# Machine Architecture and Number Systems

Topics

- Major Computer Components
- Bits, Bytes, and Words
- The Decimal Number System
- The Binary Number System
- Converting from Binary to Decimal
- Converting from Decimal to Binary
- The Hexadecimal Number System



## Major Computer Components

- Central Processing Unit (CPU)
- Bus
- Main Memory (RAM)
- Secondary Storage Media
- I / O Devices



## Schematic Diagram of a Computer

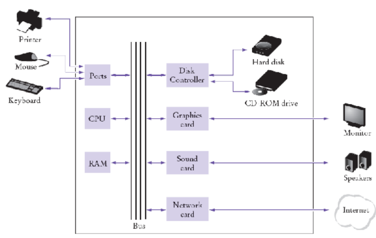


Figure 5 Schematic Diagram of a Computer

*Diagram taken from Java Concepts, Fourth Edition*



## The CPU

- Central Processing Unit
- The "brain" of the computer
- Controls all other computer functions
- In PCs (personal computers) also called the microprocessor or simply processor.



## The Bus

- Computer components are connected by a bus.
- A bus is a group of parallel wires that carry control signals and data between components.



## Main Memory

- Main memory holds information such as computer programs, numeric data, or documents created by a **word processor**.
- Main memory is made up of **capacitors.**
- If a capacitor is charged, then its state is said to be **1,** or **ON**.
- We could also say the **bit is set**.
- If a capacitor does not have a charge, then its state is said to be **0,** or **OFF**.
- We could also say that **the bit is reset** or **cleared**.

## Main Memory (cont.)

- Memory is divided into **cells**, where each cell contains 8 **bits** (a 1 or a 0). Eight bits is called a **byte**.
- Each of these cells is uniquely numbered.
- The number associated with a cell is known as its **address**.
- Main memory is **volatile** storage. That is, if power is lost, the information in main memory is lost.



## Main Memory (cont.)

- Other computer components can
  - get the information held at a particular address in memory, known as a **READ,**
  - or store information at a particular address in memory, known as a **WRITE**.
- Writing to a memory location alters its contents.
- Reading from a memory location does not alter its contents.



## Main Memory (cont.)

- All addresses in memory can be accessed in the same amount of time.
- We do not have to start at address 0 and read everything until we get to the address we really want (**sequential access**).
- We can go directly to the address we want and access the data (**direct** or **random access**).
- That is why we call main memory **RAM** (**Random Access Memory**).



## Secondary Storage Media

- Disks -- floppy, hard, removable (random access)
- Tapes (sequential access)
- CDs (random access)
- DVDs (random access)
- Secondary storage media store files that contain
  - computer programs
  - data
  - other types of information
- This type of storage is called persistent (permanent) storage because it is non-volatile.



## I/O (Input/Output) Devices

- Information input and output is handled by I/O (input/output) devices.
- More generally, these devices are known as peripheral devices.
- Examples:
  - monitor
  - keyboard
  - mouse
  - disk drive (floppy, hard, removable)
  - CD or DVD drive
  - printer
  - scanner



## Bits, Bytes, and Words

- A bit is a single binary digit (a 1 or 0).
- A byte is 8 bits
- A word is 32 bits or 4 bytes
- Long word = 8 bytes = 64 bits
- Quad word = 16 bytes = 128 bits
- Programming languages use these standard number of bits when organizing data storage and access.
- What do you call 4 bits?
  (hint: it is a small byte)

## Number Systems

- The on and off states of the capacitors in RAM can be thought of as the values 1 and 0, respectively.
- Therefore, thinking about how information is stored in RAM requires knowledge of the binary (base 2) number system.
- Let's review the decimal (base 10) number system first.



## The Decimal Number System

- The decimal number system is a positional number system.
- Example:

5 6 2 1

$10^3$ $10^2$ $10^1$ $10^0$

$1 \times 10^0 = 1$
$2 \times 10^1 = 20$
$6 \times 10^2 = 600$
$5 \times 10^3 = 5000$



## The Decimal Number System

- The decimal number system is also known as base 10. The values of the positions are calculated by taking 10 to some power.
- Why is the base 10 for decimal numbers?
  - Because we use 10 digits, the digits 0 through 9.



## The Binary Number System

- The binary number system is also known as base 2. The values of the positions are calculated by taking 2 to some power.
- Why is the base 2 for binary numbers?
  - Because we use 2 digits, the digits 0 and 1.



## The Binary Number System

- The binary number system is also a positional numbering system.
- Instead of using ten digits, 0 - 9, the binary system uses only two digits, 0 and 1.
- Example of a binary number and the values of the positions:

$\underline{1}\ \underline{0}\ \underline{0}\ \underline{1}\ \underline{1}\ \underline{0}\ \underline{1}$

$2^6$ $2^5$ $2^4$ $2^3$ $2^2$ $2^1$ $2^0$



## Converting from Binary to Decimal

$\underline{1}\ \underline{0}\ \underline{0}\ \underline{1}\ \underline{1}\ \underline{0}\ \underline{1}$

$2^6$ $2^5$ $2^4$ $2^3$ $2^2$ $2^1$ $2^0$

| | |
|---|---|
| $2^0 = 1$ | $2^4 = 16$ |
| $2^1 = 2$ | $2^5 = 32$ |
| $2^2 = 4$ | $2^6 = 64$ |
| $2^3 = 8$ | |

$1 \times 2^0 = 1$
$0 \times 2^1 = 0$
$1 \times 2^2 = 4$
$1 \times 2^3 = 8$
$0 \times 2^4 = 0$
$0 \times 2^5 = 0$
$1 \times 2^6 = \underline{64}$
$77_{10}$

## Converting from Binary to Decimal

Practice conversions:

| Binary | Decimal |
|---|---|
| 11101 | |
| 1010101 | |
| 100111 | |



## Converting from Decimal to Binary

- Make a list of the binary place values up to the number being converted.
- Perform successive divisions by 2, placing the remainder of 0 or 1 in each of the positions from right to left.
- Continue until the quotient is zero.
- Example: $42_{10}$

| $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ |
|---|---|---|---|---|---|
| 32 | 16 | 8 | 4 | 2 | 1 |
| 1 | 0 | 1 | 0 | 1 | 0 |



## Converting from Binary to Decimal

Practice conversions:

| Decimal | Binary |
|---|---|
| 59 | |
| 82 | |
| 175 | |



## Working with Large Numbers

0 1 0 1 0 0 0 0 1 0 1 0 0 1 1 1 = ?

- Humans can't work well with binary numbers; there are too many digits to deal with.
- Memory addresses and other data can be quite large. Therefore, we sometimes use the **hexadecimal number system**.



## The Hexadecimal Number System

- The hexadecimal number system is also known as base 16. The values of the positions are calculated by taking 16 to some power.
- Why is the base 16 for hexadecimal numbers ?
  - Because we use 16 symbols, the digits 0 through 9 and the letters A through F.



## The Hexadecimal Number System

| Binary | Decimal | Hexadecimal | Binary | Decimal | Hexadecimal |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 1010 | 10 | A |
| 1 | 1 | 1 | 1011 | 11 | B |
| 10 | 2 | 2 | 1100 | 12 | C |
| 11 | 3 | 3 | 1101 | 13 | D |
| 100 | 4 | 4 | 1110 | 14 | E |
| 101 | 5 | 5 | 1111 | 15 | F |
| 110 | 6 | 6 | | | |
| 111 | 7 | 7 | | | |
| 1000 | 8 | 8 | | | |
| 1001 | 9 | 9 | | | |

## The Hexadecimal Number System

- Example of a hexadecimal number and the values of the positions:

  3 C 8 B 0 5 1

  $16^6$ $16^5$ $16^4$ $16^3$ $16^2$ $16^1$ $16^0$



## Example of Equivalent Numbers

Binary: $1\,0\,1\,0\,0\,0\,0\,1\,0\,1\,0\,0\,1\,1\,1_2$

Decimal: $20647_{10}$

Hexadecimal: $50A7_{16}$

Notice how the number of digits gets smaller as the base increases.



## Converting from Binary to Hex

- Because 16 is the equivalent of $2^4$, it is easy to convert from binary to hex and vice-versa.
- Binary: 1101 0010 1111 0000
- Hex: 0x D 2 F 0



## Converting from Binary to Octal

- Octal is another number system that is base 8.
- Because 8 is the equivalent of $2^3$, it is easy to convert from binary to octal and vice-versa.
- Convert the following binary number to octal:
  - 01 101 001 011 110 000