. The following is a circuit containing an AND gate and two NOR gates. What Boolean operation does the circuit compute?



5. Use hexadecimal notation to represent the following bit patterns:

a. 0110101011110010 **b.** 111010000101010100010111
c. 01001000

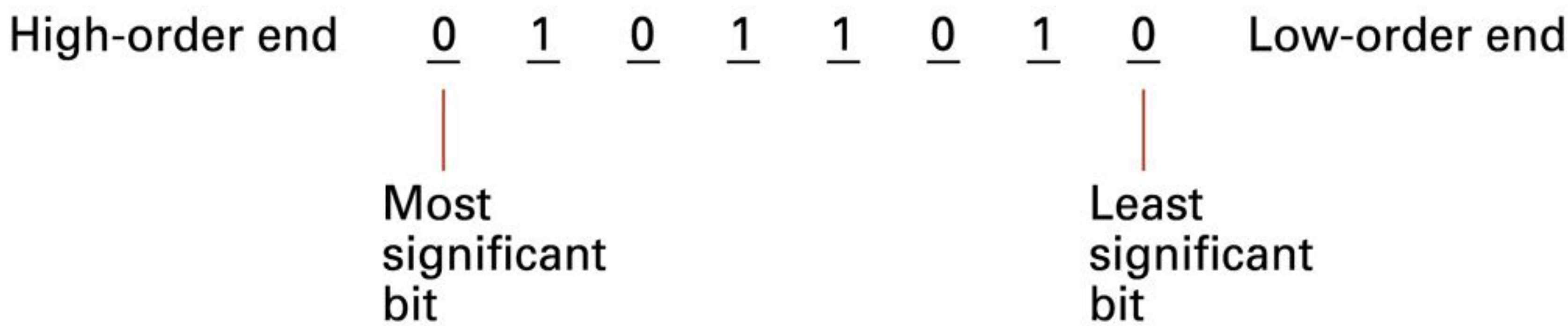
6. What bit patterns are represented by the following hexadecimal patterns?

a. 0x5FD97 **b.** 0x610A **c.** 0xABCD **d.** 0x0100

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

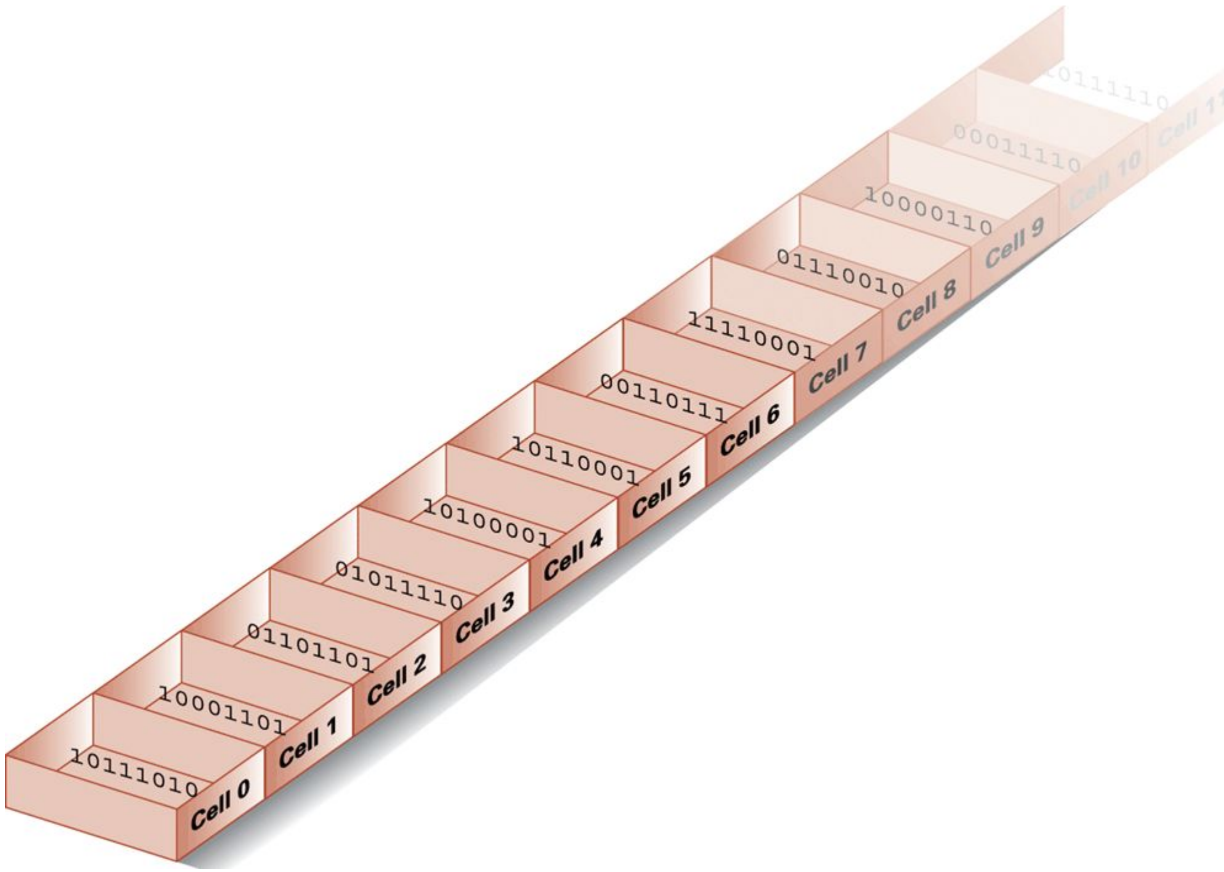
Figure 1.7 The organization of a byte-size memory cell



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

Measuring Memory Capacity

- **Kilobyte:** 2^{10} bytes = 1024 bytes
  - Example: 3 KB = 3 times1024 bytes

- **Megabyte:** 2^{20} bytes = 1,048,576 bytes
  - Example: 3 MB = 3 times 1,048,576 bytes

- **Gigabyte:** 2^{30} bytes = 1,073,741,824 bytes
  - Example: 3 GB = 3 times 1,073,741,824 bytes

1.2 Questions & Exercises

1. If the memory cell whose address is 5 contains the value 8, what is the difference between writing the value 5 into cell number 6 and moving the contents of cell number 5 into cell number 6?
2. Suppose you want to interchange the values stored in memory cells 2 and 3. What is wrong with the following sequence of steps:

   Step 1. Move the contents of cell number 2 to cell number 3.

   Step 2. Move the contents of cell number 3 to cell number 2.
3. Design a sequence of steps that correctly interchanges the contents of these cells. If needed, you may use additional cells.
4. How many bits would be in the memory of a computer with 4KB memory?

Mass Storage

- Additional devices:
  - Magnetic disks
  - CDs
  - DVDs
  - Magnetic tape
  - Flash drives
  - Solid-state disks
- Advantages over main memory
  - Less volatility
  - Larger storage capacities
  - Low cost
  - In many cases can be removed

Figure 1.9 A magnetic disk storage system

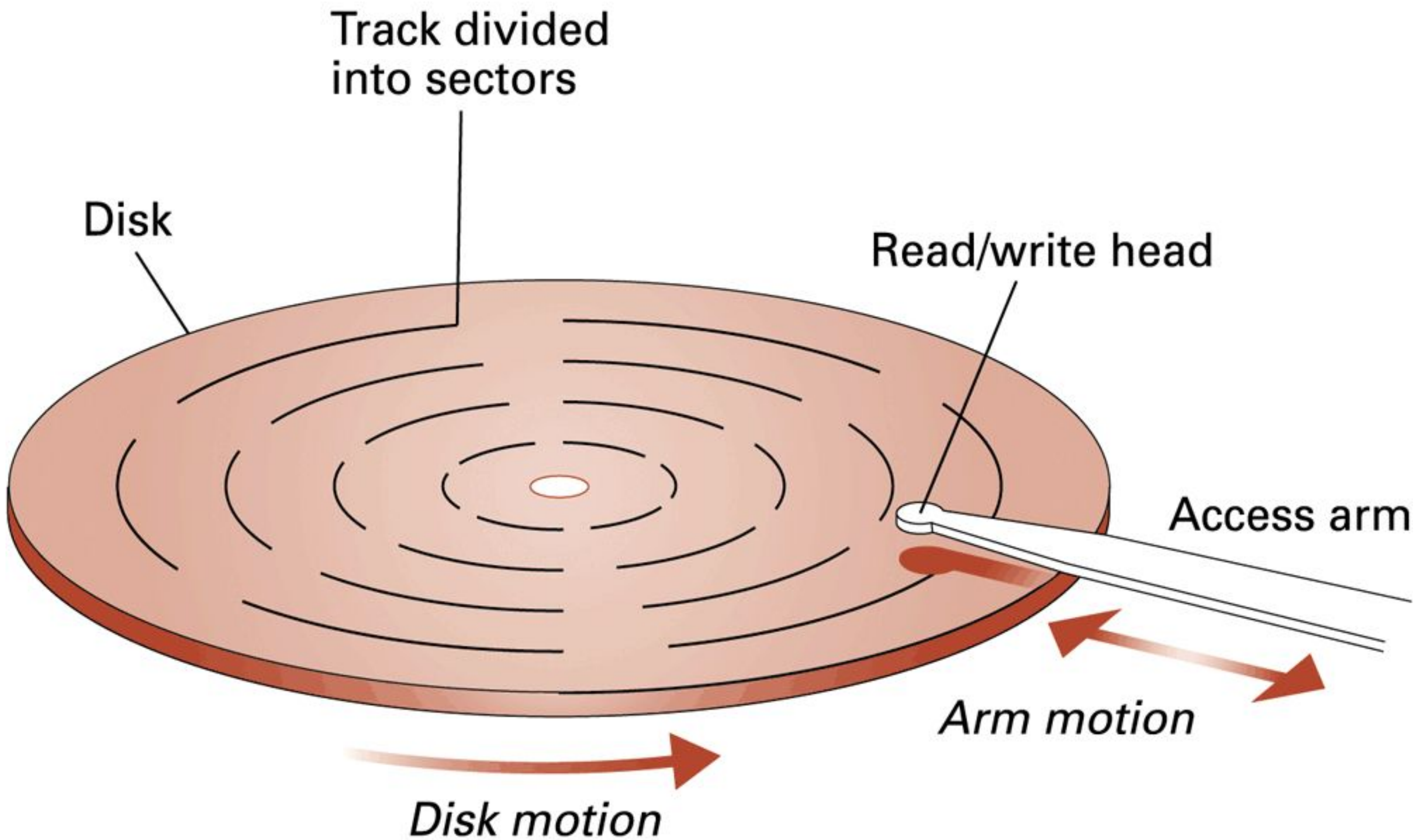
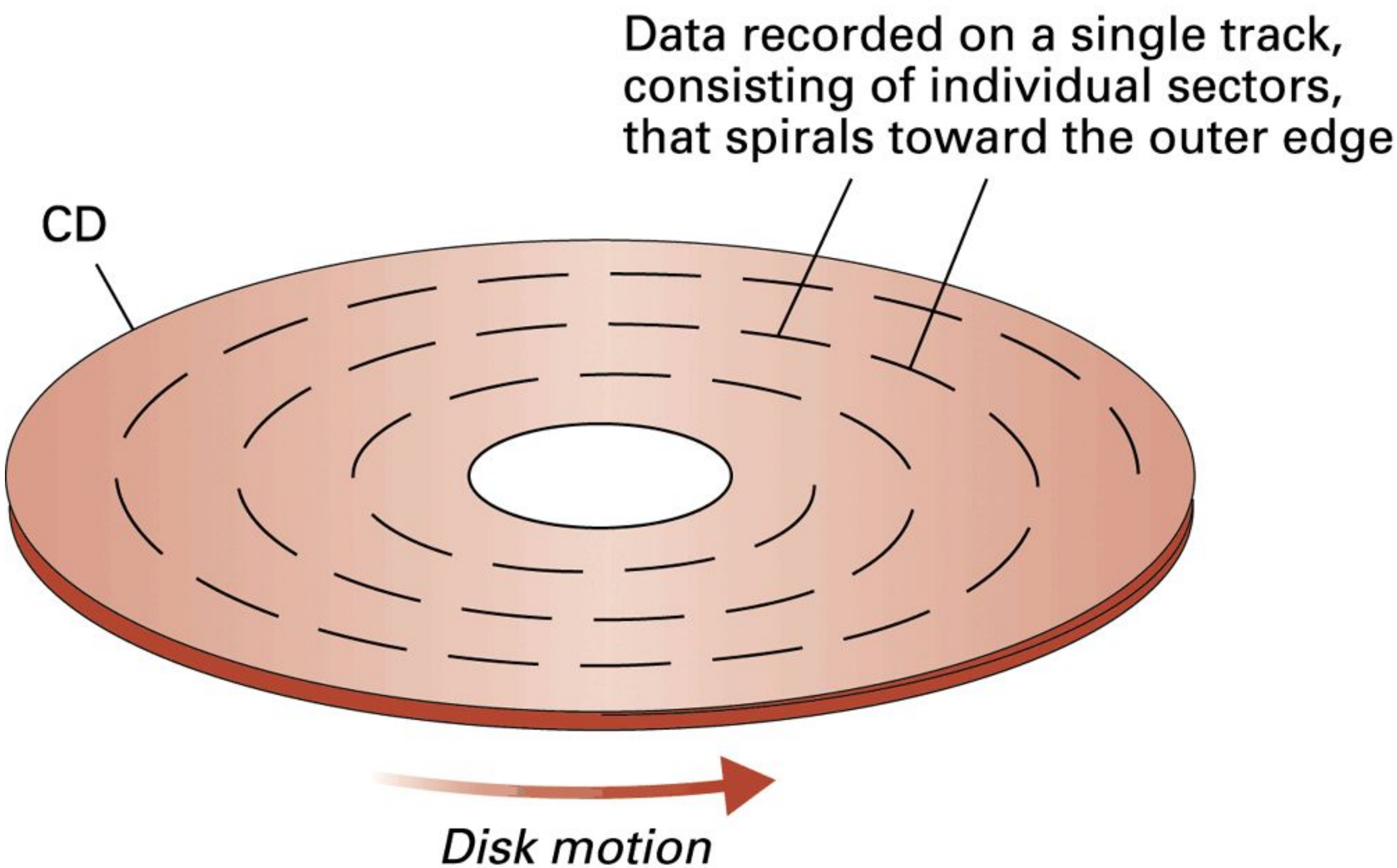


Figure 1.10 CD storage



Flash Drives

- **Flash Memory** – circuits that traps electrons in tiny silicon dioxide chambers
- Repeated erasing slowly damages the media
- Mass storage of choice for:
  - Digital cameras
- **SD Cards** provide GBs of storage

– Smartphones

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
  - ISO developed a number of 8 bit extensions to ASCII, each designed to accommodate a major language group
  - **Unicode**: Uses patterns up to 21-bits to represent the symbols used in languages world wide, 16-bits for world's commonly used languages

Figure 1.11 The message “Hello.” in ASCII or UTF-8 encoding

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: occurs when a value is too big to be represented
  - Truncation: occurs when a value cannot be represented accurately

The Binary System

The traditional decimal system is based on powers of ten.

The Binary system is based on powers of two.

Figure 1.13 The base ten and binary systems

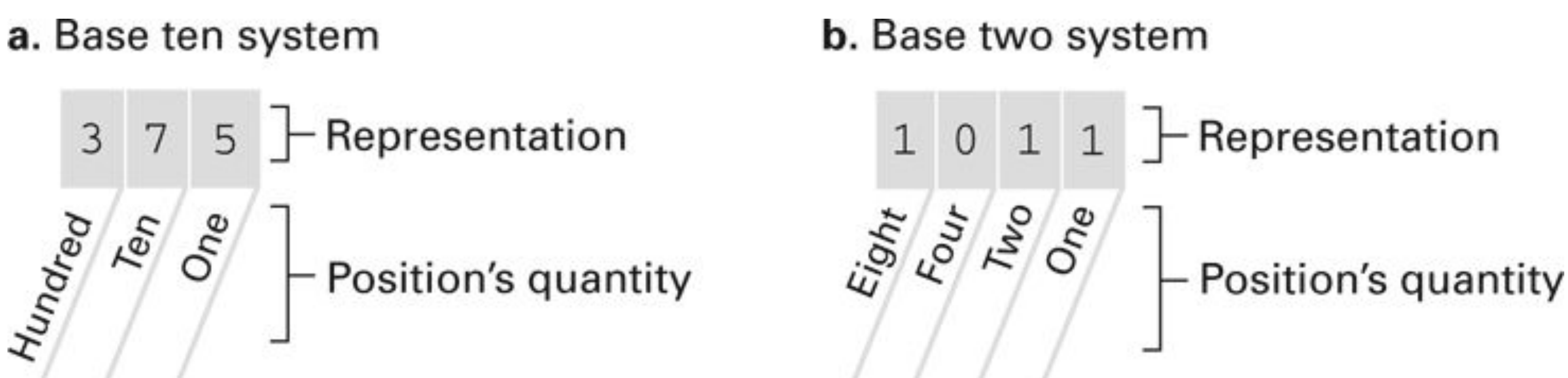


Figure 1.14 Decoding the binary representation 100101

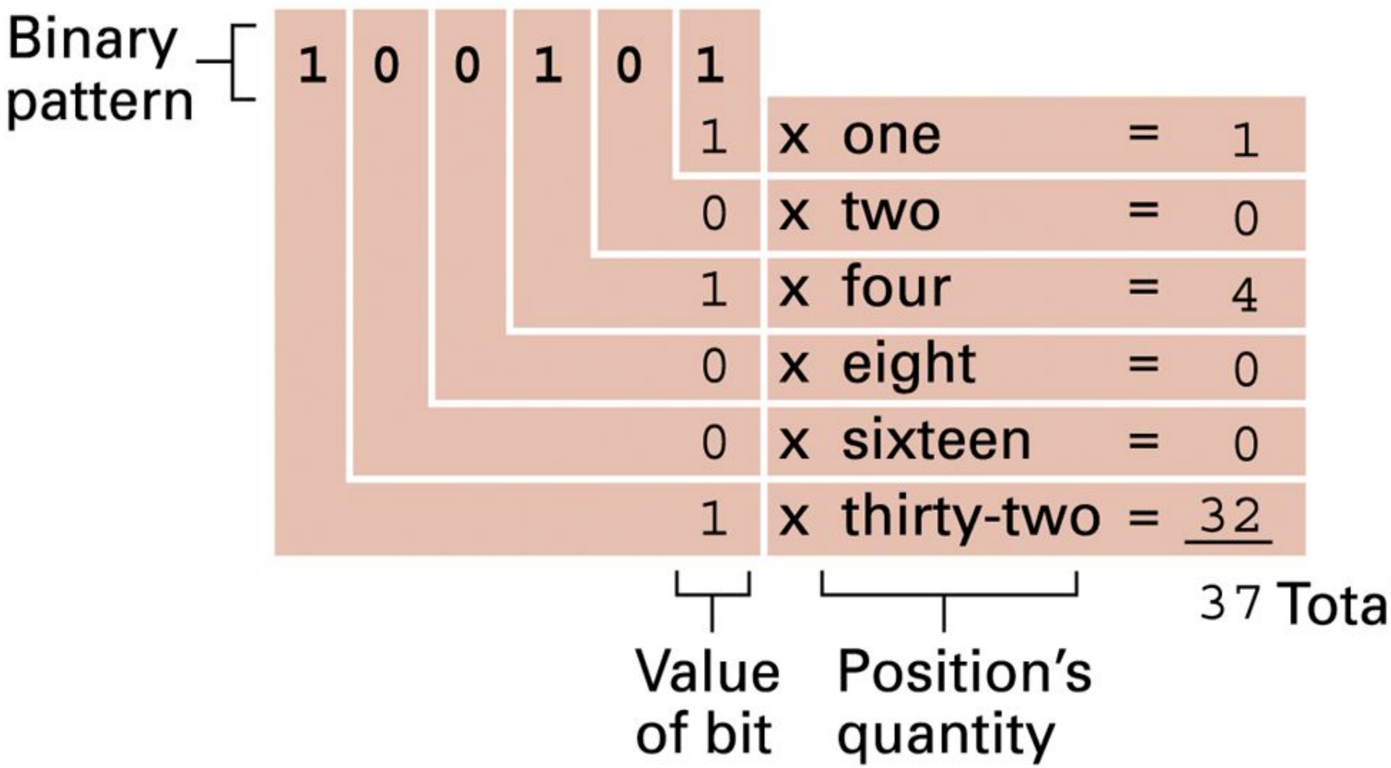


Figure 1.15 An algorithm for finding the binary representation of a positive integer

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

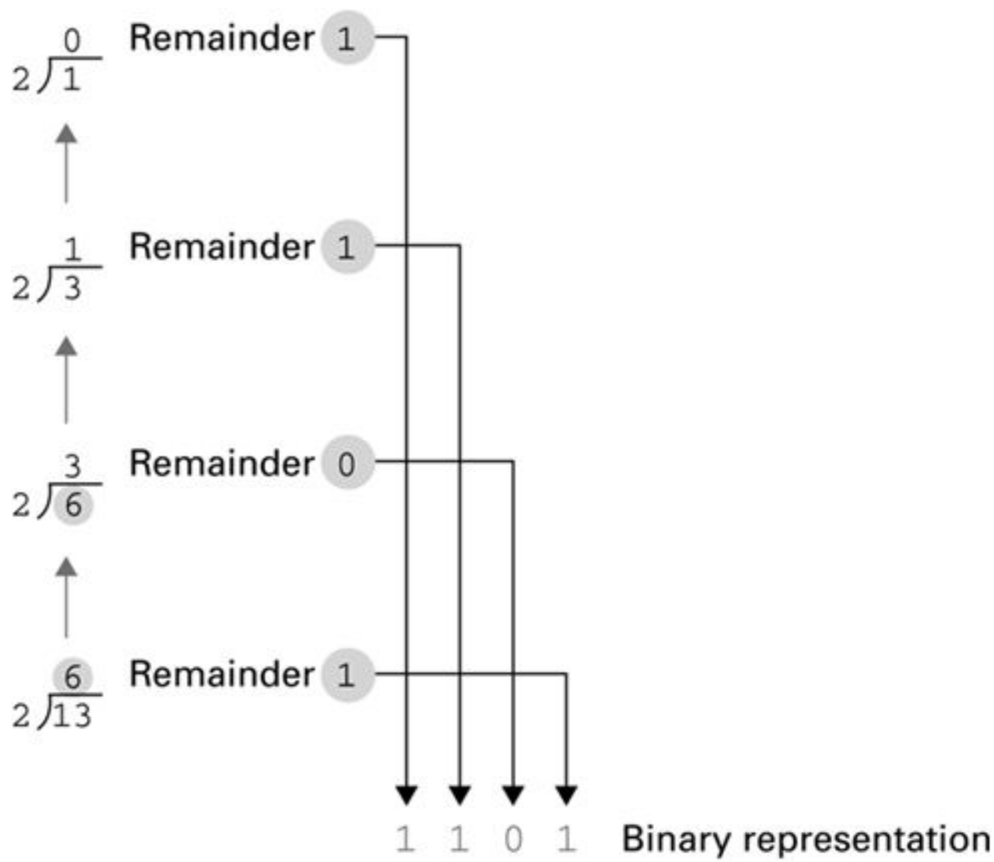
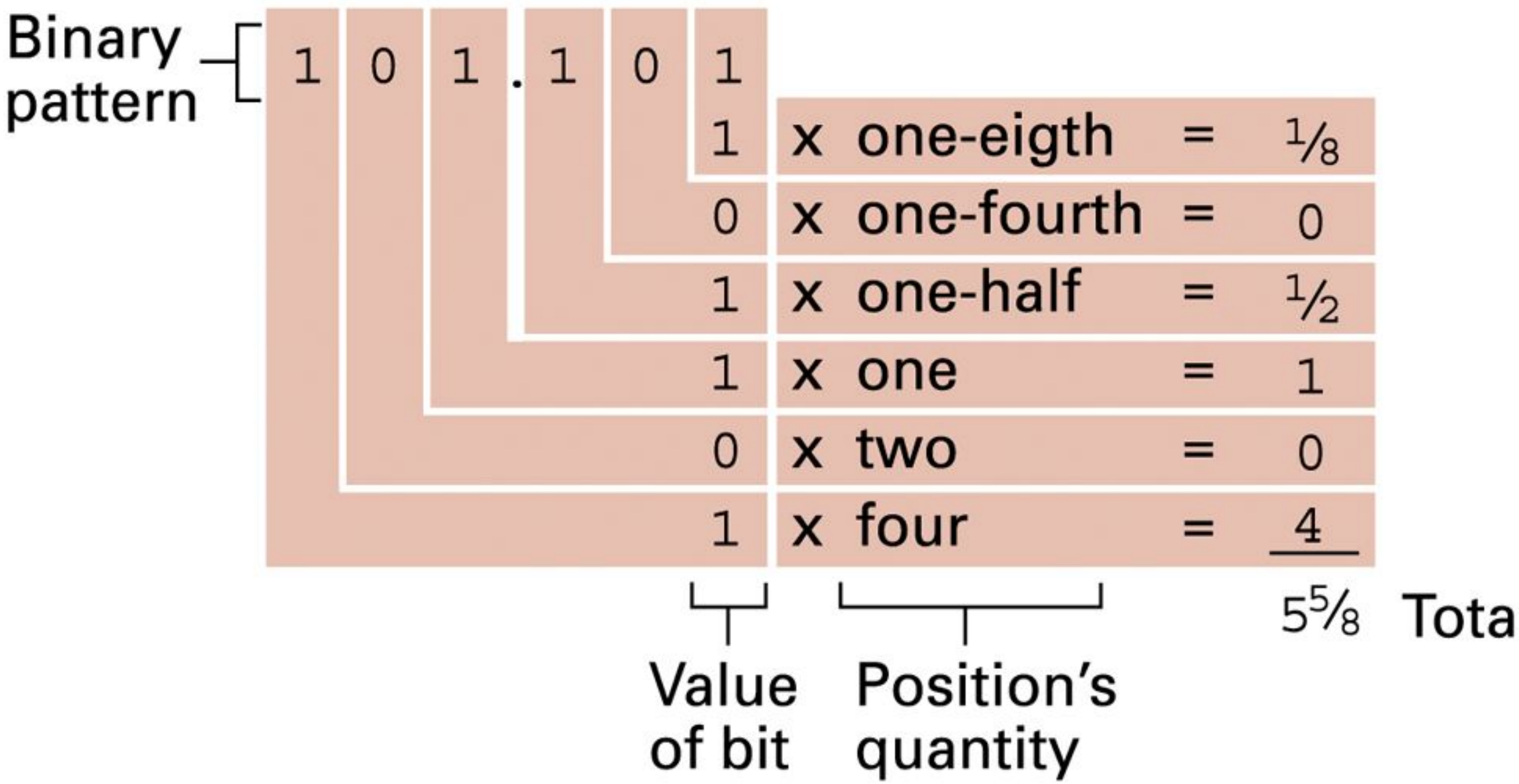


Figure 1.17 The binary addition facts

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

Figure 1.18 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 1.19 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 1.20 Coding the value -6 in two's complement notation using four bits

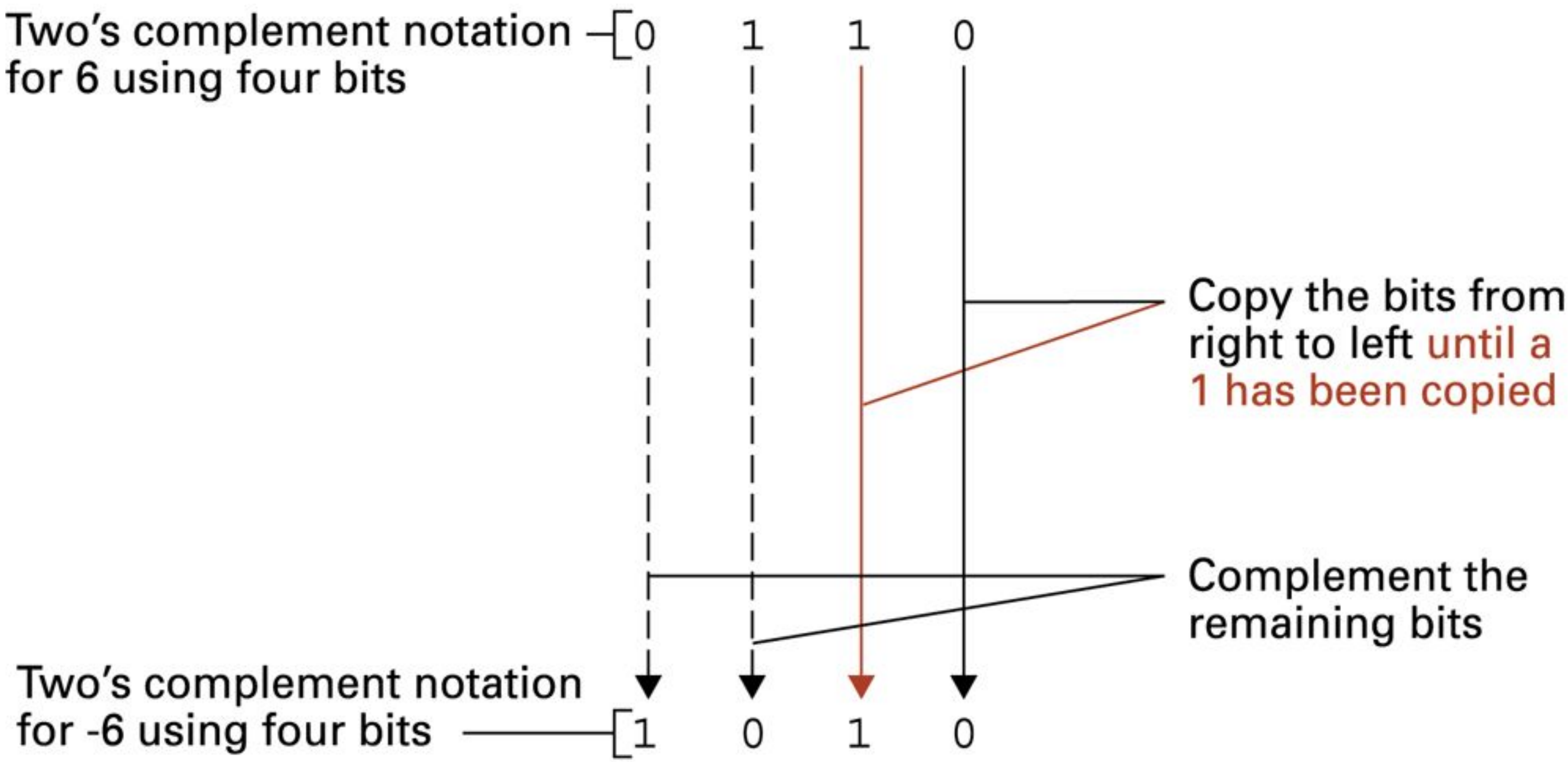


Figure 1.21 Addition problems converted to two's complement notation

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 1.22 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 1.23 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 1.24 Floating-point notation components

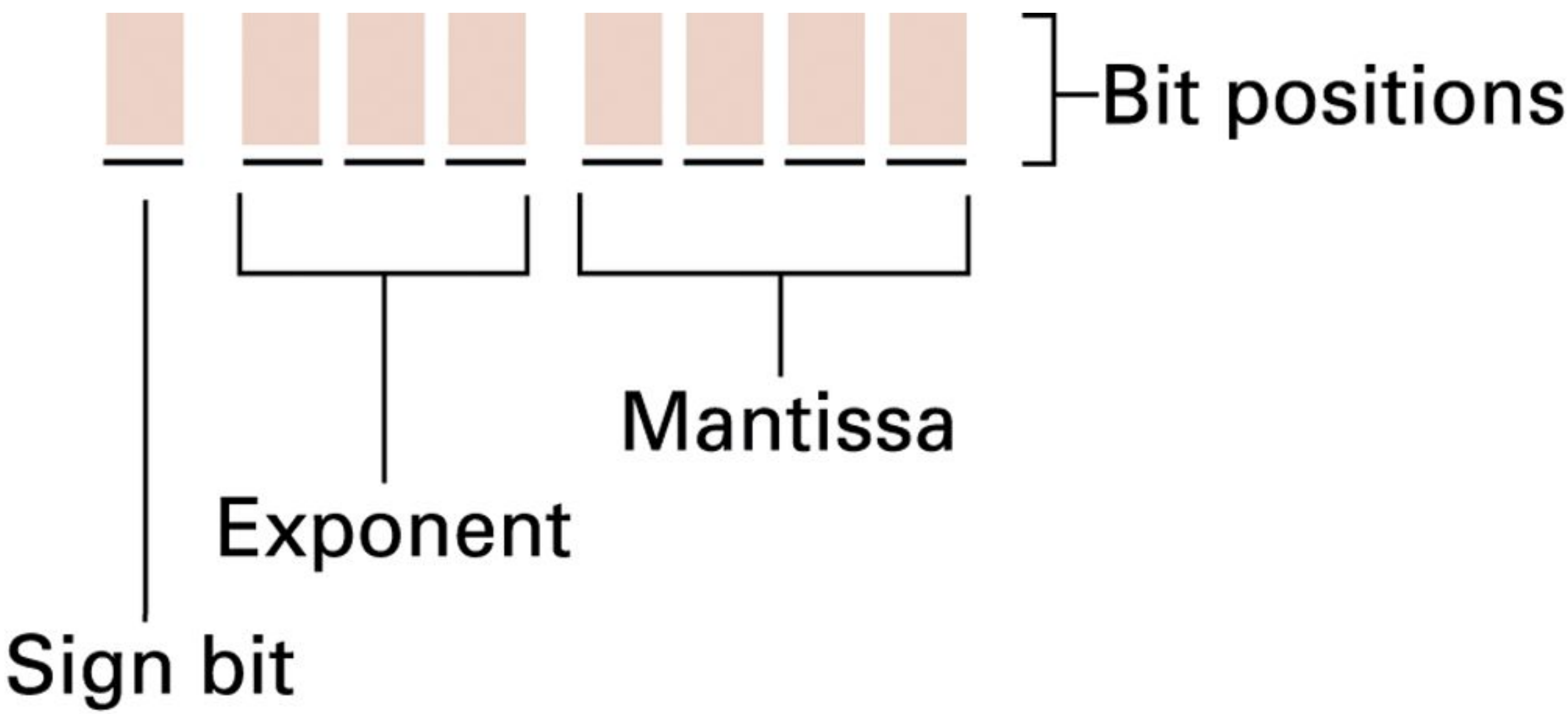
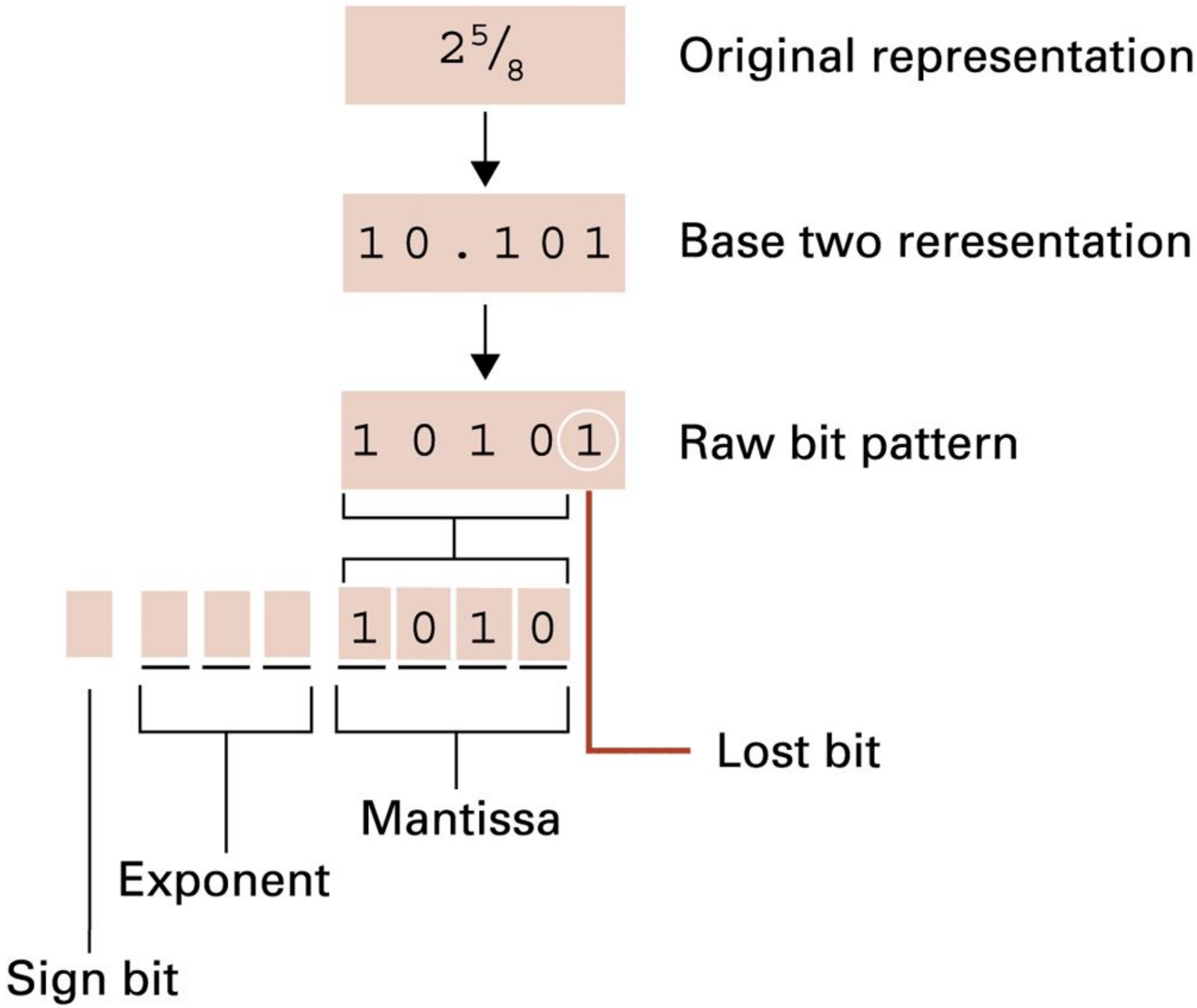


Figure 1.25 Encoding the value $2\,{}^5\!/_8$



Communication Errors

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

Figure 1.26 The ASCII codes for the letters A and F adjusted for odd parity

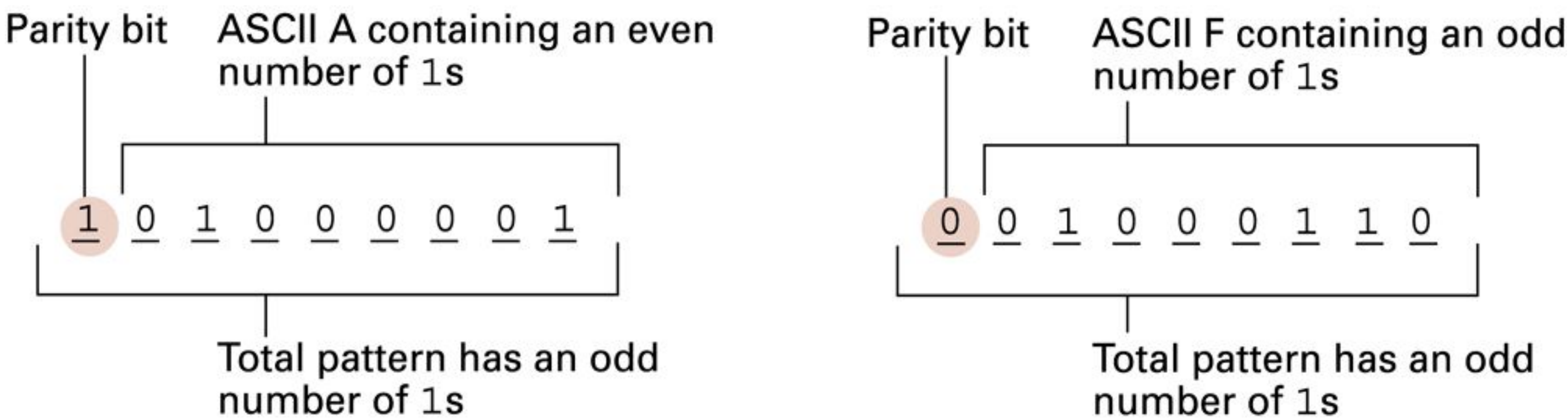


Figure 1.27 An error-correcting code

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

Figure 1.28 Decoding the pattern 010100 using the code in Figure 1.27

Character	Code	Pattern received	Distance between received pattern and code
A	0 0 0 0 0 0	0 **1** 0 **1** 0 0	2
B	0 0 1 1 1 1	0 **1** **0** 1 **0** **0**	4
C	0 1 0 0 1 1	0 1 0 **1** **0** **0**	3
D	0 1 1 1 0 0	0 1 **0** 1 0 0	**1** Smallest distance
E	1 0 0 1 1 0	**0** **1** 0 1 **0** 0	3
F	1 0 1 0 0 1	**0** **1** **0** **1** 0 **0**	5
G	1 1 0 1 0 1	**0** 1 0 1 0 **0**	2
H	1 1 1 0 1 0	**0** 1 **0** **1** **0** 0	4