Module 1

Introduction Computer Organization and Computer Evolution

- CO1: Inspect the simplified structure and function of a computer system

Lesson:

1.1 Structure and Function of a Computer and Importance of Computer Organization and Architecture

Learning Outcomes:

- LO 1.1.1 Present and distinguish the differences of computer organization and architectures.
- LO 1.1.2 Explain the concepts of Computer structure and function.
- LO 1.1.3 Inculcate the importance of Computer Organization and Architecture based on IEEE (Institute of Electrical and Electronics Engineers) and ACM (Association of Computing machines) rationale.

In describing computers, a distinction is often made between computer architecture and computer organization, although it is difficult to give precise definitions for these terms, a consensus exists about the general areas covered by each.

Computer Architecture refers to those attributes of a system visible to a programmer or, put it another way, those attributes that have direct impact on the logical execution of a program. Example of architectural attributes include the instruction set, the number of bits used to represent various data types (e.g. number, characters), I/O mechanisms, and techniques for addressing memory.

Computer Organization refers to the operational units and refers to the operational units and their interconnections that realize the architectural specifications. Organizational attributes include those hardware details transparent to the programmer, such as control signals, interfaces between computer and peripherals, and the memory technology used.

As an example, it is an architectural design issue whether a computer will have a multiply instruction. It is an organizational issue whether that instruction will be implemented by a special multiply unit or by a mechanism that makes repeated use of the add unit of the system. The organizational decision may be based on the anticipated frequency of use of the multiply instruction, the relative speed of the two approaches, and the cost and physical size of a special unit.

Historically, and still today, the distinction between architecture and organization has been an important one. Many computer manufacturers offer a family of computer model, all with the same architecture but with differences in organization. Consequently, the different models in the family have different price and performance characteristics. Furthermore, a particular architecture may span many years and encompass a number of different computer models, its organization changing with changing technology. A prominent example of both these phenomena is the IBM System/370 architecture. This architecture was first introduced in 1970 and included a slower model and, if demand increased, later upgrade to more expensive, faster model without having to abandon software that have already been developed. These newer models retain the same architecture so that the customer's software investment was protected. Remarkably, the System/370 architecture, with a few enhancements survived to this day as the architecture o IBM mainframe product line.

Structure and Function

A computer is complex system; contemporary computers contain millions of elementary electronic components. The key is to recognize the hierarchical nature of most complex systems, including the computer. A hierarchical system is a set of interrelated subsystems, each of the latter, in turn, hierarchical in structure until we reach some lowest level of elementary subsystems.

The hierarchical nature of complex systems is essential to both their design and their description. The designer need only deal with a particular level of the system at a time. At each level, the system consists of a set of components and their interrelationship. The behavior at each level depends only on a simplified, abstracted characterization of the system at the next lower level. At each level, the designer is concerned with the structure and function.

- ***Structure:*** The way in which the components are interrelated
- ***Function:*** The operation of each individual component as part of the structure.

The computer systems will be described top down. We begin with the major components of a computer, describing their structure and function, and proceed to the lower levels of the hierarchy.

Function:

Both the structure and functioning of a computer are, in essence, simple. Figure 1.1 depicts the basic function that a computer can perform. In general terms, there are only four

- ***Data processing*** – the computer, of course, must be able to process data. The data may take a wide variety of forms, and the range of processing requirements is broad. However we shall see that there are only a few fundamental methods or types of data processing
- ***Data storage*** **–** It is also essential that a computer store data. Even if the computer is processing data on the fly, the computer must temporarily store at least those pieces of data that are being worked on at any given moment. Equally important, the computer performs a long-term data storage function. Files of data are stored on the computer for subsequent retrieval and update.
- ***Data movement*** **–** the computer must be able to move data between itself and the outside world. The computer's operating environment consists of device that serves as either sources or destinations of data. When data are received from or delivered to a device that is directly connected to the computer, the process in known as input-output (I/O), and the device is referred to as a peripheral. When data are moved over to longer distances, to or from remote devices, the process is known as data communication
- ***Control*** **–** ultimately, this control is exercised by the individual(s) who provide the computer with instructions. With in the computer, a control unit manages the computer resources and orchestrates the performance of its functional parts in response to those instructions.

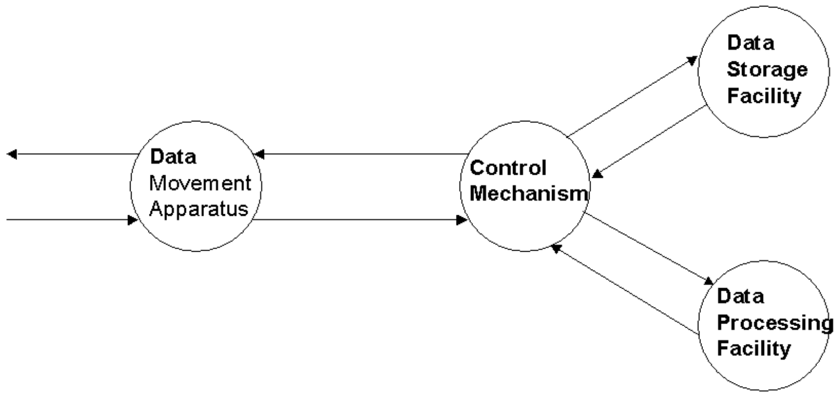

Figure 1.1 A functional view of the computer.

At this general level of discussion, the number of possible operations that can be performed are few. Figure 1.2 depicts the four possible types of operations. The computer can function as a data movement device (Figure 1.2a), simply transferring data from one peripheral or communications line to another. It can also function as a data storage device (Figure 1.2b), with data transferred from the external environment to computer storage (read) and vice versa (write). The final two diagrams show operations involving data processing, on either in storage (Figure 1.2c) or en route between storage and the external environment.(Figure 1.2d)

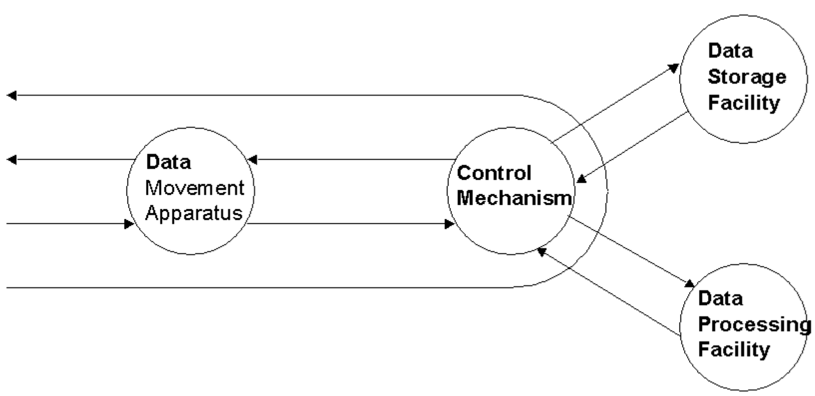

Figure 1.2a

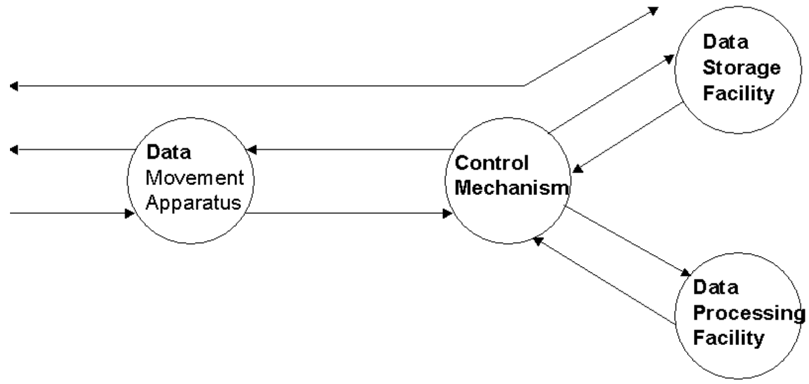

Figure 1.2b

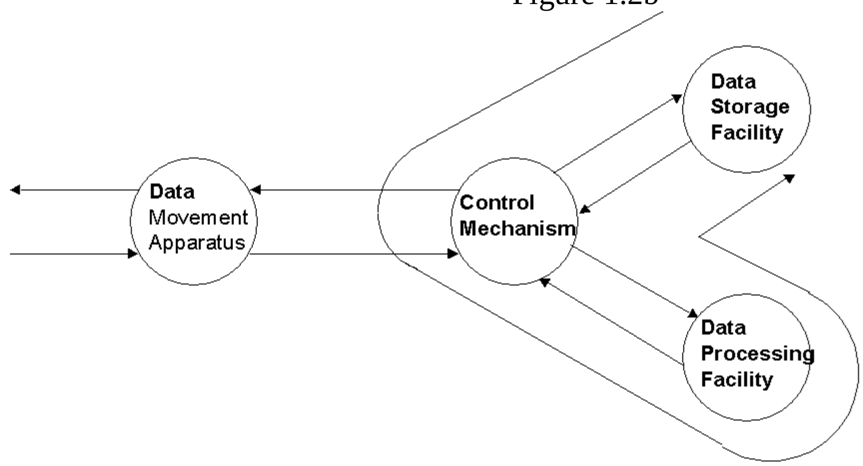

Figure 1.2c

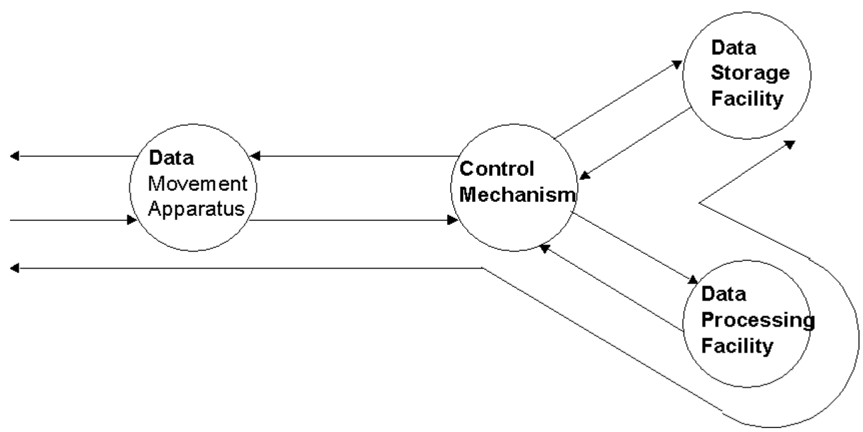

Figure 1.2d

Figure 1.2 Possible computer operations

Structure

Figure 1.3 is the simplest possible depiction of a computer. The computer interacts in some fashion with its external environment. In general, all its linkages to the external environment can be classified as peripheral devices or communication lines. There are four main structural components (Figure 1.4):

- **Central processing unit (CPU):** Controls the operation of the computer and performs its data processing functions; often simply referred to as processor.
- **Main Memory:** Stores data
- **I/O:** Moves data between the computer and its external environment.
- **System interconnection:** Some mechanism that provides for communication among CPU, main memory, and I/O

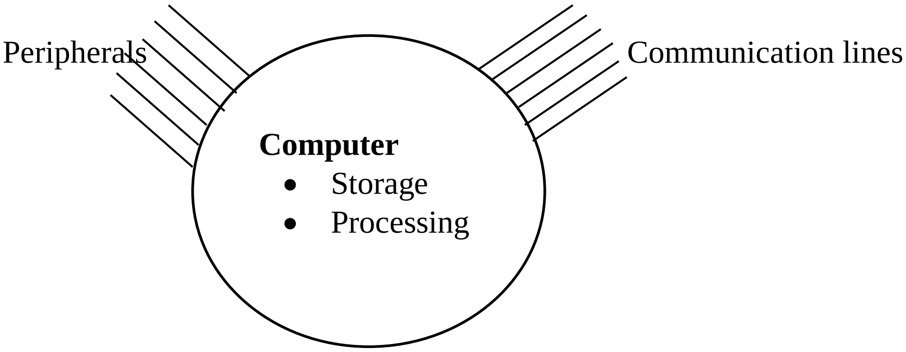

Figure 1.3 The Computer

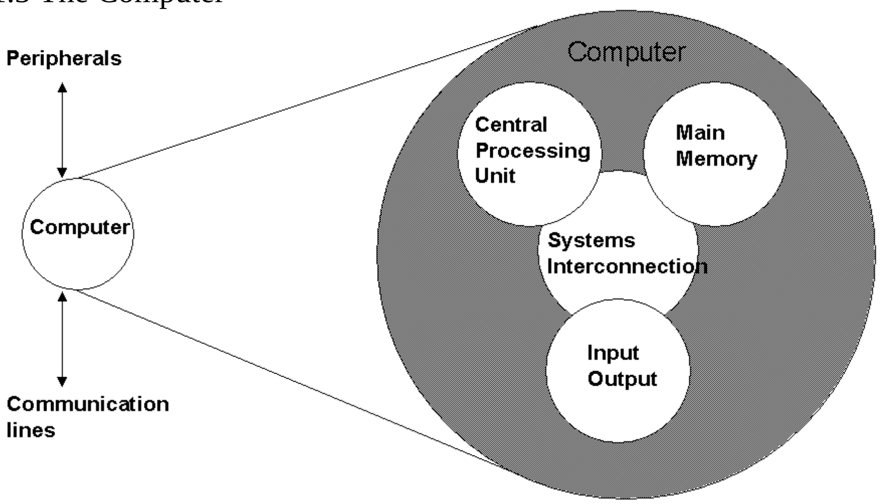

Figure 1.4 The Compute r: Top Level Structure

There may be one or more of each of the aforementioned components. Traditionally, there has been just a single CPU. In recent years, there has been increasing use of multiple processors in a single computer. Some design issues relating to multiple processors in a single computer. The most interesting and in some ways the most complex component is the CPU; its structure is depicted in Figure 1.5. Its major structural components are:

- ***Control Unit:*** Controls the operation of the CPU and hence the computer
- ***Arithmetic and Logic Unit (ALU):*** Performs the computer's data processing functions.
- ***Registers:*** Provides storage internal to the CPU.
- ***CPU interconnection:*** Some mechanism that provides for communication among the control unit. ALU, and registers.

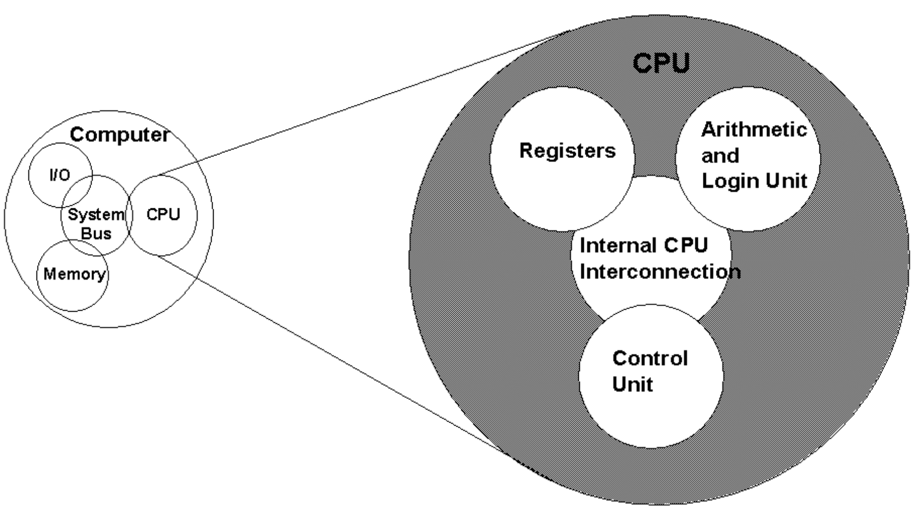

Figure 1.5 The Central Processing Unit

Finally there are several approaches to the implementation of the control unit, one common approach is a microprogrammed implementation. In essence, a *microprogrammed* control unit operates by executing the microinstructions that define the functionality of the control unit. The structure of the control unit is depicted in Figure 1.6.

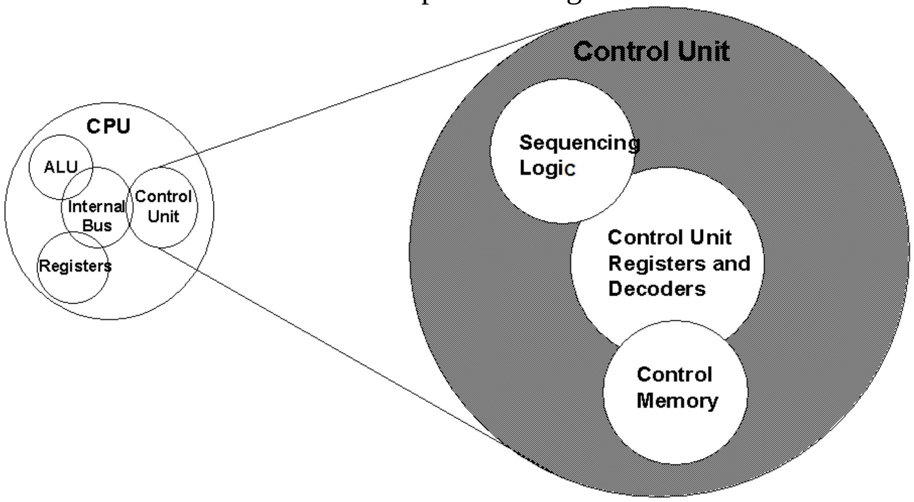

Figure 1.6 The Control Unit

Importance of Computer Organization and Architecture

The computer lies at the heart of computing. Without it most of the computing disciplines today would be a branch of theoretical mathematics. To be a professional in any field of computing today, one should not regard the computer as just a black box that executes programs by magic. All students of computing should acquire some understanding and appreciation of a computer system's functional components and characteristics, their performance, and their interactions. There are practical implications as well. Students need to understand computer architecture in order to structure a program so that it runs more efficiently on real machine. In selecting a system to use, they should be able to understand the tradeoff among various components, such as CPU clock speeds vs. memory size. [Reported by the Joint Task Force of Computing Curricula of the IEEE (Institute of Electrical and Electronics Engineers) Computer Society and ACM (Association of Computing Machinery)]

Lesson:
1.2 Computer Evolution

- LO 1.2.1 Examine the historical perspective of computer evolution.

The First Generation: Vacuum Tubes

ENIAC: The ENIAC (Electronic Numerical Integrator and Computer), designed and constructed under the supervision of John Mauchly and John Presper Eckert at the University Of Pennsylvania, was the first general-purpose electronic digital computer.

The project was a response to U.S. wartime needs during World War II. The Army's Ballistics Research Laboratory (BRL), an agency responsible for developing range and trajectory for new weapons, was having difficulty in supplying tables accurately within the necessary time frame.

Mauchly, a professor of electrical engineering at the University of Pennsylvania and Eckert his graduate student, proposed building a general purpose computer using vacuum tube for BRL's application. The proposal was accepted on 1943, by the Army and work began. In its completion the resulting machine was

- Over 30 Tons, occupying 1500 sq ft. of floor area
- Composed of 18,000 vacuum tubes, and consumes 140KW of power
- Faster than electromechanical computers, capable of (5000 additions per second)

- The numbers are represented in decimal, rather than binary. A ring of vacuum tubes represent a digit
- Its memory consisted of 20 “accumulators”, each capable of holding 10 digits.
- The machine has to be programmed manually by setting switches and plugging and unplugging cables

It was completed in 1946, too late to be used in the war effort. Instead, its first task war to perform a series of calculation that were used to help determine the feasibility of the hydrogen bomb. It continued to operate until 1955, when it was disassembled.

The Von Neumann Machine: The task of entering and altering programs for ENIAC was extremely tedious. The programming process could be facilitated if the program could be represented in form suitable for storing in memory alongside the data. Then the computer could get its instruction by reading them from memory, and a program could be set or altered by setting the values of a portion of memory.

This idea, known as the stored-program concept, is usually attributed to the mathematician John Von Neumann, who was a consultant of the ENIAC project. Alan Turing developed the idea at about the same time. The first publication of the idea was in 1945 proposal by Von Neumann for new computer, the EDVAC (Electronic Discrete Variable Computer). In 1946, von Neumann and his colleagues began the design of stored program computer, referred as the IAS computer, at the Princeton Institute of Advance Studies. It was completed on 1952, and the prototype of all subsequent computers. Figure 1.7 shows the structure of IAS, consisting of:

- Main memory, stores both data and instruction.
- An arithmetic and logic unit (ALU) capable of operating binary numbers
- A control unit, which interprets the instructions in the main memory and causes them to be executed
- Input and Output (I/O) equipment operated by the control unit.

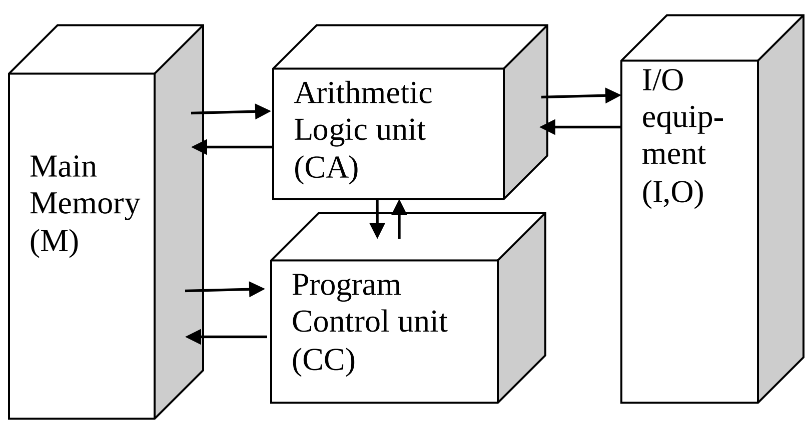

Figure 1.7 Structure of the IAS computer

Commercial Computers

UNIVAC I: (Universal Automatic Computer) was the first commercially manufactured computer by Eckert and Mauchly Computer Corporation (A company formed by Eckert and Mauchly in 1947, later this company become UNIVAC division of Sperry-Rand). This machine was used in the Bureau of Census is 1950 calculation. It was considered as the first successful computer, intended for scientific and commercial applications such as matrix algebra calculation, statistical problems, premium billings of a life insurance company, and logistical problems.

UNIVAC II , which had greater memory capacity and higher performance that UNIVAC I, was delivered in the late 1950s and illustrates several trends that remained in the computer industry.

- First, advances in technology allow companies to continue to build larger, more powerful computers.

- Second, each company tries to make its new machines upward compatible with the older machines.

The UNIVAC division began development of UNIVAC 1100 series of computers, which was to be the major source of revenue. This series illustrates that existed at one time.

IBM in 1955 introduced the companion 702 product, which had a number of hardware features that suited it to business applications. This were the first long series of 700/7000 computers that established IBM as a dominant computer manufacturer.

Second Generation: Transistors

The major change in the electronic computer came with the replacement of the vacuum tube by the transistor.

- The transistor is smaller, cheaper and dissipates less heat than a vacuum tube but has the functionality similar to a vacuum tube.
- It is a solid state device made from silicon, unlike the vacuum tubes that require wire, metal plates and glass capsule.
- The transistor was invented on 1947 in Bell labs, and in 1950's it started an electronic revolution
- NCR (National Cash Register) and RCA (Radio Corporation of America) were the forerunners, followed by IBM (International Business Machines).
- DEC (Digital Equipment Corporation - founded on 1957) delivered the first transistor based computer in 1957, namely the DEC PDP-1

IBM 7094: From the introduction of the 700 series in 1952 to the introduction of the last member of the 7000 series in 1964, the IBM product line underwent an evolution that is typical of computer products. Successive member product lines increased performance, capacity, and lower the cost. Table 1.1 illustrates the trend.

Model Number	First Delivery	CPU Technology	Memory Technology	Cycle Time (µs)	Memory Size (K)	Number of Opcodes	Number of Index Registers	Hardwired Floating-Point	I/O Overlap (Channels)	Instruction Fetch Overlap	Speed (relative to 701)
701	1952	Vacuum tubes	Electrostatic tubes	30	2–4	24	0	no	no	no	1
704	1955	Vacuum tubes	Core	12	4–32	80	3	yes	no	no	2.5
709	1958	Vacuum tubes	Core	12	32	140	3	yes	yes	no	4
7090	1960	Transistor	Core	2.18	32	169	3	yes	yes	no	25
7094 I	1962	Transistor	Core	2	32	185	7	yes (double precision)	yes	yes	30
7094 II	1964	Transistor	Core	1.4	32	185	7	yes (double precision)	yes	yes	50

Table 1.1

Third Generation: Integrated Circuit

A single, self contained transistor is called a discrete component. Throughout the 1950s and early 1960s, electronic equipment was composed largely of discrete components – transistors, resistors, capacitors. Discrete components were manufactured separately, packaged in their own containers, and soldered or together onto a masonite-like circuit boards, which were then installed in computers, oscilloscope, and other electronic equipment. Early second generation computers contained 10,000 transistors, this figure hundreds of thousands making on more powerful machines making it increasingly difficult to manufacture.

In 1958 came the achievement that revolutionized electronics and started the era of microelectronics: the invention of the integrated circuit.

Microelectronics: Microelectronics literally means, "small electronics". Since the beginnings of digital electronics and the computer industry, there has been persistent and consistent reduction of size of digital electronic circuits. The basic elements of a digital computer, as we know, must perform storage, movement, processing, and control functions. Only two types of components are required; gates and memory cell. Gates implements a simple Boolean or logical function. The memory cell is a device that can store one bit of data; that is, the device can be in one of two stable states at any time. Thus we can relate this to our basic function as follows.

- **Data storage:** Provided by memory cells
- **Data processing:** Provided by gates.
- **Data movement:** The path between components are used to move data from the memory to memory and from memory through gates to memory
- **Control:** The paths between components can carry control signals. When the control signal is ON, the gate would perform its function on the data inputs, similarly, the memory cell will store the bit of data when write control is ON.

Thus computers consist of gates, memory cells, and interconnections among these elements. The integrated circuit exploits the fact that such components as transistors, resistors, and conductors can be fabricated from a semiconductor such as silicon. It is merely an extension of the solid-state art to fabricate an entire circuit in a tiny piece of silicon rather than assemble discrete components made from separate pieces of silicon into the same circuit. Thus many transistors can be produced in a single piece of silicon wafer and these transistors can be connected with the process of metallization.

Figure 1.8 depicts the key concepts in an integrated circuit. A thin wafer of silicon is divided into a matrix of small areas, each a few millimeters square. The identical circuit is fabricated in each area, and the wafer is broken up into chips. Each chip consists of many gates and/or memory cells plus number of input and output attachment points. The chip is packaged in housing that protects it and provides pin attachment to the device beyond the chip. Then a number of this chip can be connected into a PCB (printed circuit board) to produce larger and more complex circuits.

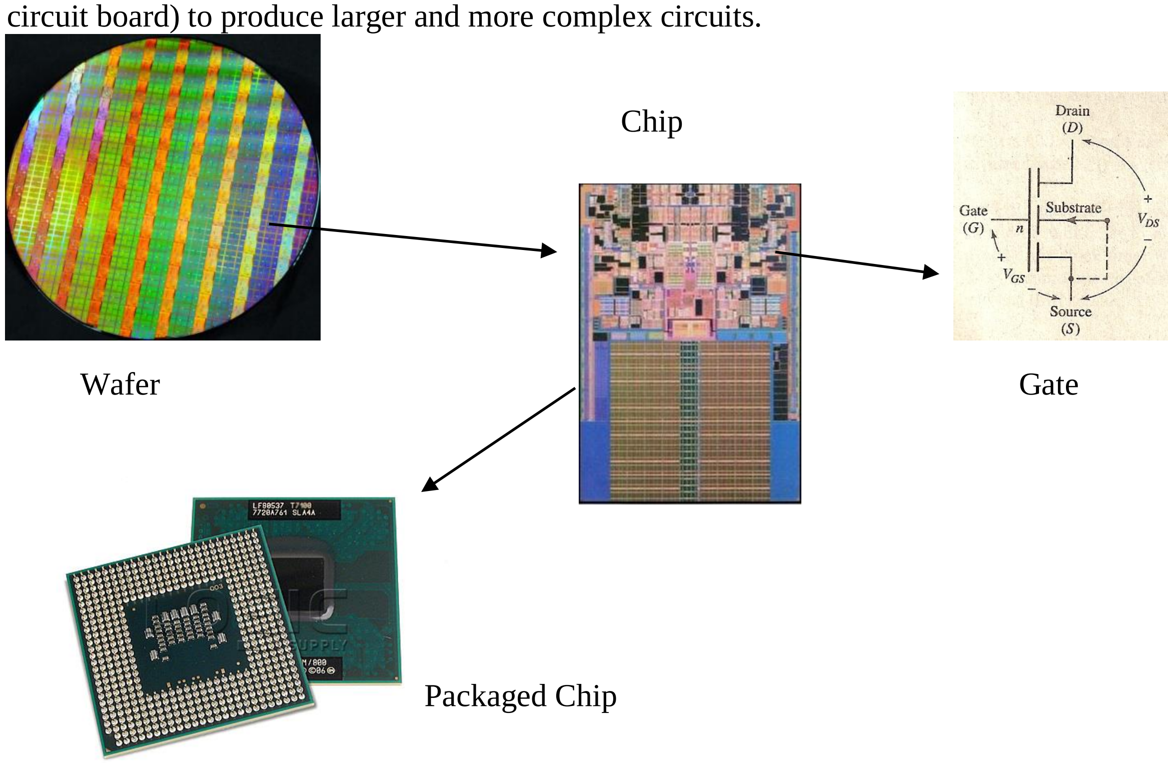

Figure 1.8 Relationships among Wafer, Chip and Gate

As time went on, it become possible to pack more small-scale integration components in a chip. This growth in density is illustrated in Figure 1.9, it is the most remarkable technological trend ever recorded. This figure reflects the Moore’s Law, which was propounded by Gordon Moore, cofounder of Intel. Moore observed that the number of transistors that could be put on a single chip would double each year.

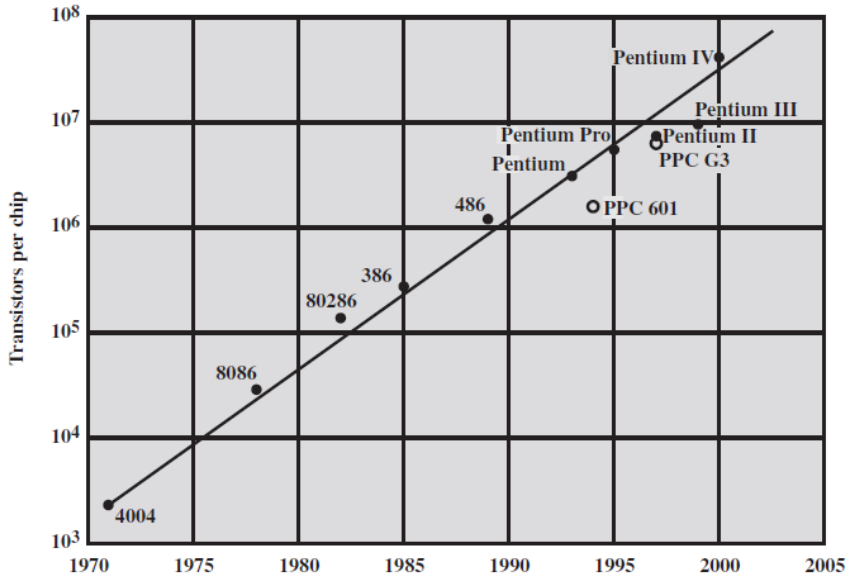

Figure 1.9 Growth in CPU transistor count.

The consequences of Moore's law are profound:

1. The cost of a chip is remained virtually unchanged during the period of rapid growth in density
2. Because logic and memory elements are placed closed together on more densely packed chips, the electrical path length is shortened, increasing operating speed.
3. The computer becomes smaller, making it more convenient to place in a variety of environment
4. There is a reduction in power and cooling requirement
5. The interconnections on the integrated circuit are more reliable than solder components.

IBM System/360: When IBM had a firm grip in the computer market, the released IBM system 360 a successor of IBM 7000 which was not compatible with the older architecture. This was done in order to break out some constraints of the old architecture; therefore IBM's effort pays off by cementing them in the computer industry with 70% share.

The System/360 was the industry's first planned family of computer. The family covered a wide range of performance and cost. Table 1.2 some key characteristics of various models in 1965.

Characteristic	Model 30	Model 40	Model 50	Model 65	Model 75
Maximum memory size (bytes)	64K	256K	256K	512K	512K
Data rate from memory (Mbytes/sec)	0.5	0.8	2.0	8.0	16.0
Processor cycle time µsec)	1.0	0.625	0.5	0.25	0.2
Relative speed	1	3.5	10	21	50
Maximum number of data channels	3	3	4	6	6
Maximum data rate on one channel (Kbytes/sec)	250	400	800	1250	1250

Table 1.2 Key characteristics f the System/360 Family

The concept of a family of compatible computers was both novel and extremely successful, because the characteristic o the family are as follows.

- **Similar or identical instruction set:** The programs that execute on one machine will also execute on any other.
- **Similar or identical operating system:** The same basic operating system is available for all family members.

- **Increasing speed:** The rate of instruction execution increases in going from lower to higher family members
- **Increasing number of I/O ports:** In going lower to higher family members
- **Increasing memory size:** In going lower to higher family members
- **Increasing cost:** In going lower to higher family members

DEC PDP-8: The PDP-8 was dubbed as minicomputer was small enough that it could be placed on top of a lab bench or be built into other equipment. It could not do everything the mainframe could, but at $16,000, it was cheap enough for a lab technician to have one. The low cost and small size of the PDP-8 enabled another manufacturer to purchase a PDP-8 and integrate it into a total system for resale. These other manufacturers come to be known as original equipment manufacturers (OEM), and the OEM market became and remains a major segment of the computer marketplace. DEC paved way for a multi-billion dollar industry.

Later Generations

Beyond the third generation there is less general agreement on defining generations of computers. Table 1.3 suggest that there have been number of later generations, based on advances in integrated circuit technology.

Generation	Approximate Dates	Technology	Typical Speed (operations per second)
1	1946–1957	Vacuum tube	40,000
2	1958–1964	Transistor	200,000
3	1965–1971	Small and medium scale integration	1,000,000
4	1972–1977	Large scale integration	10,000,000
5	1978–1991	Very large scale integration	100,000,000
6	1991-	Ultra large scale integration	1,000,000,000 up

Table 1.3 Computer generations

With the rapid pace of technology, the high rate of introduction of new products and the importance of software and communication as well as hardware, the classification by generations becomes less clear and less meaningful. In the latter part, we would mention two of the most important results

Semiconductor Memory: The first application of integrated circuit technology computers was construction of the processor out of integrated circuit chips. But it was also found that this same technology could be used to construct memories.

In the 1950s and 1960s, most computer memory was constructed from tiny rings of ferromagnetic material, each about a sixteenth of an inch diameter. These rings were strung up on grids of fine wires suspended on small screens inside the computer. Magnetized one way, a ring (called core) represents a one; magnetized to the other way, it stood for zero.

Then in 1970, Fairchild produced the relatively capacious semiconductor memory. This chip, about the size of a single core, could hold 256 bits of memory. It was non destructive and much faster. However the price per bit is much higher than that of core. In 1974, a seminal event occurred: The price per bit of semiconductor memory dropped below the price per bit of core memory. Following this, there has been and rapid decline of memory cost accompanied by a corresponding increase in physical memory density. Since 1970, semiconductor memory has been through 11 generations: 1K, 4K, 16K,

64K, 256K, 1M, 4M, 16M, 64M, 256M, 1G. Each generation has provided four times the storage density of the previous generations, accompanied by declining cost per bit and declining access time.

Microprocessor: Just as the density of elements on memory chips has continued to rise, so has the density of elements of processor chips. As time went on, more and more elements were placed on each chip, so that fewer and fewer chips were needed to construct a single processor computer.

A breakthrough was achieved in 1971, when Intel developed its 4004. The 4004 was the first chip to contain all of the components of a CPU on a single chip: The Microprocessor was born.

The 4004 can add two 4-bit numbers and can multiply only by repeated addition. By today's standard, the 4004 is hopelessly primitive, but it marked the beginning of a continuing evolution of microprocessor capability and power. In the next chapter, a detailed discussion would be aimed on how Intel microprocessor evolved.