Chapter 1
Microprocessors, Microcomputers, and Assembly Language

Introduction

- In this course we will discus two microprocessors.
  - 8-Bit Intel 8085.
- Text Books:
  - Gaonkar, R. S. (2002/2013). “Microprocessor architecture, programming, and application with the 8085”, 5th edition, Prentice Hall.
  - Brey, B. B. (1993). “The 8085A microprocessor software, programming and architecture”, 2nd edition, Prentice Hall. .

Synopsis

- The microprocessor is a general-purpose programmable logic device.
- Understanding the microprocessor concepts is crucial in understanding the operation of digital computer.
- This course is an introduction to the basic concept of microprocessor architecture and operation, programming model, pins configuration and microprocessor interfacing.
- The content of the course is divided into three sections:
  - microprocessor architecture,
  - programming and
  - interfacing input/output.
- The course is designed around the Intel 8-bit microprocessor (8085A) and its assembly language.

LEARNING OUTCOME

At the end of the course, student should be:

- Able to understand the basic operation of microprocessor.
- Able to understand the basic concept of microprocessor architecture and its pins configuration.
- Able to understand the machine language programs.
- Able to design and write programs in assembly language.
- Able to understand the basic concept of microprocessor input/output interfacing

Introduction

- The majority of people think that computers are some kind of complicated device that is impossible to learn and infinitely intelligent, able to *think* better than a person.
  - The truth is much less glamorous.
- **A computer can only do what the programmer has *told* it to do, in the form of a *program*.**
- A program is just a sequence of very simple commands that lead the computer to solve some problem.
- Once the program is written and debugged, the computer can execute the instructions **very fast**, and always do it the same, every time, without a mistake.

Introduction

- Even though the program consists of very simple instructions, the overall result can be very impressive, due mostly to the speed at which the computer can process the instructions.
- Even though each step in the program is very simple, the sequence of instructions, executing at *millions* of steps per second, can appear to be very complicated, when taken as a whole.
- The *trick* is not to think of it as a whole, but as a *series of very simple steps, or commands*.

Introduction

- The microprocessor itself is usually a single integrated circuit (IC).
- Most microprocessors (MPU), or very small computers, have much the same commands or instructions that they can perform.
  - They vary mostly in the names used to describe each command.
- In a typical MPU, there are commands to move data around, do simple math (add, subtract, multiply, and divide), bring data into the micro from the outside world, and send data out of the micro to the outside world.
  - Sounds too simple....right? .

Microprocessors

- The microprocessor is a programmable integrated device that has computing and decision-making capability similar to that of the central processing unit (CPU) of a computer.
- The fact that the microprocessor is programmable means it can be instructed to perform given tasks within its capability.
- The microprocessor is a clock-driven semiconductor device consisting of electronic logic circuits manufactured by using either a large-scale integration (LSI) or very-large-scale integration (VLSI) technique.

Microprocessors

- A typical MPU has three basic parts inside. They are:
  - the Program Counter (PC)
  - Memory, and
  - Input / Output (I/O).
- The Program Counter keeps track of which command is to be executed.
- The Memory contains the commands to be executed.
- The Input / Output handles the transfer of data to and from the outside world (outside the MPU physical package).
- There are many other actual parts inside the MPU, however, we will learn about every single one, one step at a time.

Microprocessors

- Nowadays, the microprocessor is being used in a wide range of products called microprocessor-based products or systems.
- The microprocessor can he embedded in a larger system, can be a stand alone unit controlling processes, or it can function as the CPU of a computer called a microcomputer.

Microprocessors

- The microprocessor communicates and operates in the binary numbers 0 and 1, called bits.
- Each microprocessor has a fixed set of instructions in the form of binary patterns called a machine language.
- It is difficult for humans to communicate in the language of 0 s and 1 s.
- Therefore, the binary instructions are given abbreviated names, called mnenomics, which form the assembly language for a given microprocessor.

Microprocessors

- A typical programmable machine can be represented with four components: microprocessor, memory, input, and output.
- These four components work together or interact with each other to perform a given task; thus, they comprise a system.
- The physical components of this system are called hardware.
- A set of instructions written for the microprocessor to perform a task is called a program, and a group of programs is called software.

Microprocessors

- The microprocessor applications are classified primarily in two categories:
  - reprogrammable systems and
  - embedded systems.

Microprocessors

- In reprogrammable systems, such as microcomputers, the microprocessor is used for computing and data processing. These systems include:
  - general-purpose microprocessors capable of handling large data, mass storage devices (such as disks and CD-ROMs), and peripherals such as printers;
  - a personal computer (PC) is a typical illustration.

Microprocessors

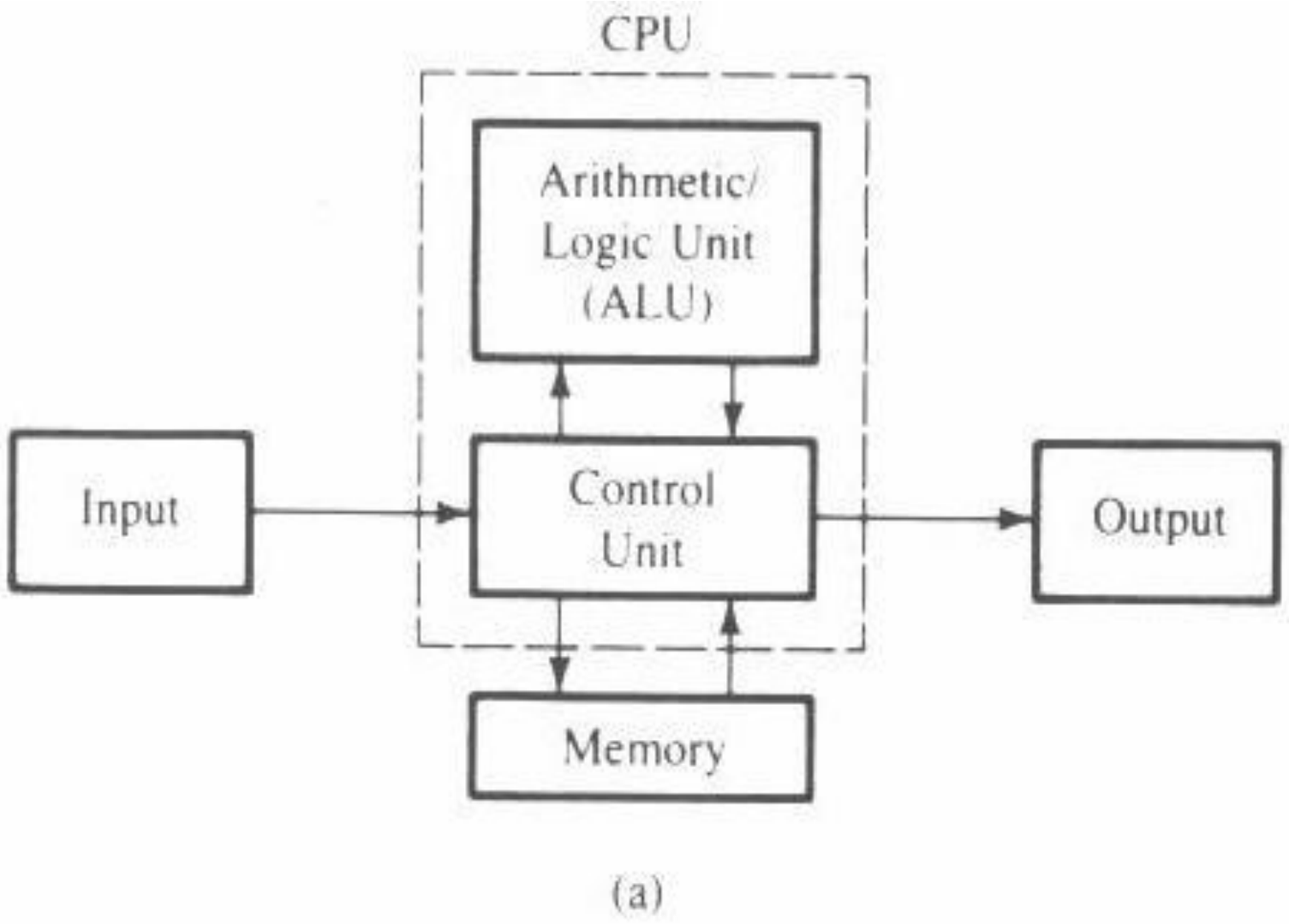
- In embedded systems, the microprocessor is a part of a final product and is not available for reprogramming to the end user. Example:
  - copying machine
  - washing machine.
  - Air-conditioner
  - Etc.

Microprocessor, CPU & Microcontroller

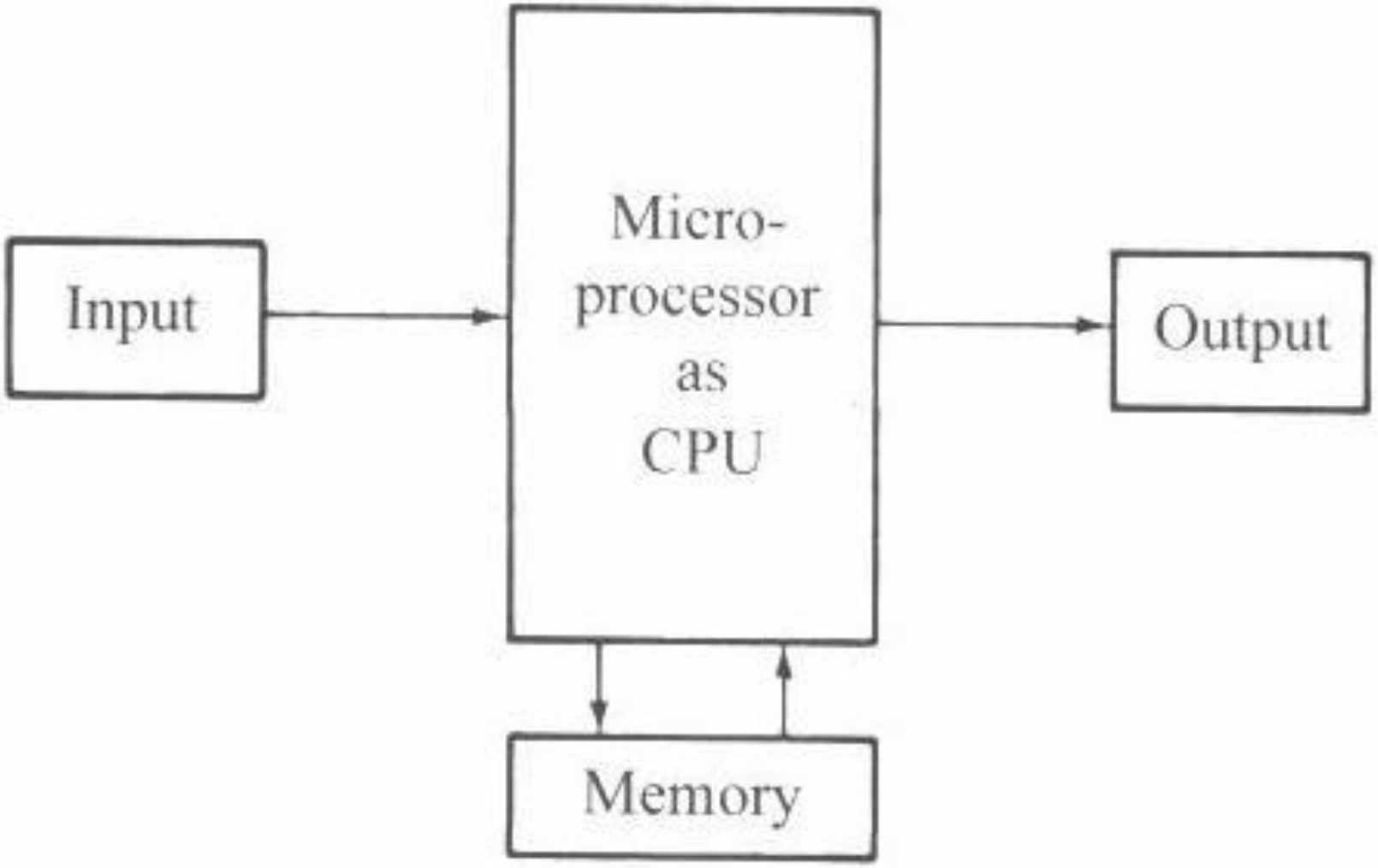
- Microprocessor (MPU) - a semiconductor device (integrated circuit) manufactured by using the LSI technique.
  - It includes the ALU, register arrays, and control circuits on a single chip.
- CPU - the central processing unit.
  - The group of circuits that processes data and provides control signals and timing. It includes the arithmetic/logic unit, registers, instruction decoder, and the control unit.
- Microcontroller - a device that includes microprocessor, memory, and I/O signal lines on a single chip, fabricated using VLSI technology.

Microprocessor, CPU & Microcontroller

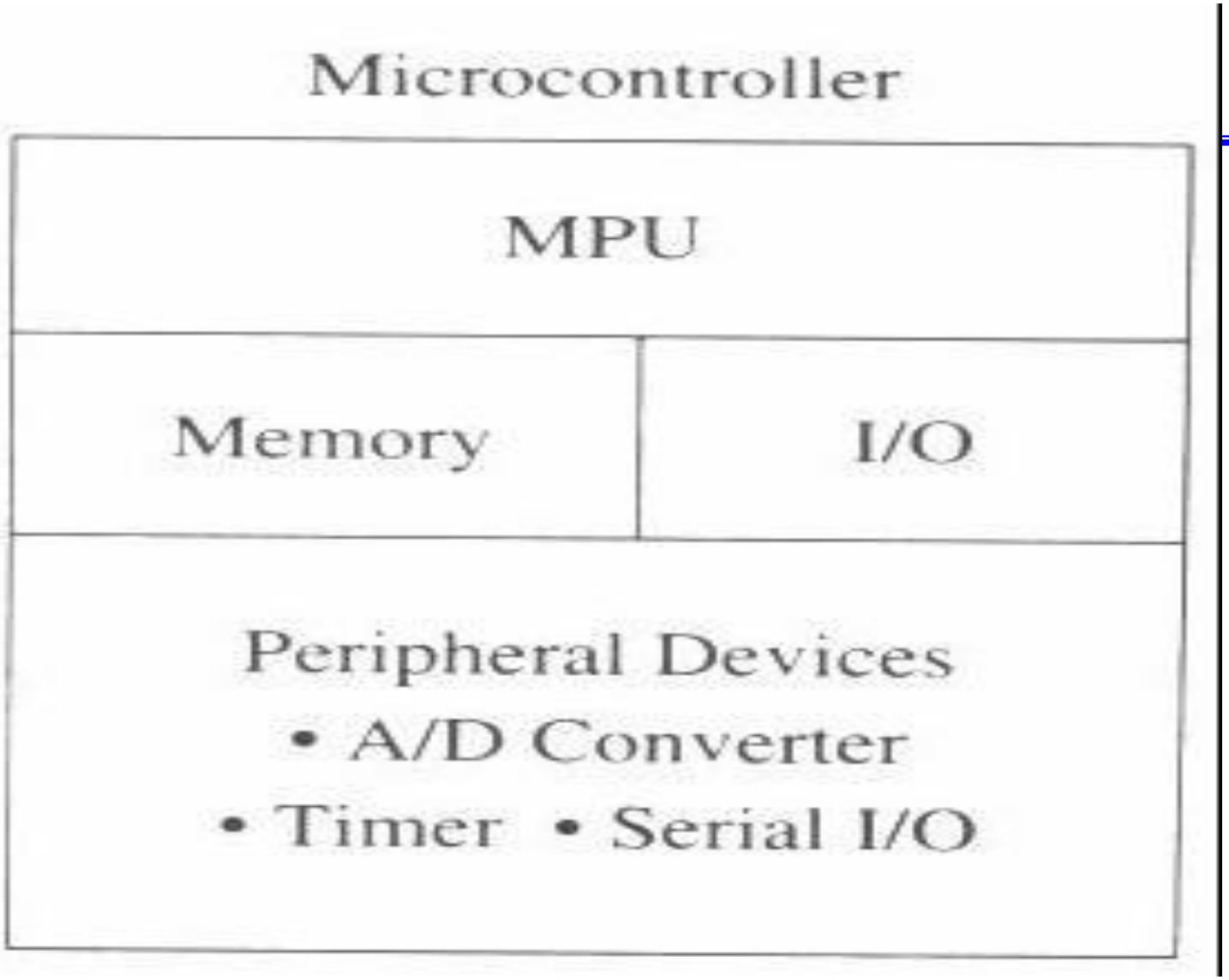
- In large computers, a CPU implemented on one or more circuit boards performs these computing functions.
- The microprocessor is in many ways similar to the CPU, but includes all the logic circuitry, including the control unit, on one chip.



Traditional block diagram of a computer



Block diagram of a computer with the microprocessor as a CPU



Block diagram of a microcontroller

A Simple Program

- A program is a sequence or series of very simple commands or instructions.
- A real world example program might be the problem of crossing a busy street.
  - Step 1: Walk up to the traffic lights and stop.
  - Step 2: Look at the traffic light.
  - Step 3: Is your light green?
  - Step 4: If the light is red, goto step 2. (otherwise continue to step 5)
  - Step 5: Look to the left.
  - Step 6: Are there cars still passing by?
  - Step 7: If yes, goto step 5. (otherwise continue to step 8).
  - Step 8: Look to the right.
  - Step 9: Are there cars still passing by? (there shouldn't be any by now, but, you never know!)
  - Step 10: If yes, goto step 8. (otherwise continue to step 11)
  - Step 11: Proceed across the street, carefully!! .

A Simple Program

- Now this may seem childish at first glance, but this is exactly what you do every time you cross a busy street, that has a traffic light.
- This is also exactly how you would tell a MPU to cross the street, if one could.
- This is what I mean by a sequence or series of very simple steps.
- Taken as a whole, the steps lead you cross a busy intersection, which, if a computer did it, would seem very intelligent.
- It is intelligence, people are intelligent. A programmer that programmed these steps into a MPU, would impart that intelligence to the micro.
- The MPU would not, however, in this case, know what to do when it got to the other side, since we didn't tell it.

A Simple Program

- In a MPU, the problems are different but the logical steps to solve the problem are similar, that is, a series of very simple steps, leading to the solution of a larger problem.
- Also notice that since the steps are numbered, 1 through 11, that is the order in which they're executed.
  - The Program Counter (PC), in this case, starting with 1 and ending with 11, doing what each one says.
  - The PC automatically advances to the next step, after doing what the current step says, unless a *branch,* or *jump*, is encountered.
  - A branch is an instruction that directs the PC to go to a specific step, **other than the next in the sequence**.

A Simple Program

- The point of this lesson is to show how a simple set of instructions can solve a bigger problem.
  - Taken as a whole, the solution could appear to be more complicated than any of the separate steps it took to solve it.
- The most difficult problem to be solved in programming a MPU is to define the problem you are trying to solve.
  - Sounds silly but I assure you, it's not.
  - This is the *Logical Thought Process*.
  - It is having a good understanding of the problem you're trying to solve.

You must **understand** the information I'm presenting in order to pass the course. Trying to **remember** everything does not work at university.

Decimal, Binary & Hex

- The microprocessor operates in binary digits, 0 and 1, also known as bits.
  - Bit is an abbreviation for the term binary digit.
  - These digits are represented in terms of electrical voltages in the machine: Generally, 0 represents low voltage level, and 1 represents high voltage level.
- Each MPU recognises and processes a group of bits called the word.
  - A word is a group of bits the computer recognizes and processes at a time.
- MPUs are classified according to their word length.
  - For example, a processor with an 8-bit word is known as an 8-bit microprocessor, and a processor with a 32-bit word is known as a 32-bit microprocessor.

Decimal, Binary & Hex

- All numbering systems follow the same rules.
- Decimal is Base 10, Binary is Base 2, and Hex(adecimal) is Base 16.
- The base of a system refers to how many possible numbers can be in each digit position.
  - In decimal, a single digit number is 0 through 9.
  - In binary a single digit number is 0 or 1.
  - In hex a single digit number is 0 through 9, A,B,C,D,E, and F.

Decimal, Binary & Hex

- General format to represent number:

$$N = A_nB^n + A_{n-1}B^{n-1} + \ldots\ldots\ldots + A_1B^1 + A_0B^0$$

Where,

N is number

B is base

A is any digit in that base.

A binary 10 (one zero) is decimal 2

A decimal 10 is ten

A hex 10 is decimal 16.

Number Conversion (revision)

For example, number 154 can be represented in various number systems as follows:

Decimal: $154 = 1 \times 10^2 + 5 \times 10^1 + 4 \times 10^0 = 154$

Octal: $232 = 2 \times 8^2 + 3 \times 8^1 + 2 \times 8^0$

$= 128 + 24 + 2 = 154$

Hexadecimal: $9A = 9 \times 16^1 + A \times 16^0$

$= 144 + 10 = 154$

Binary: 10011010

$= 1 \times 2^7 + 0 \times 2^6 + 0 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$

$= 128 + 0 + 0 + 16 + 8 + 0 + 2 + 0 = 154$

Number Conversion (revision)

CONVERSION TABLE: DECIMAL, BINARY, OCTAL, AND HEXADECIMAL

Decimal	Hex	Binary	Octal
0	0	0000	00
1	1	0001	01
2	2	0010	02
3	3	0011	03
4	4	0100	04
5	5	0101	05
6	6	0110	06
7	7	0111	07
8	8	1000	10
9	9	1001	11
10	A	1010	12
11	B	1011	13
12	C	1100	14
13	D	1101	15
14	E	1110	16
15	F	1111	17

Number Conversion

- Convert the binari number 1001 1011 into its hex:
  - Arrange the binary digits in groups of four:

    1001 1011

  - Convert each group into its equivalent Hex number.

    1001 1011

    9 B

Advances in Semiconductor Technology

- After the invention of the transistor, integrated circuits (ICs) appeared on the scene at the end of the 1950s.
  - an entire circuit consisting of several transistors, diodes, and resistors could be designed on a single chip.
- In the early 1960s, logic gates 7400 series were commonly available as ICs, and the technology of integrating the circuits of a logic gate on a single chip became known as small-scale integration (SSI).

Advances in Semiconductor Technology

- As semiconductor technology advanced, more than 100 gates were fabricated on one chip:
  - medium-scale integration (MSI).
  - Example:a decade counter (7490).
- Within a few years, it was possible to fabricate more than 1000 gates on a single chip
  - large-scale integration (LSI).
- Now we are in the era of very-large- scale integration (VLSI) and super-large-scale integration (SLSI).
- The lines of demarcation between these different scales of integration are rather ill defined and arbitrary.

Historical Perspective

- The microprocessor revolution began with a bold and innovative approach in logic design pioneered by Intel engineer Ted Hoff.
- In 1969, Intel was primarily in the business of designing semiconductor memory.
  - it introduced a 64-hit bipolar RAM chip that year.

Historical Perspective

- Intel coined the term “microprocessor” and in 1971 released the first 4-bit microprocessor as the 4004.
  - It was designed with LSI technology;
  - It had 2,300 transistors, 640 bytes of memory-addressing capacity, and a 108 kHz clock. Thus, the microprocessor revolution began with this tiny chip.
- Gordon Moore, cofounder of Intel Corporation, predicted that the number of transistors per integrated circuit would double every 18 months;
  - this came to he known as “Moore’s Law.”
  - Just twenty-five years since the invention of the 4004, we have processors that are designed with 15 million transistors, that can address one terabyte ($1 \text{ X } 1^{12}$) of memory, and that can operate at 400 MHz to I .5-0Hz frequency (see Table 1.1).

TABLE 1.1
Intel Microprocessors: Historical Perspective

Processor	Year of Introduction	Number of Transistors	Initial Clock Speed	Address Bus	Data Bus	Addressable Memory
4004	1971	2,300	108 kHz	10-bit	4-bit	640 bytes
8008	1972	3,500	200 kHz	14-bit	8-bit	16 K
8080	1974	6,000	2 MHz	16-bit	8-bit	64 K
8085	1976	6,500	5 MHz	16-bit	8-bit	64 K
8086	1978	29,000	5 MHz	20-bit	16-bit	1 M
8088	1979	29,000	5 MHz	20-bit	8-bit*	1 M
80286	1982	134,000	8 MHz	24-bit	16-bit	16 M
80386	1985	275,000	16 MHz	32-bit	32-bit	4 G
80486	1989	1.2 M	25 MHz	32-bit	32-bit	4 G
Pentium	1993	3.1 M	60 MHz	32-bit	32/64-bit	4 G
Pentium Pro	1995	5.5 M	150 MHz	36-bit	32/64-bit	64 G
Pentium II	1997	8.8 M	233 MHz	36-bit	64-bit	64 G
Pentium III	1999	9.5 M	650 MHz	36-bit	64-bit	64 G
Pentium 4	2000	42 M	1.4 GHz	36-bit	64-bit	64 G

*External 8-bit and internal 16-bit data bus

Organization of a Microprocessor-Based System

- It includes three components:
  - Microprocessor;
  - I/O (input/output) and
  - memory (read/write memory and read-only memory).
- These components are organised around a common communication path called a bus.
- The entire group of components is also referred to as a system or a microcomputer system.

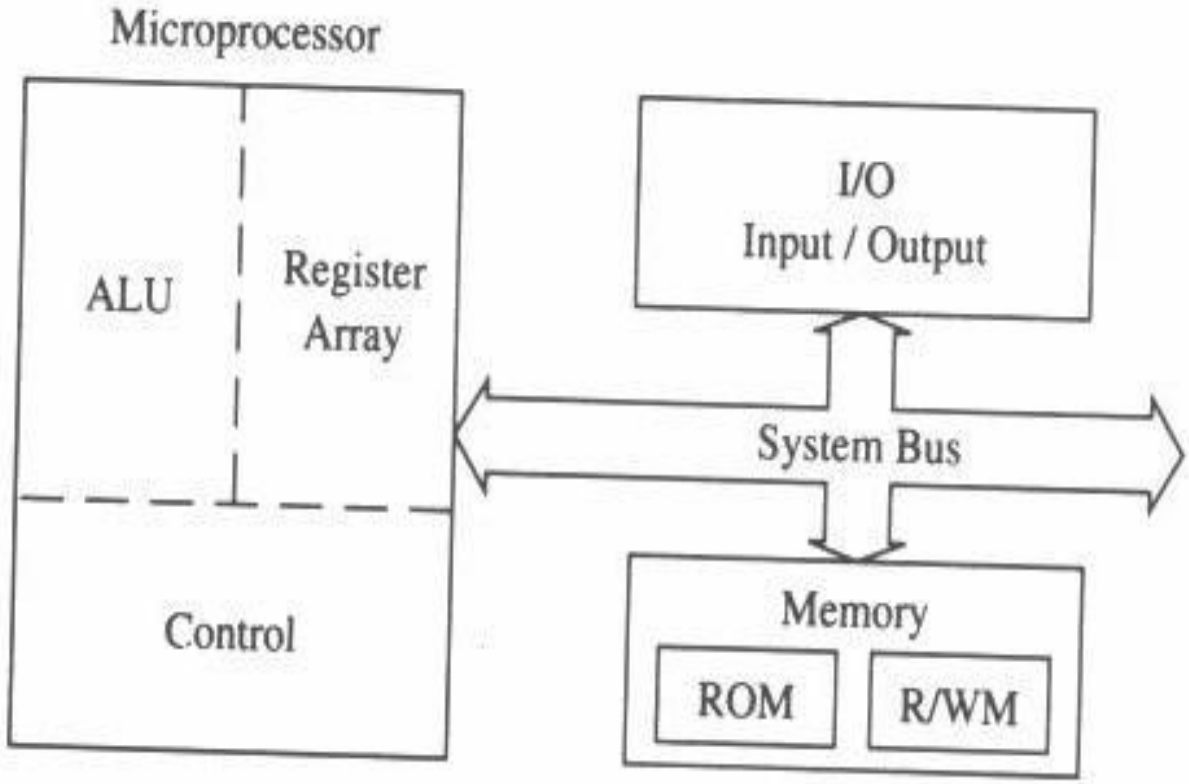


FIGURE 1.3
Microprocessor-Based System with Bus Architecture

Organization of a Microprocessor-Based System

- The functions of various components:
  - The microprocessor
    - reads instructions from memory.
    - communicates with all peripherals (memory and 1/Os) using the system bus.
    - controls the timing of information flow.
    - performs the computing tasks specified in a program.
  - The memory
    - stores binary information, called instructions and data.
    - provides the instructions and data to the microprocessor on request.
    - stores results and data for the microprocessor.
  - The input device
    - enters data and instructions under the control of a program such as program.
  - The output device
    - accepts data from the microprocessor as specified in a program.
  - The bus
    - carries bits between the microprocessor and memory and I/Os.

Microprocessor Instruction Set and Computer Languages

- Microprocessors recognize and operate in binary numbers.
- Each microprocessor has its own binary words, meanings, and language.
- The words are formed by combining a number of bits for a given machine.
  - The word (or word length) is defined as the number of bits the microprocessor recognizes and processes at a time.
  - The word length ranges from 4-bit to 64-bit.
- Another term commonly used to express word length is byte.
  - A byte is defined as a group of eight bits.
  - For example, a 16-bit microprocessor has a word length to two bytes.
- The term nibble stands for a group of four bits.
  - A byte has two nibbles.

Microprocessor Instruction Set and Computer Languages

- Each machine has its own set of instructions based on the design of its CPU or of its microprocessor.
- To communicate with the computer, one must give instructions in binary language (machine language).
  - Difficult for most people to write programs in sets of 0s and 1s, computer manufacturers have devised English-like words to represent the binary instructions of a machine - assembly language.
  - An assembly language is machine-specific.

Microprocessor Instruction Set and Computer Languages

- The 8085 is a microprocessor with 8-bit word length:
  - its instruction set (or language) is designed by using various combinations of these eight bits.
  - 8085 has 74 different instructions - instruction set.

Microprocessor Instruction Set and Computer Languages

- For convenience, the 8085 instructions can be written in hexadecimal code and entered in a single-board microcomputer by using Hex keys.
  - E.g., the binary instruction $0011\ 1100_2 \equiv 3C_h$.
  - This instruction can be entered in a single-board microcomputer system with a Hex keyboard by pressing two keys: 3 and C.
  - The monitor program of the system translates these keys into their equivalent binary pattern.

8085 Assembly Language

- Even though the instructions can be written in hexadecimal code, it is still difficult to understand a program written in hexadecimal numbers.
  - Therefore, each manufacturer of a MPU has devised a symbolic code for each instruction, called a mnemonic.
  - The mnemonic for a particular instruction consists of letters that suggest the operation to be performed by that instruction.
  - For example, $0011\ 1100_2$ ($3C_h$) is represented by the mnemonic INR A.

8085 Assembly Language

- The complete set of 8085 mnemonics is called the 8085 assembly language.
- A program written in these mnemonics is called an assembly language program.
- Machine language and assembly language are microprocessor-specific and are both considered low-level languages.
- The machine language is in binary, and the assembly language is in English-like words; however, the microprocessor understands only the binary.

8085 Assembly Language

- The mnemonics can be written by hand on paper and translated manually in hexadecimal code, called hand assembly.
- Or the mnemonics can be written on a computer using a program called an Editor in the ASCII code and translated into binary code by using the program called an assembler.

ASCII—American Standard Code for Information Interchange. This is a 7-bit alphanumeric code with 128 combinations. Each combination is assigned to either a letter, decimal digit, a symbol, or a machine command.

Hand Assembly

- To manually write and execute an assembly language program on a single-board computer, with a Hex keyboard for input and LEDs for output, the following steps are necessary:
  - Write the instructions in mnemonics obtained from the instruction set supplied by the manufacturer.
  - Find the hexadecimal machine code for each instruction by searching through the set of instructions.
  - Enter (load) the program in the user memory in a sequential order by using the Hex keyboard as the input device.
  - Execute the program by pressing the Execute key. The answer will be displayed by the LEDs.

Assembler

- The hand assembly:
  - tedious and subject to errors;
  - suited for small programs.
- Alternative, use assembler:
  - The assembler is a program that translates the mnemonics entered by the ASCII keyboard into the corresponding binary machine codes of the microprocessor.
  - Each microprocessor has its own assembler because the mnemonics and machine codes are specific to the microprocessor being used, and each assembler has rules that must be followed by the programmer.

High-Level Languages

- Programming languages that are intended to be machine-independent are called high-level languages.
- These include such languages as BASIC, PASCAL, C, C++ and Java, all of which have certain sets of rules and draw on symbols and conventions from English.
- Instructions written in these languages are known as statements rather than mnemonics.

High-Level Languages

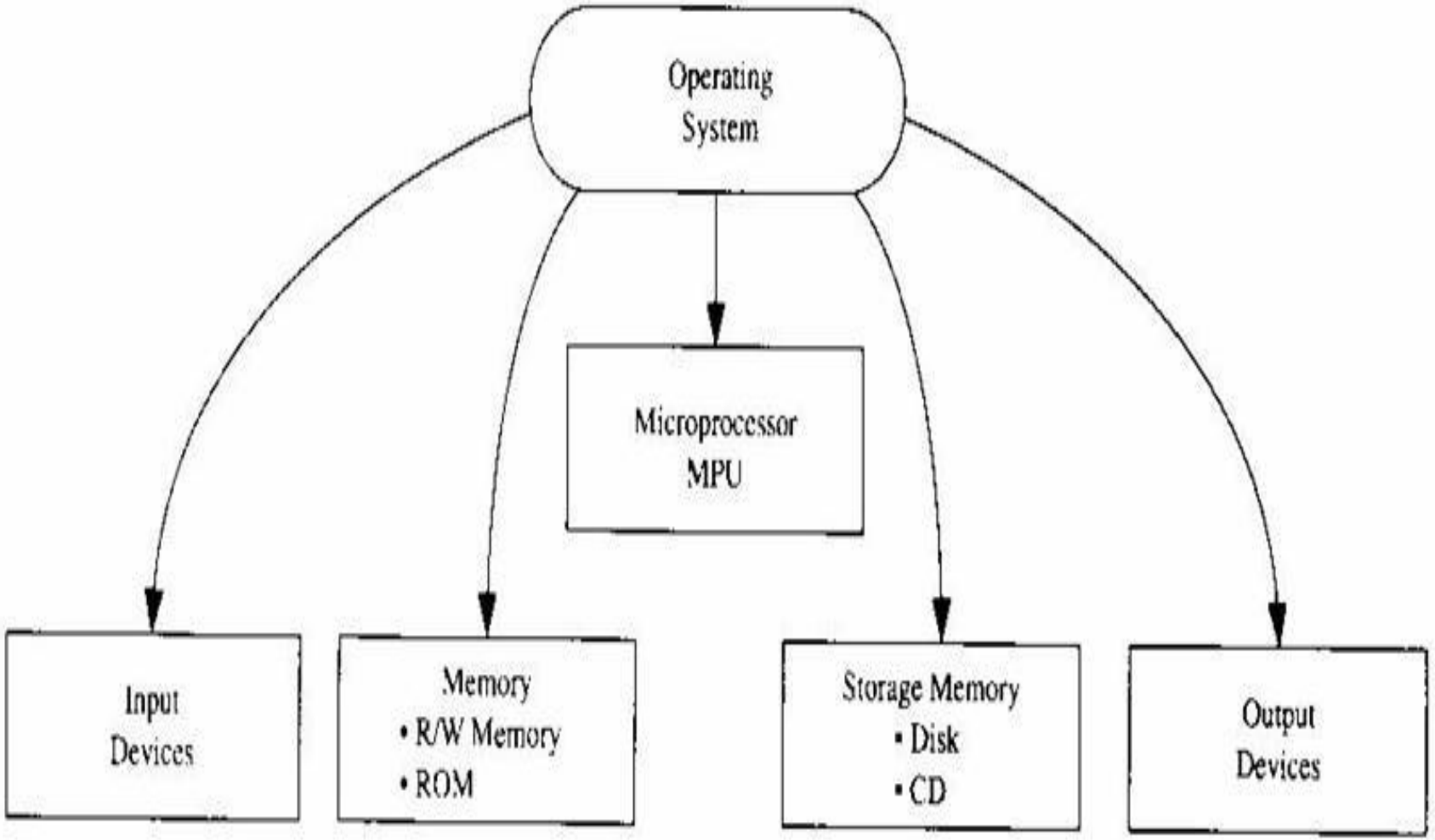
- How are words in English converted into the binary languages of different microprocessors?
  - Through another program called either a compiler or an interpreter.
  - These programs accept English-like statements as their input, called the source code.
  - The compiler or interpreter then translates the source code into the machine language compatible (object code) with the microprocessor being used in the system.
  - Each microprocessor needs its own compiler or an interpreter for each high-level language.

High-Level Languages

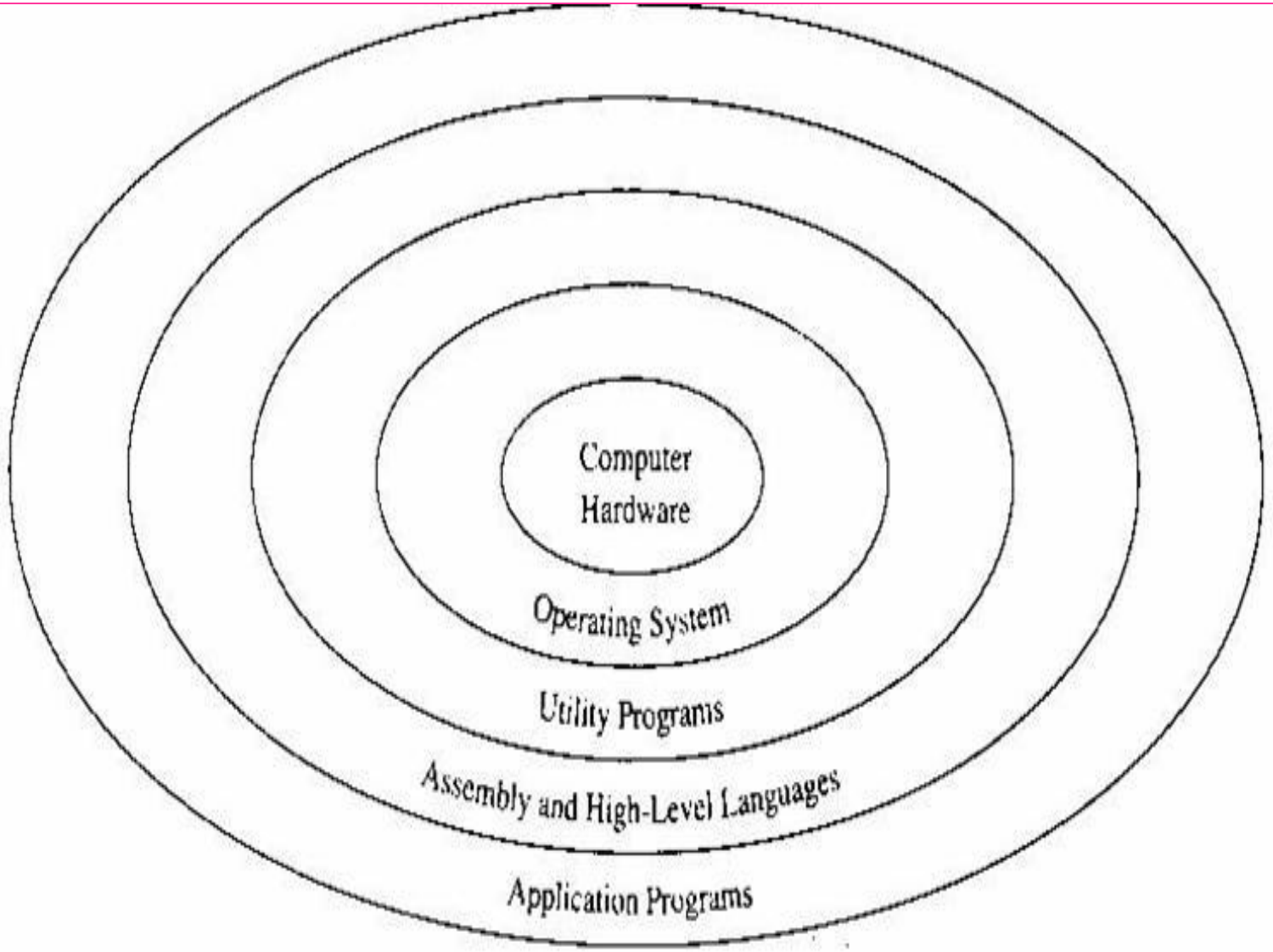
- Compiler - a program that translates English-like words of a high-level language into the machine language of a computer.
  - A compiler reads a given program, called a source code, in its entirety and then translates the program into the machine language, which is called an object code.
- Interpreter - a program that translates the English-like statements of a high-level language into the machine language of a computer.
  - An interpreter translates one statement at a time from a source code to an object code.
- Assembler - a computer program that translates an assembly language program from mnemonics to the binary machine code of a computer.

Operating system

- Operating system - a set of programs that manages interaction between hardware and software.
  - Responsible primarily for storing information on disks and for communication between microprocessor, memory, and peripherals.



OS and its relationship with various hardware components



Hierarchical relationship between computer hardware and software.

Single-board microcomputer

- Typically, these microcomputers include an 8- or 16-bit microprocessor, from 256 bytes to 8K bytes of user memory, a Hex keyboard, and seven-segment LEDs as display.
- The interaction between the microprocessor, memory, and I/Os in these small systems is managed by a monitor program, which is generally small in size, stored in less than 2K bytes of ROM.
- When a single-board microcomputer is turned on, the monitor program is in charge of the system;
  - it monitors the keyboard inputs, interprets those keys, stores progranis in memory, sends system displays to the LEDs, and enables the execution of the user programs.

Single-board microcomputer

- Monitor program - a program that interprets the input from a keyboard and converts the input into its binary equivalent.
  - The function of the monitor program in a small system is similar to that of the operating system in a large system.

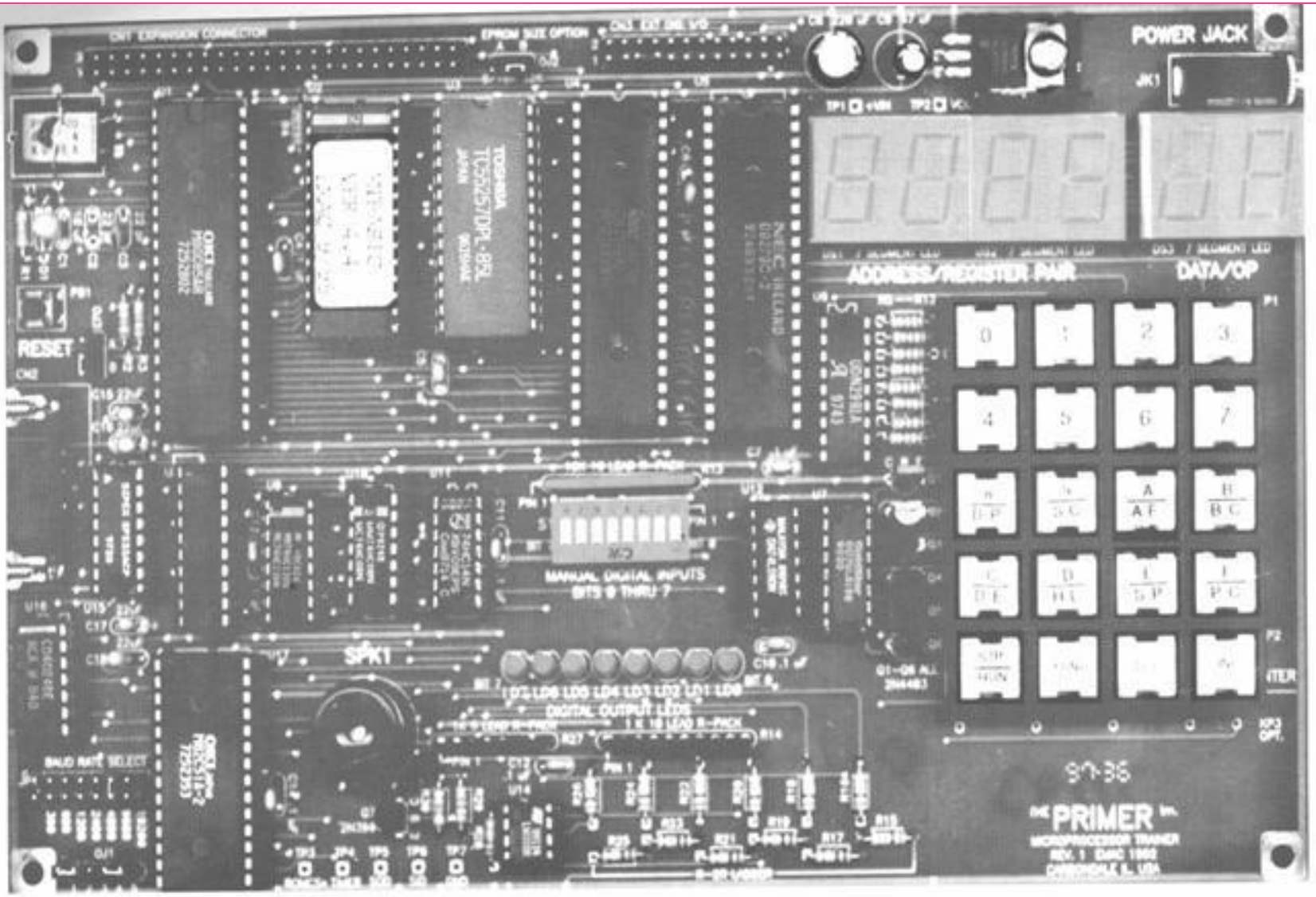


FIGURE 1.7
Single-Board Microcomputer: The Primer
SOURCE: Courtesy of EMAC Inc.

Application: Microprocessorcontrolled Temperature System (Mcts)

- This system is expected:
  - to read the temperature in a room;
  - display the temperature at a liquid crystal display (LCD) panel (described later);
  - turn on a fan if the temperature is above a set point, and
  - turn on a heater if the temperature is below a set point.

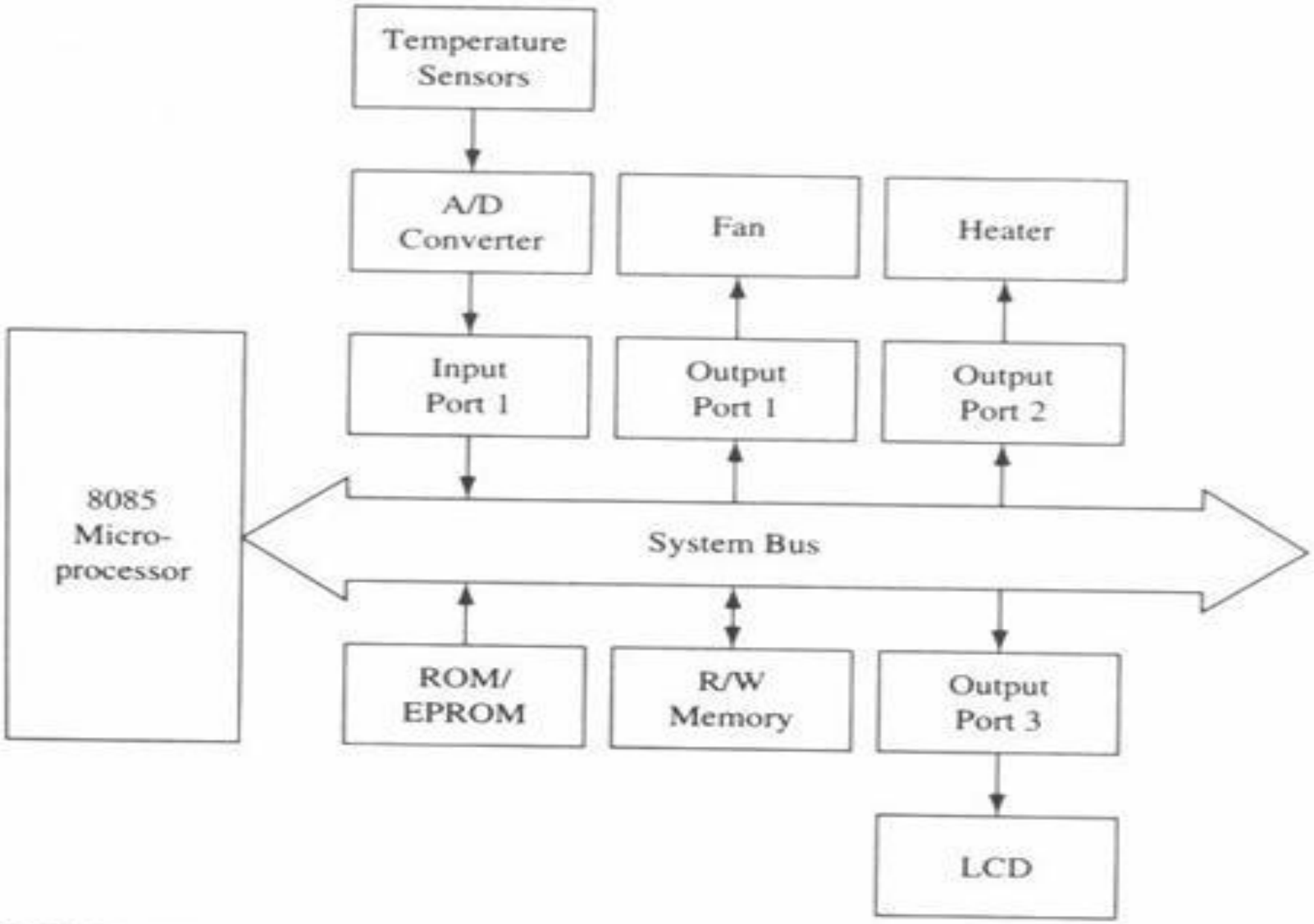


FIGURE 1.8
Microprocessor-Controlled Temperature System (MCTS)