Computer Organization and Architecture

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Computer Organization and Architecture

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Chapter 01

OVERVIEW

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1. INTRODUCTION

1.1. Computer architecture and computer organization

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- **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.
  - For example, Instruction set, number of bits used for data representation, I/O mechanisms, addressing techniques.
  - An architectural design issue whether a computer will have a multiply instruction

1.1. Computer architecture and computer organization

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- **Computer organization** refers to the operational units and their interconnections that realize the architectural specifications or how features are implemented.
  - For example Organizational attributes include
    - ✓Those hardware details transparent to the programmer, such as control signals; interfaces between the computer and peripherals; and the memory technology used.

1.1. Computer architecture and computer organization

- Historically, and still today, the distinction between architecture and organization has been an important one.
- Many computer manufacturers offer a family of computer models, **all with the same architecture** but with **differences in organization.**
- Consequently, the different models in the family have different **price** and **performance** characteristics.

1.1. Computer architecture and computer organization

- A particular architecture may span many years and encompass a number of different computer models, its organization changing with changing technology.
  - IBM System/370 architecture. This architecture was first introduced in 1970 and included a number of models.
    - ✓Over the years, IBM has introduced many new models with improved technology to replace older models, offering the customer greater speed, lower cost, or both. These newer models retained the same architecture
  - All Intel x86 family share the same basic architecture.

1.2. Structure and Function

- **Structure**
  - is the way in which components relate to each other
- **Function**
  - is the operation of individual components as part of the structure
- The computer system will be described from the top down. We begin with the major components of a computer, describing their structure and function, and proceed to successively lower layers of the hierarchy.

1.2. Structure and Function

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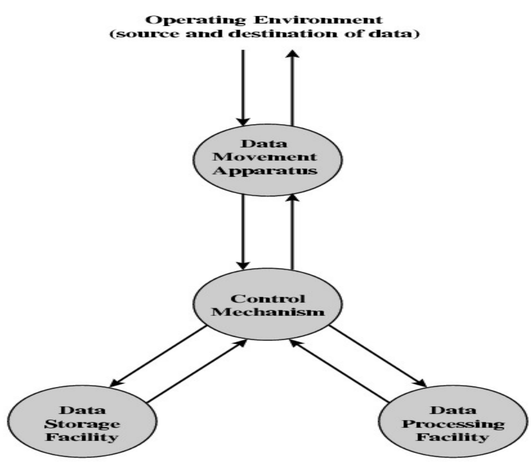

Figure.1.1. A Functional View of the Computer

1.2. Structure and Function

- **Function**
  - Data processing
  - Data storage
  - Data movement
  - Control
- **Data processing**
  - 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.

1.2. Structure and Function

- **Data storage**
  - It is also essential that a computer store data. Even if the computer is processing data on the fly (i.e., data come in and get processed, and the results go out immediately),the computer must temporarily store at least those pieces of data that are being worked on at any given moment.Thus, there is at least a short-term data storage function.
  - Equally important, the computer performs a long-term data storage function. Files of data are stored on the computer for subsequent retrieval and update.

1.2. Structure and Function

- **Data movement**
  - The computer must be able to move data between itself and the outside world.
  - The computer's operating environment consists of devices that serve 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 is known as *input–output* (I/O), and the device is referred to as a *peripheral.*
  - *When data are moved over longer* distances, to or from a remote device, the process is known as *data communications.*

1.2. Structure and Function

- **Control**
  - Finally, there must be control of these three functions. Ultimately, this control is exercised by the individual(s) who provides the computer with instructions.
  - Within the computer, a control unit manages the computer's resources and orchestrates the performance of its functional parts in response to those instructions.

1.2. Structure and Function

- **Structure**
  - The computer interacts in some fashion with its external environment.
  - In general, all of its linkages to the external environment can be classified as peripheral devices or communication lines.

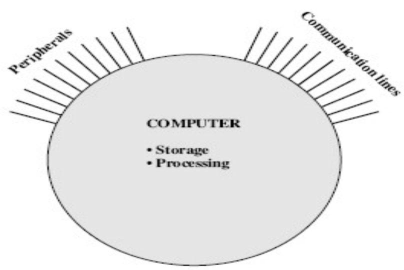

Figure 1.2. The Computer

1.2. Structure and Function

- **Structure**
  - The internal structure of the computer itself, which is shown in Figure 1.3.There are four main structural components.
    - ✓**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.

1.2. Structure and Function

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✓**System interconnection:** Some mechanism that provides for communication among CPU, main memory, and I/O. A common example of system interconnection is by means of a **system bus, consisting of a number of conducting** wires to which all the other components attach.

- There may be one or more of each of the aforementioned components.Traditionally, there has been just a single processor. In recent years, there has been increasing use of multiple processors in a single computer.

1.2. Structure and Function

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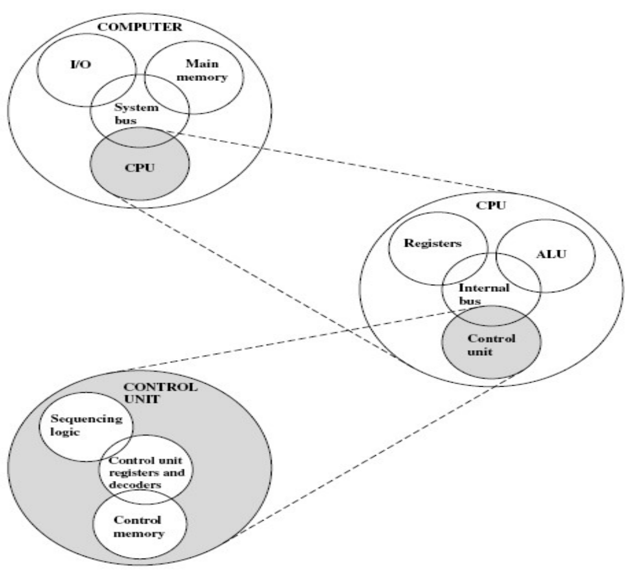

Figure 1.3. The Computer:Top-Level Structure

1.2. Structure and Function

- The most interesting and in some ways the most complex component is the CPU. Its major structural components are as follows:
  - **Control unit**: Controls the operation of the CPU.
  - **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

OVERVIEW

2. Computer Evolution and Performance

2.1. A Brief History of Computers

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- **The First Generation:Vacuum Tubes**
  - ***ENIAC The ENIAC (Electronic Numerical Integrator And Computer),*** *designed* and constructed at the University of Pennsylvania, was the world's first general purpose electronic digital computer.
  - The project was a response to U.S. needs during World War II.
  - John Mauchly and John Eckert
  - Started 1943 and finished 1946. Too late for war effort.
  - Used until 1955

2.1. A Brief History of Computers

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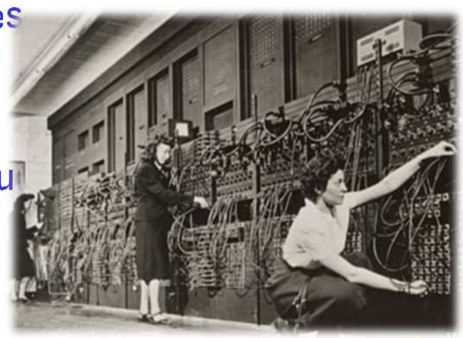
- Decimal (not binary)
- 20 accumulators of 10 digits
- Programmed manually by switches and plugging and unplugging cables.
- 18,000 vacuum tubes
- 30 tons
- 15,000 square feet
- 140 kW power consu
- 5,000 additions per second



2.1. A Brief History of Computers

- von Neumann/Turing
  - entering and altering programs for the ENIAC was extremely tedious
  - A computer could get its instructions 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.*
  - The first publication of the idea was in a 1945 proposal by von Neumann for a new computer, the EDVAC (Electronic Discrete Variable Computer).
  - Alan Turing developed the idea at about the same time

2.1. A Brief History of Computers

- In 1946, von Neumann and his colleagues began the design of a new stored program computer, referred to as the IAS computer, at the Princeton Institute for Advanced Studies.
- The IAS computer, although not completed until 1952, is the prototype of all subsequent general-purpose computers.
- It consists of
  - ✓A main memory, which stores both data and instructions.
  - ✓An arithmetic and logic unit (ALU) capable of operating on binary data
  - ✓A control unit, which interprets the instructions in memory and causes them to be executed.
  - ✓Input and output (I/O) equipment operated by the control unit

2.1. A Brief History of Computers

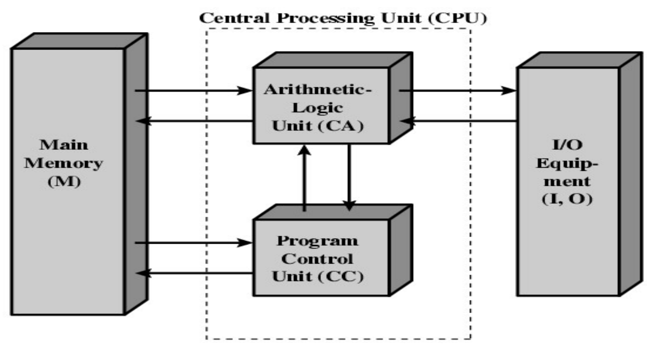


Figure 2.1 Structure of the IAS Computer

- With rare exceptions, all of today's computers have this same general structure and function and are thus referred to as von Neumann machines.

2.1. A Brief History of Computers

- The memory of the IAS consists of 1000 storage locations, called *words, of* 40 binary digits (bits) each.
- Both data and instructions are stored there. Numbers are represented in binary form, and each instruction is a binary code.
- Each number is represented by a sign bit and a 39-bit value.
- A word may also contain two 20-bit instructions, with each instruction consisting of an 8-bit operation code (opcode) specifying the operation to be performed and a 12-bit address designating one of the words in memory (numbered from 0 to 999).

2.1. A Brief History of Computers

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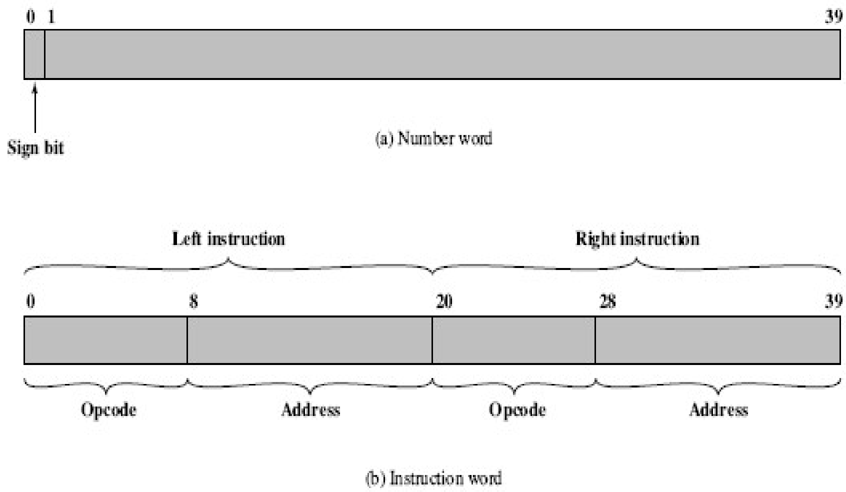

Figure 2.2 IAS Memory Formats

2.1. A Brief History of Computers

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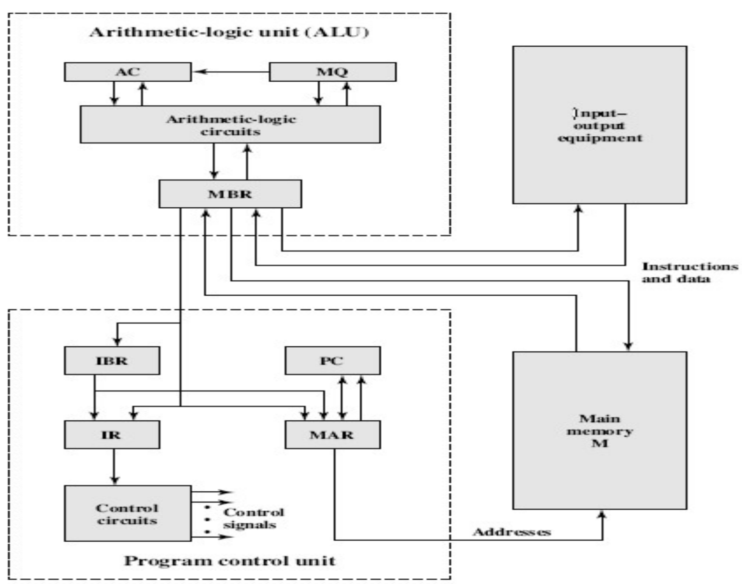

Figure 2.3 Expanded Structure of IAS Computer

2.1. A Brief History of Computers

- Figure 2.3 reveals that both the control unit and the ALU contain storage locations, called *registers, defined as follows:*
  - ✓**Memory buffer register (MBR):** Contains a word to be stored in memory or sent to the I/O unit, or is used to receive a word from memory or from the I/O unit.
  - ✓**Memory address register (MAR):** Specifies the address in memory of the word to be written from or read into the MBR.
  - ✓**Instruction register (IR):** Contains the 8-bit opcode instruction being executed.

2.1. A Brief History of Computers

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- ✓**Instruction buffer register (IBR):** Employed to hold temporarily the right hand instruction from a word in memory.
- ✓**Program counter (PC):** Contains the address of the next instruction-pair to be fetched from memory.
- ✓**Accumulator (AC) and multiplier quotient (MQ):** Employed to hold temporarily operands and results of ALU operations. For example, the result of multiplying two 40-bit numbers is an 80-bit number; the most significant 40 bits are stored in the AC and the least significant in the MQ.

2.1. A Brief History of Computers

Commercial Computers

- The 1950s saw the birth of the computer industry with two companies, Sperry and IBM, dominating the marketplace.
- In 1947, Eckert and Mauchly formed the Eckert-Mauchly Computer Corporation to manufacture computers commercially.
  - Their first successful machine was the UNIVAC I (Universal Automatic Computer), which was commissioned by the Bureau of the Census for the 1950 calculations.
  - The Eckert-Mauchly Computer Corporation became part of the UNIVAC division of Sperry-Rand Corporation, which went on to build a series of successor machines.

2.1. A Brief History of Computers

- IBM, the major manufacturer of punched-card processing equipment, delivered its first electronic stored-program computer, the 701, in 1953.
- 701 was intended primarily for scientific applications.
- In 1955, IBM introduced the companion 702 product, which had a number of hardware features that suited it to business applications.
- These were the first of a long series of 700/7000 computers that established IBM as the overwhelmingly dominant computer manufacturer.

2.1. A Brief History of Computers

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The Second Generation:Transistors

- The first 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 can be used in the same way as a vacuum tube to construct computers.
- Unlike the vacuum tube, which requires wires, metal plates, a glass capsule, and a vacuum, the transistor is a *solid-state device, made from silicon.*

2.1. A Brief History of Computers

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- The transistor was invented at Bell Labs in 1947 and by the 1950s had launched an electronic revolution.
- It was not until the late 1950s, however, that fully transistorized computers were commercially available.

2.1. A Brief History of Computers

- The use of the transistor defines the *second generation of computers. It has become* widely accepted to classify computers into generations based on the fundamental hardware technology employed

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

Figure 2.4. Computer Generations

2.1. A Brief History of Computers

- Each new generation is characterized by greater processing performance, larger memory capacity, and smaller size than the previous one.
- But there are other changes as well.
  - The second generation saw the introduction of more complex arithmetic and logic units and control units
  - The use of highlevel programming languages, and the provision of *system software with the* computer.

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- The second generation is noteworthy also for the appearance of the DigitalEquipment Corporation (DEC). DEC was founded in 1957 and, in that year, delivered its first computer, the PDP-1.
- This computer and this company began the minicomputer phenomenon that would become so prominent in the third generation.

2.1. A Brief History of Computers

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The Third Generation: Integrated Circuits

- 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, and so on.
- Discrete components were manufactured separately, packaged in their own containers, and soldered or wired together onto circuit boards, which were then installed in computers, oscilloscopes, and other electronic equipment.

2.1. A Brief History of Computers

- These facts of life were beginning to create problems in the computer industry. Early second-generation computers contained about 10,000 transistors. This figure grew to the hundreds of thousands, making the manufacture of newer, more powerful machines increasingly difficult.
- In 1958 came the achievement that revolutionized electronics and started the era of microelectronics: the invention of the integrated circuit.
- It is the integrated circuit that defines the third generation of computers.

2.1. A Brief History of Computers

- 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.
- Many transistors can be produced at the same time on a single wafer of silicon. Equally important, these transistors can be connected with a process of metallization to form circuits.

2.1. A Brief History of Computers

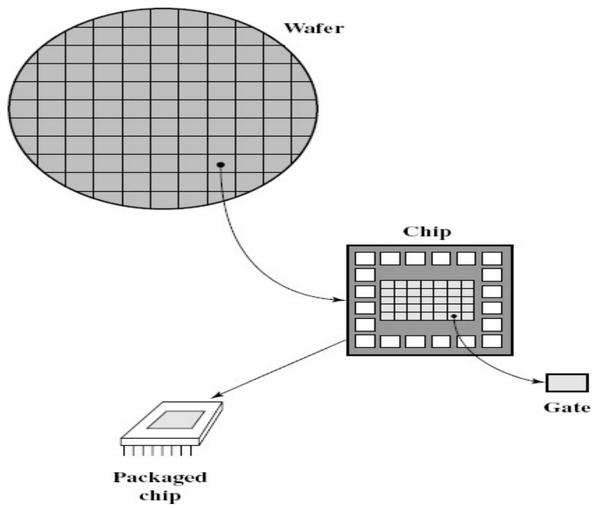

Figure 2.5. Relationship among Wafer, Chip, and Gate

2.1. A Brief History of Computers

Later Generations

- Beyond the third generation there is less general agreement on defining generations of computers.
- Figure 2.4 suggests that there have been a number of later generations, based on advances in integrated circuit technology.
- With the introduction of large scale integration (LSI), more than 1000 components can be placed on a single integrated circuit chip. Very-large-scale integration (VLSI) achieved more than 10,000 components per chip, while current ultra-large-scale integration (ULSI) chips can contain more than one million components.

2.1. A Brief History of Computers

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SEMICONDUCTOR MEMORY

- *The first application of integrated circuit technology* to computers was construction of the processor (the control unit and the arithmetic and logic unit) 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

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  - Each about a sixteenth of an inch in diameter.These rings were strung up on grids
  - Magnetized one way, a ring (called a *core) represented a one; magnetized* the other way, it stood for a zero.
  - Magnetic-core memory was rather fast; it took as little as a millionth of a second to read a bit stored in memory.
- Then, in 1970, Fairchild produced the first relatively capacious semiconductor memory
  - This chip, about the size of a single core, could hold 256 bits of memory.
  - much faster than core, It took only 70 billionths of a second to read a bit.

2.1. A Brief History of Computers

- Since 1970, semiconductor memory has been through 13 generations:
  - 1K, 4K,16K, 64K, 256K, 1M, 4M, 16M, 64M, 256M, 1G, 4G, and, as of this writing, 16 Gbits on a single chip
  - Each generation has provided four times the storage density of the previous generation, accompanied by declining cost per bit and declining access time.

2.1. A Brief History of Computers

MICROPROCESSORS

- *Just as the density of elements on memory chips has continued* to rise, so has the density of elements on 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 computer processor.
- 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.

2.1. A Brief History of Computers

(a) 1970s Processors

	4004	8008	8080	8086	8088
Introduced	1971	1972	1974	1978	1979
Clock speeds	108 kHz	108 kHz	2 MHz	5 MHz, 8 MHz, 10 MHz	5 MHz, 8 MHz
Bus width	4 bits	8 bits	8 bits	16 bits	8 bits
Number of transistors	2,300	3,500	6,000	29,000	29,000
Feature size (μm)	10		6	3	6
Addressable memory	640 Bytes	16 KB	64 KB	1 MB	1 MB

(b) 1980s Processors

	80286	386TM DX	386TM SX	486TM DX CPU
Introduced	1982	1985	1988	1989
Clock speeds	6 MHz–12.5 MHz	16 MHz–33 MHz	16 MHz–33 MHz	25 MHz–50 MHz
Bus width	16 bits	32 bits	16 bits	32 bits
Number of transistors	134,000	275,000	275,000	1.2 million
Feature size (μm)	1.5	1	1	0.8–1
Addressable memory	16 MB	4 GB	16 MB	4 GB
Virtual memory	1 GB	64 TB	64 TB	64 TB
Cache	—	—	—	8 kB

2.1. A Brief History of Computers

(c) 1990s Processors

	486TM SX	Pentium	Pentium Pro	Pentium II
Introduced	1991	1993	1995	1997
Clock speeds	16 MHz–33 MHz	60 MHz–166 MHz,	150 MHz–200 MHz	200 MHz–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 2 Quad
Introduced	1999	2000	2006	2008
Clock speeds	450–660 MHz	1.3–1.8 GHz	1.06–1.2 GHz	3 GHz
Bus sidth	64 bits	64 bits	64 bits	64 bits
Number of transistors	9.5 million	42 million	167 million	820 million
Feature size (nm)	250	180	65	45
Addressable memory	64 GB	64 GB	64 GB	64 GB
Virtual memory	64 TB	64 TB	64 TB	64 TB
Cache	512 kB L2	256 kB L2	2 MB L2	6 MB L2

Figure 2.6. Evolution of Intel Microprocessors

2.2 Designing for Performance (Reference)

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- Performance Balance
  - Processor speed increased
  - Memory capacity increased
  - Memory speed lags behind processor speed

2.2 Designing for Performance (Reference)

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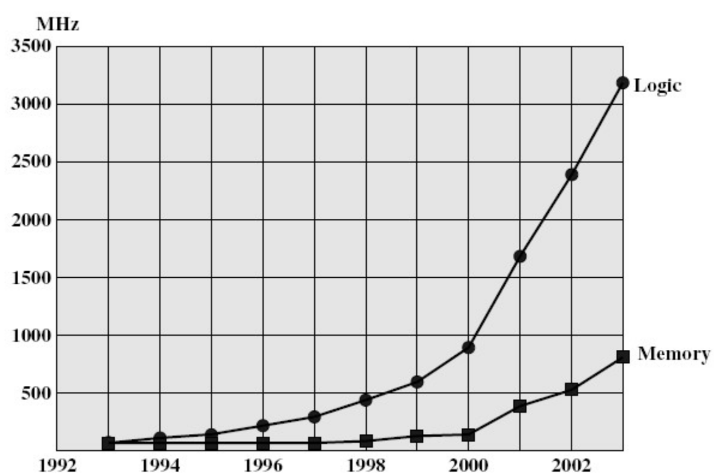

Figure 2.7. Logic and Memory Performance Gap