PART ONE

1.1 Organization and Architecture

Computer architecture refers to those attributes of a system visible to a programmer or, put another way, those attributes that have a direct impact on the logical execution of a program. A term that is often used interchangeably with computer architecture is instruction set architecture (ISA) . The ISA defines instruction formats, instruction opcodes, registers, instruction and data memory; the effect of executed instructions on the registers and memory; and an algorithm for controlling instruction execution.

Computer organization refers to the operational units and their interconnections that realize the architectural specifications. Examples of architectural attributes include the instruction set, the number of bits used to represent various data types (e.g., numbers, characters), I/O mechanisms, and techniques for addressing memory.

1.2 Structure and Function

A hierarchical system is a set of interrelated subsystems; each subsystem may, in turn, contain lower level subsystems, until we reach some lowest level of elementary subsystem. At each level, the system consists of a set of components and their interrelationships. At each level, the designer is concerned with structure and function:

<u>Structure</u>: The way in which the components are interrelated.
<u>Function</u>: The operation of each individual component as part of the structure.

Function

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

1. Data processing
2. Data storage
3. Data movement.
4. Control

Structure

We now look in a general way at the internal structure of a computer. We begin with a traditional computer with a single processor that employs a microprogrammed control unit, then examine a typical multicore structure.

1. ***SIMPLE SINGLE-PROCESSOR COMPUTER***

   Figure 1.1 provides a hierarchical view of the internal structure of a traditional single-processor computer. There are four main structural components:

   - Central processing unit (CPU):
   - Main memory:
   - System interconnection:

However, for our purposes, the most interesting and in some ways the most complex component is the CPU. Its major structural components are as follows:

- Control unit:
- Arithmetic and logic unit (ALU)
- Registers: Provides storage internal to the CPU.
- CPU interconnection: Some mechanism that provides for communication among the control unit, ALU, and registers

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 microinstructions that define the functionality of the control unit. With this approach, the structure of the control unit can be depicted, as in Figure 1.1..

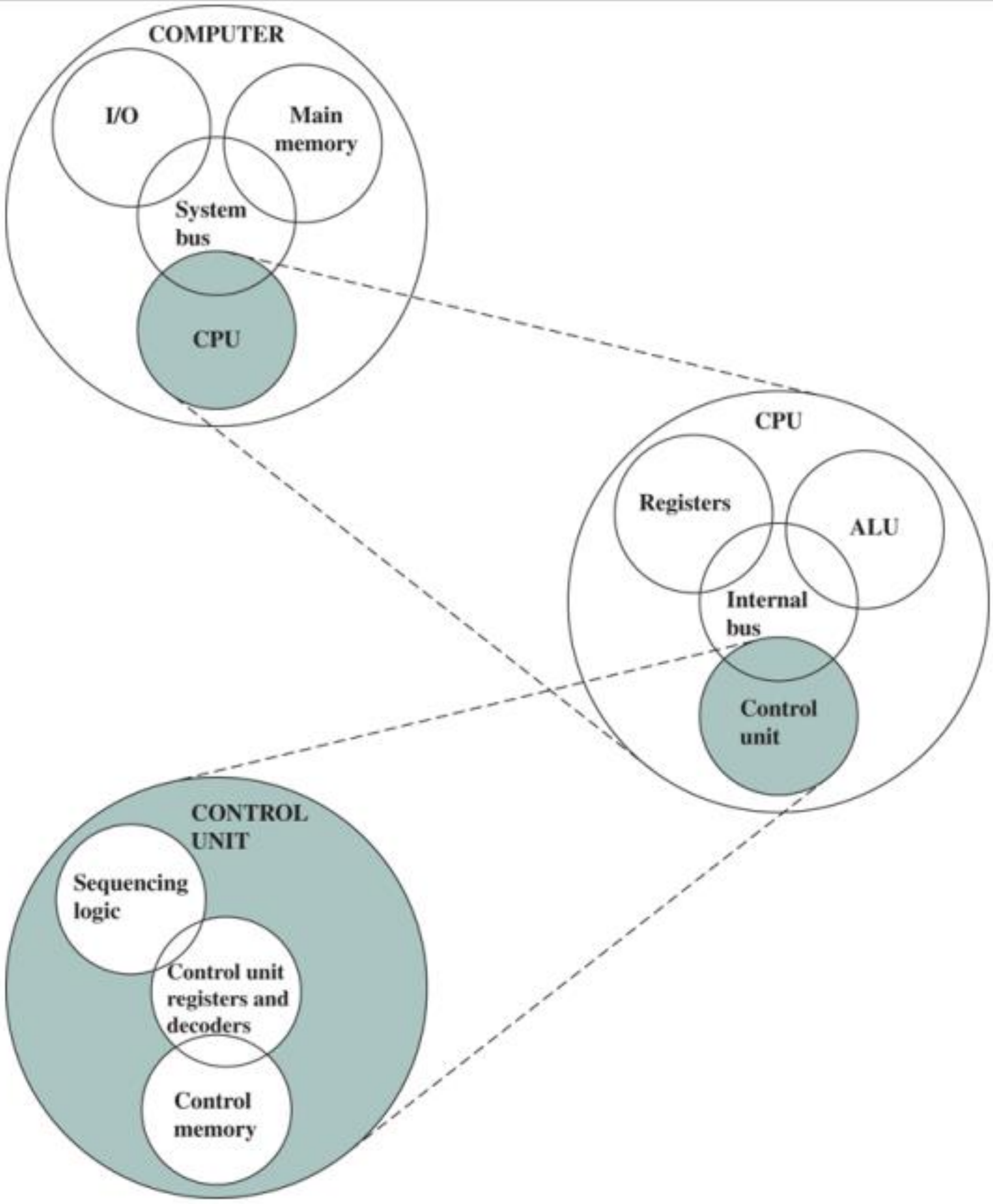


Figure 1.1 The Computer: Top-Level Structure

2. *MULTICORE COMPUTER STRUCTURE*

When these processors all reside on a single chip, the term multicore computer is used, and each processing unit (consisting of a control unit, ALU, registers, and perhaps cache) is called a core.

- Central processing unit (CPU):. It consists of an ALU, a control unit, and registers. In a system with a single processing unit, it is often simply referred to as a *processor*.
- Core: An individual processing unit on a processor chip. A core may be equivalent in functionality to a CPU on a single-CPU system.
- Processor: A physical piece of silicon containing one or more cores. The processor is the computer component that interprets and executes instructions. If a processor contains multiple cores, it is referred to as a multicore processor.

Figure 1.2 is a simplified view of the principal components of a typical multicore computer.

A printed circuit board (PCB) is a rigid, flat board that holds and interconnects chips and other electronic components. The board is made of layers, typically two to ten, that interconnect components via copper pathways that are etched into the board. The main printed circuit board in a computer is called a system board or motherboard, while smaller ones that plug into the slots in the main board are called expansion boards.

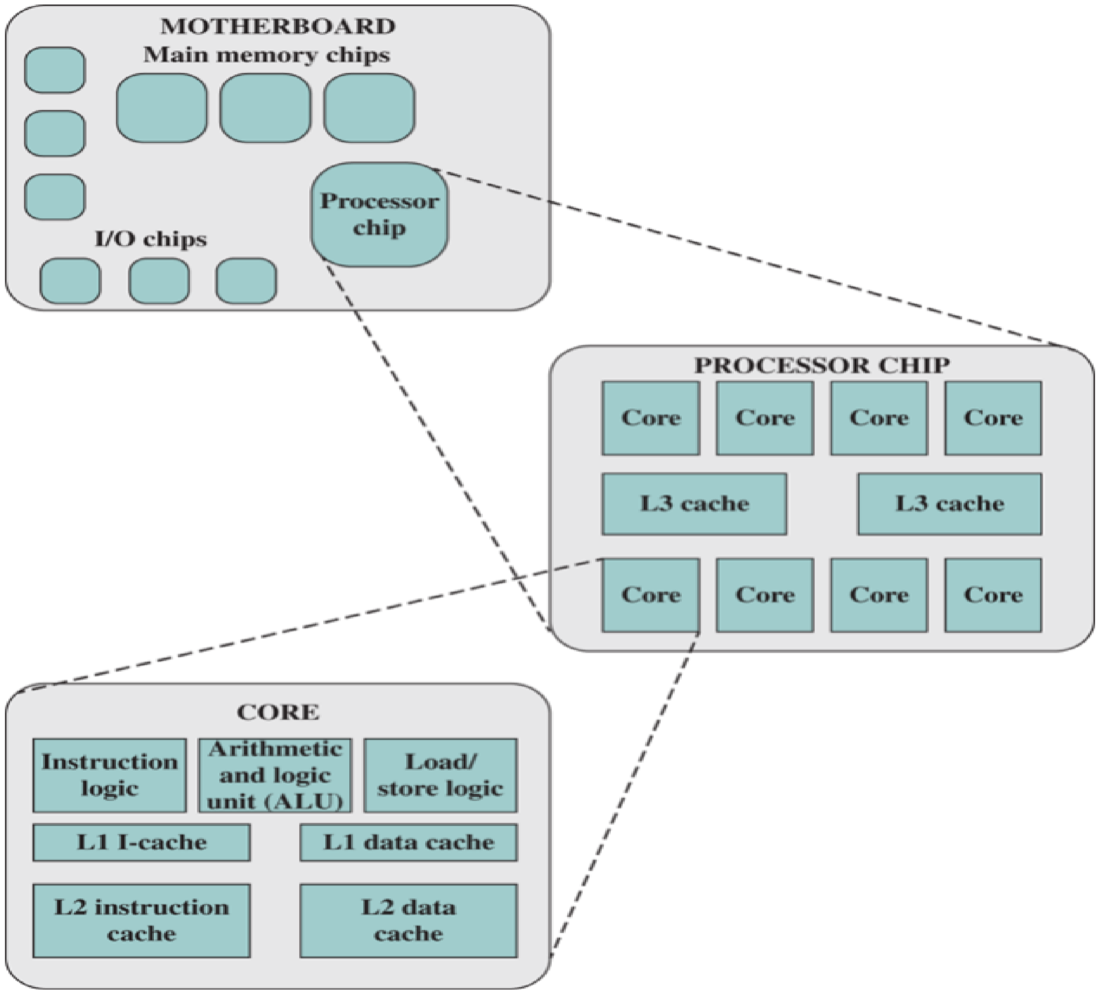


Figure 1.2 Simplified View of Major Elements of a Multicore Computer

The most prominent elements on the motherboard are the chips. A chip is a single piece of semiconducting material, typically silicon, upon which electronic circuits and logic gates are fabricated. The resulting product is referred to as an integrated circuit .

1.3 The Evolution of the Intel x86 Architecture

The current x86 offerings represent the results of decades of design effort on complex instruction set computers (CISCs). The x86 incorporates the sophisticated design principles once found only on mainframes and supercomputers and serves as an excellent example of CISC design. An alternative approach to processor design is the reduced instruction set computer (RISC) . The ARM architecture is used in a wide variety of embedded systems and is one of the most powerful and best-designed RISC based systems on the market. Table 1.1 shows that evolution

	(c) 1990s Processors			
	486TM SX	Pentium	Pentium Pro	Pentium II
Introduced	1991	1993	1995	1997
Clock speeds	16–33 MHz	60–166 MHz,	150–200 MHz	200–300 MHz
Bus width	32 bits	32 bits	64 bits	64 bits
Number of transistors	1.185 million	3.1 million	5.5 million	7.5 million
Feature size (μm)	1	0.8	0.6	0.35
Addressable memory	4 GB	4 GB	64 GB	64 GB
Virtual memory	64 TB	64 TB	64 TB	64 TB
Cache	8 kB	8 kB	512 kB L1 and 1 MB L2	512 kB L2

	(d) Recent Processors				
	Pentium III	Pentium 4	Core 2 Duo	Core i7 EE 4960X	Core i9-7900X
Introduced	1999	2000	2006	2013	2017
Clock speeds	450–660 MHz	1.3–1.8 GHz	1.06–1.2 GHz	4 GHz	4.3 GHz
Bus width	64 bits	64 bits	64 bits	64 bits	64 bits
Number of transistors	9.5 million	42 million	167 million	1.86 billion	7.2 billion
Feature size (nm)	250	180	65	22	14
Addressable memory	64 GB	64 GB	64 GB	64 GB	128 GB
Virtual memory	64 TB	64 TB	64 TB	64 TB	64 TB
Cache	512 kB L2	256 kB L2	2 MB L2	1.5 MB L2/ 15 MB	14 MB L2

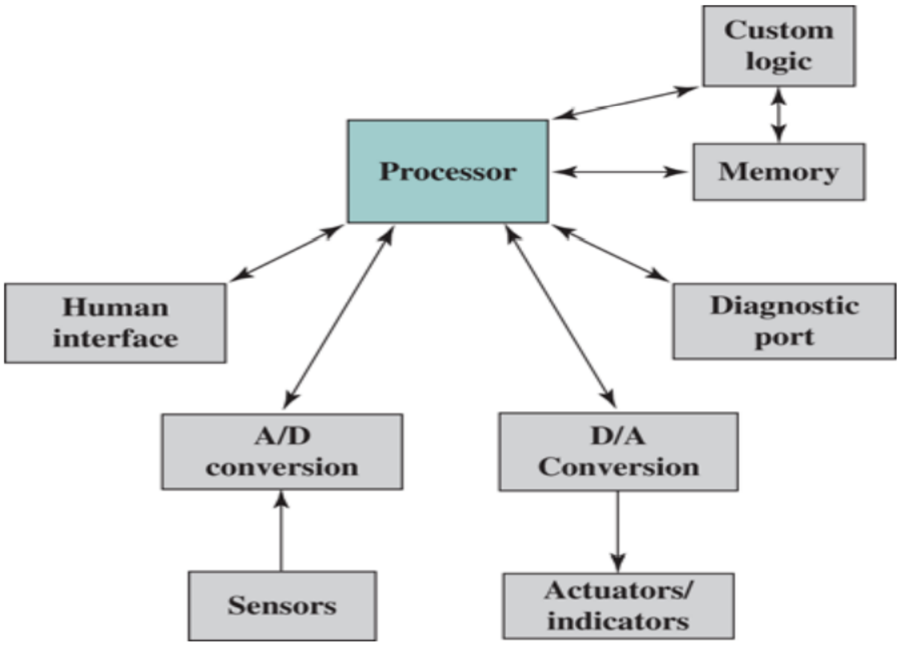
8080: This was an 8-bit machine, with an 8-bit data path to memory. 8080 was used in the first personal computer, the Altair.
8086: is the first appearance of the x86 architecture., 16-bit machine. In addition to a wider data path and larger registers. A variant of this processor, the 8088, was used in IBM's first personal computer, securing the success of Intel.
80386: Intel's first 32-bit machine, and a major overhaul of the product. With a 32-bit architecture. This was the first Intel processor to support multitasking, meaning it could run multiple programs at the same time.
80486: The 80486 introduced the use of much more sophisticated and powerful cache technology and sophisticated instruction pipelining. The 80486 also offered a built-in math coprocessor.
Pentium: With the Pentium, Intel introduced the use of superscalar techniques, which allow multiple instructions to execute in parallel.
Pentium Pro: The Pentium Pro continued the move into superscalar organization begun with the Pentium, with aggressive use of register renaming, branch prediction, data flow analysis, and speculative execution.
Pentium II: The Pentium II incorporated Intel MMX technology, which is designed specifically to process video, audio, and graphics data efficiently.
Pentium III: The Pentium III incorporates additional floating-point instructions: The Streaming SIMD Extensions (SSE) instruction set extension added 70 new instructions designed to increase performance.
Pentium 4: The Pentium 4 includes additional floating-point and other enhancements formultimedia.
Core: This is the first Intel x86 microprocessor with a dual core, referring to the implementation of two cores on a single chip.
Core 2: The Core 2 extends the Core architecture to 64 bits. The Core 2 Quad provides four cores on a single chip. More recent Core offerings have up to 10 cores per chip.

1.4 Embedded Systems

The term embedded system refers to the use of electronics and software within a product, computing systems.
Types of devices with embedded systems are almost too numerous to list. Examples include cell phones, digital cameras, video cameras, calculators, microwave ovens, home security systems, washing machines, lighting systems, thermostats, printers, various automotive systems (e.g., transmission control, cruise control, fuel injection, anti-lock brakes, and suspension systems), tennis rackets, toothbrushes, and numerous types of sensors and actuators in automated systems.

Often, embedded systems are tightly coupled to their environment. This can give rise to real-time constraints imposed by the need to interact with the environment. Constraints, such as required speeds of motion, required precision of measurement, and required time durations, dictate the timing of software operations. If multiple activities must be managed simultaneously, this imposes more complex real-time constraints.

The following figure shows in general terms an embedded system organization. In addition to the processor and memory, there are a number of elements that differ from the typical desktop or laptop computer



. Possible Organization of an Embedded System

Microprocessors versus Microcontrollers

microprocessor chips included registers, an ALU, and some sort of control unit or instruction processing logic. Contemporary microprocessor chips, as shown in Figure 1.2, include multiple cores and a substantial amount of cache memory.

A microcontroller is a single chip that contains the processor, non-volatile memory for the program (ROM), volatile memory for input and output (RAM), a clock, and an I/O control unit. The processor portion of the microcontroller has a much lower silicon area than other microprocessors and much higher energy efficiency. See figure 1.3

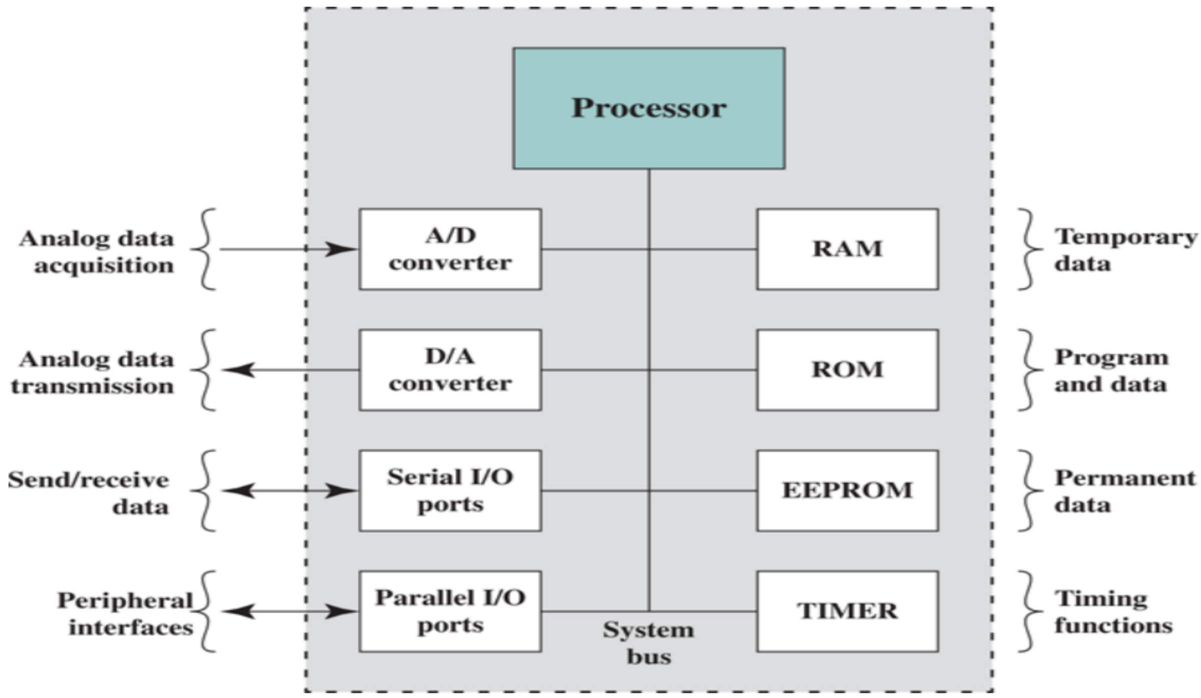


Figure 1.3 Typical Microcontroller Chip Elements

1.5 ARM Architecture

The ARM architecture refers to a processor architecture that has evolved from RISC design principles and is used in embedded systems. ARM is probably the most widely used embedded processor architecture and indeed the most widely used processor architecture of any kind in the world

ARM chips are

- high-speed processors that are known for their small die size
- and low power requirements.
- They are widely used in smartphones and other handheld devices
- ARM chips are the processors in Apple's popular iPod and iPhone devices, and are used in virtually all Android smartphones as well