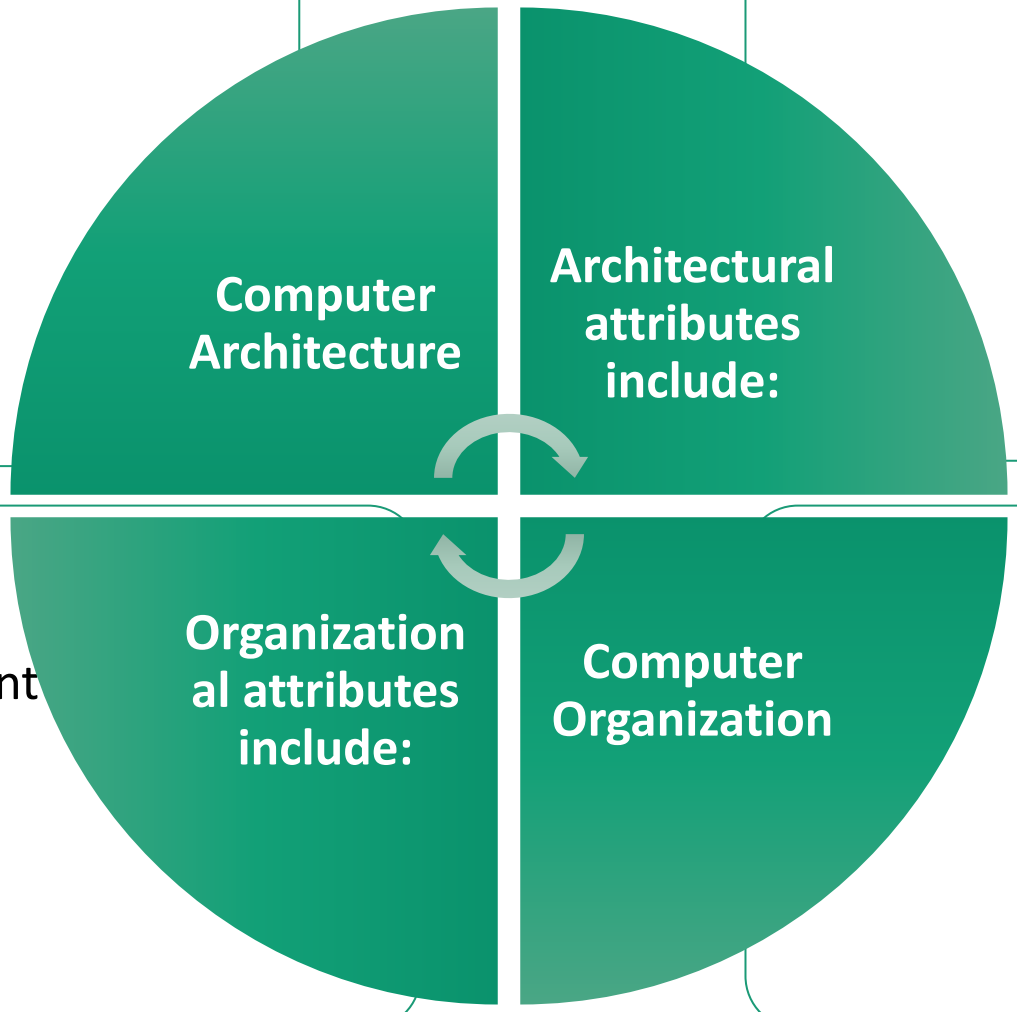
Computer Organization and Architecture

SANTOSH KUMAR VERMA
Mentor
GeeksforGeeks

Basic Concepts and Computer Evolution

Computer Architecture Computer Organization

- Attributes of a system visible to the programmer
- Have a direct impact on the logical execution of a program



- Instruction set, number of bits used to represent various data types, I/O mechanisms, techniques for addressing memory

- Hardware details transparent to the programmer, control signals, interfaces between the computer and peripherals, memory technology used

- The operational units and their interconnections that realize the architectural specifications

Structure and Function

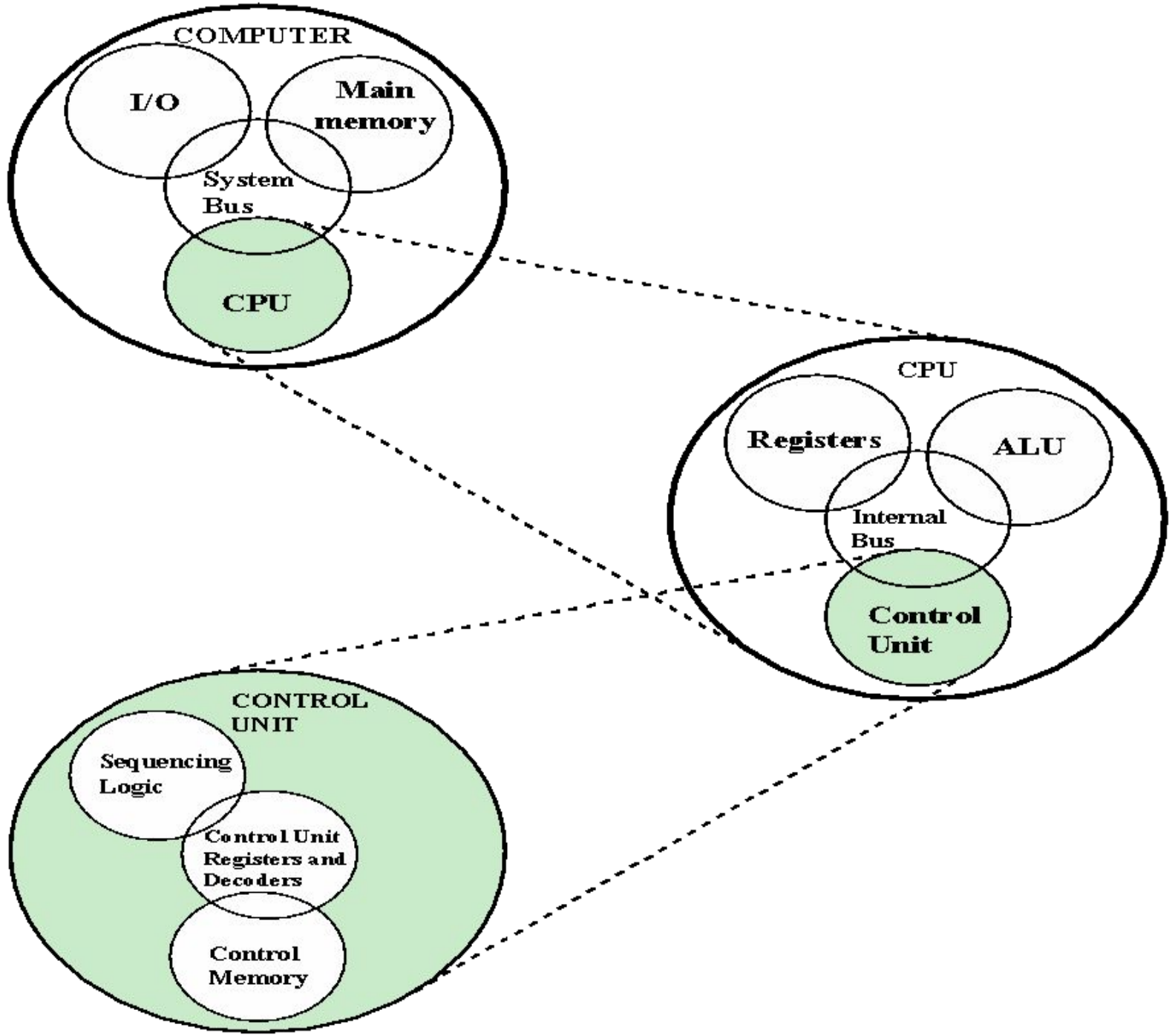
- Hierarchical system
  - Set of interrelated subsystems
- Hierarchical nature of complex systems is essential to both their design and their description
- Designer need only deal with a particular level of the system at a time
  - Concerned with structure and function at each level

- Structure
  - The way in which components relate to each other
- Function
  - The operation of individual components as part of the structure

Function

- There are four basic functions that a computer can perform:
  - **Data processing**
    - Data may take a wide variety of forms and the range of processing requirements is broad
  - **Data storage**
    - Short-term
    - Long-term
  - **Data movement**
    - Input-output (I/O) - when data are received from or delivered to a device (peripheral) that is directly connected to the computer
    - Data communications – when data are moved over longer distances, to or from a remote device
  - **Control**
    - A control unit manages the computer's resources and orchestrates the performance of its functional parts in response to instructions

Structure


COMPUTER
I/O
Main memory
System Bus
CPU
CPU
Registers
ALU
Internal Bus
Control Unit
CONTROL UNIT
Sequencing Logic
Control Unit Registers and Decoders
Control Memory

- CPU – controls the operation of the computer and performs its data processing functions
- 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

CPU

Major structural components:

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

Multicore Computer Structure

- **Central processing unit (CPU)**
  - Portion of the computer that fetches and executes instructions
  - Consists of an ALU, a control unit, and registers
  - Referred to as a processor in a system with a single processing unit
- **Core**
  - An individual processing unit on a processor chip
  - May be equivalent in functionality to a CPU on a single-CPU system
  - Specialized processing units are also referred to as cores
- **Processor**
  - A physical piece of silicon containing one or more cores
  - Is the computer component that interprets and executes instructions
  - Referred to as a *multicore processor* if it contains multiple cores

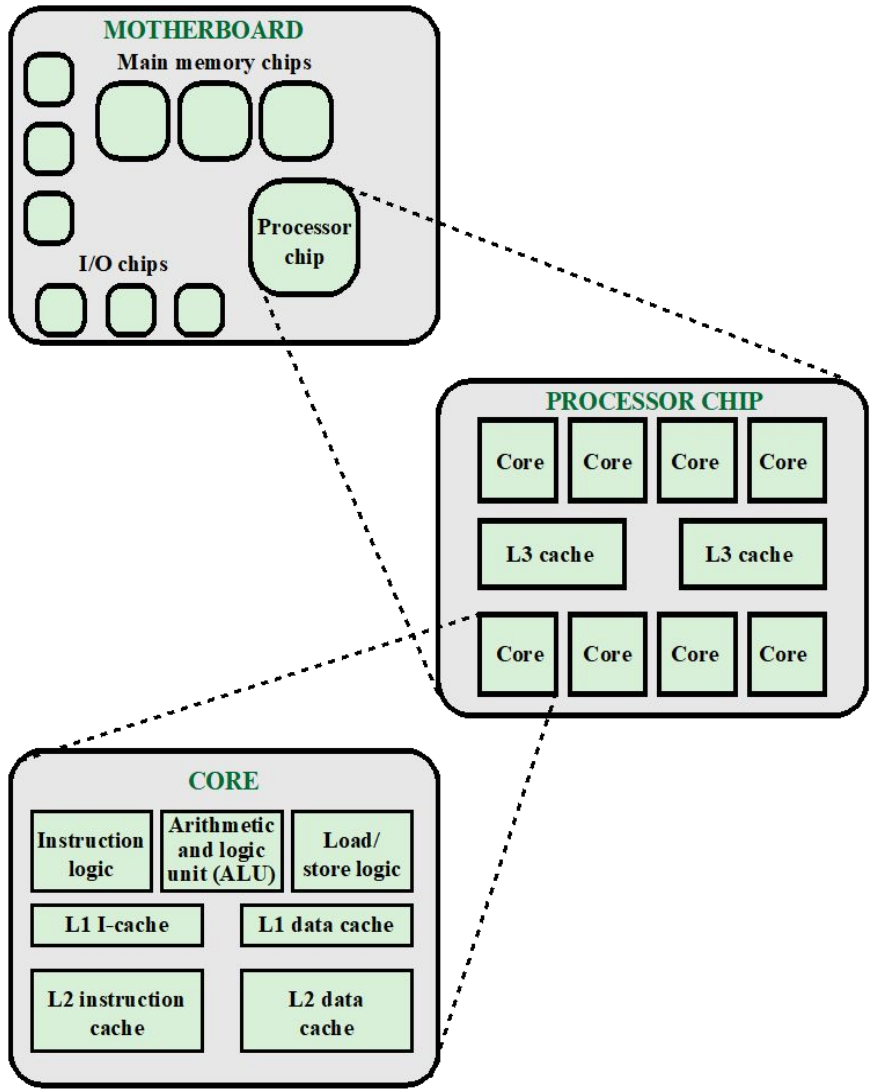


Figure 1.2 Simplified View of Major Elements of a Multicore Computer

Cache Memory

- Multiple layers of memory between the processor and main memory
- Is smaller and faster than main memory
- Used to speed up memory access by placing in the cache data from main memory that is likely to be used in the near future
- A greater performance improvement may be obtained by using multiple levels of cache, with level 1 (L1) closest to the core and additional levels (L2, L3, etc.) progressively farther from the core

History: Computer Generations

Generation	Approximate Dates	Technology	Typical Speed (operations per second)
1	1946–1957	Vacuum tube	40,000
2	1957–1964	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

IAS (Institute for Advanced Studies) computer

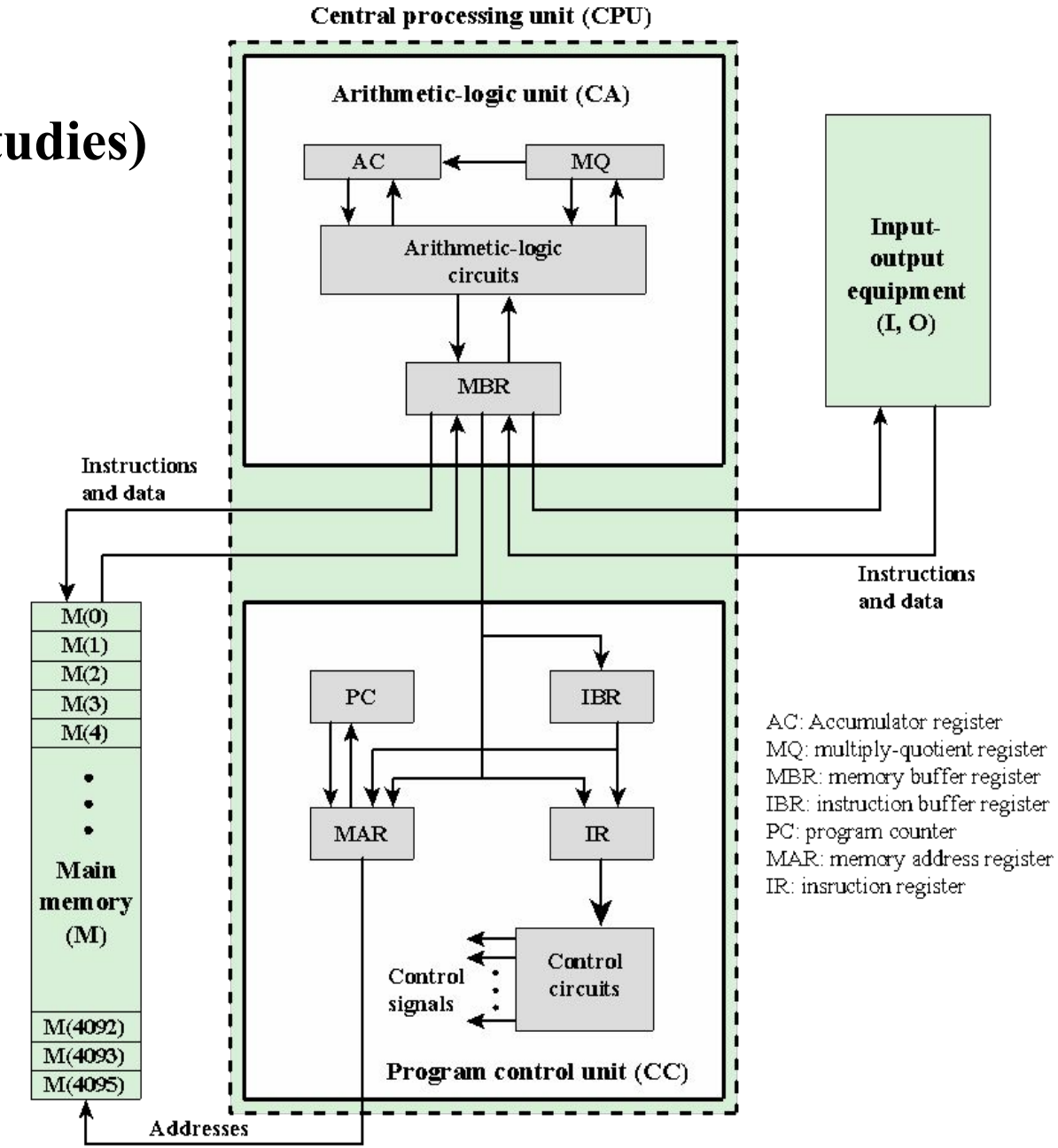
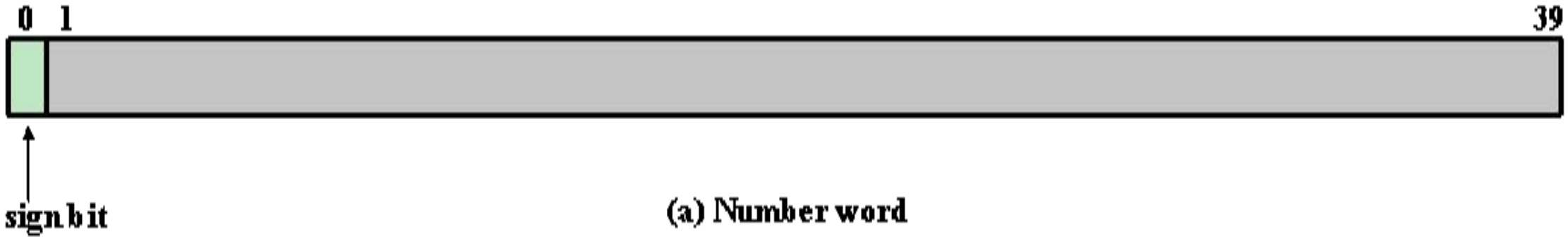


Figure 1.6 IAS Structure



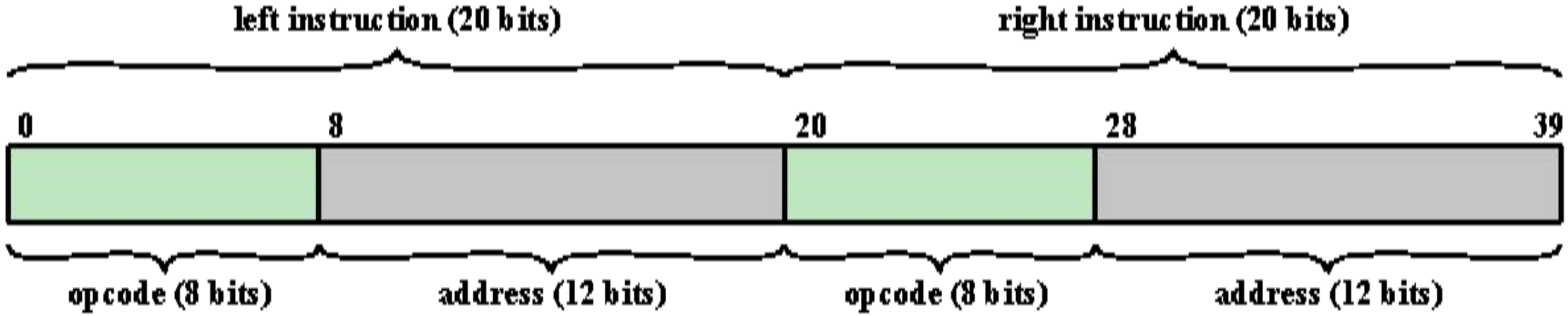
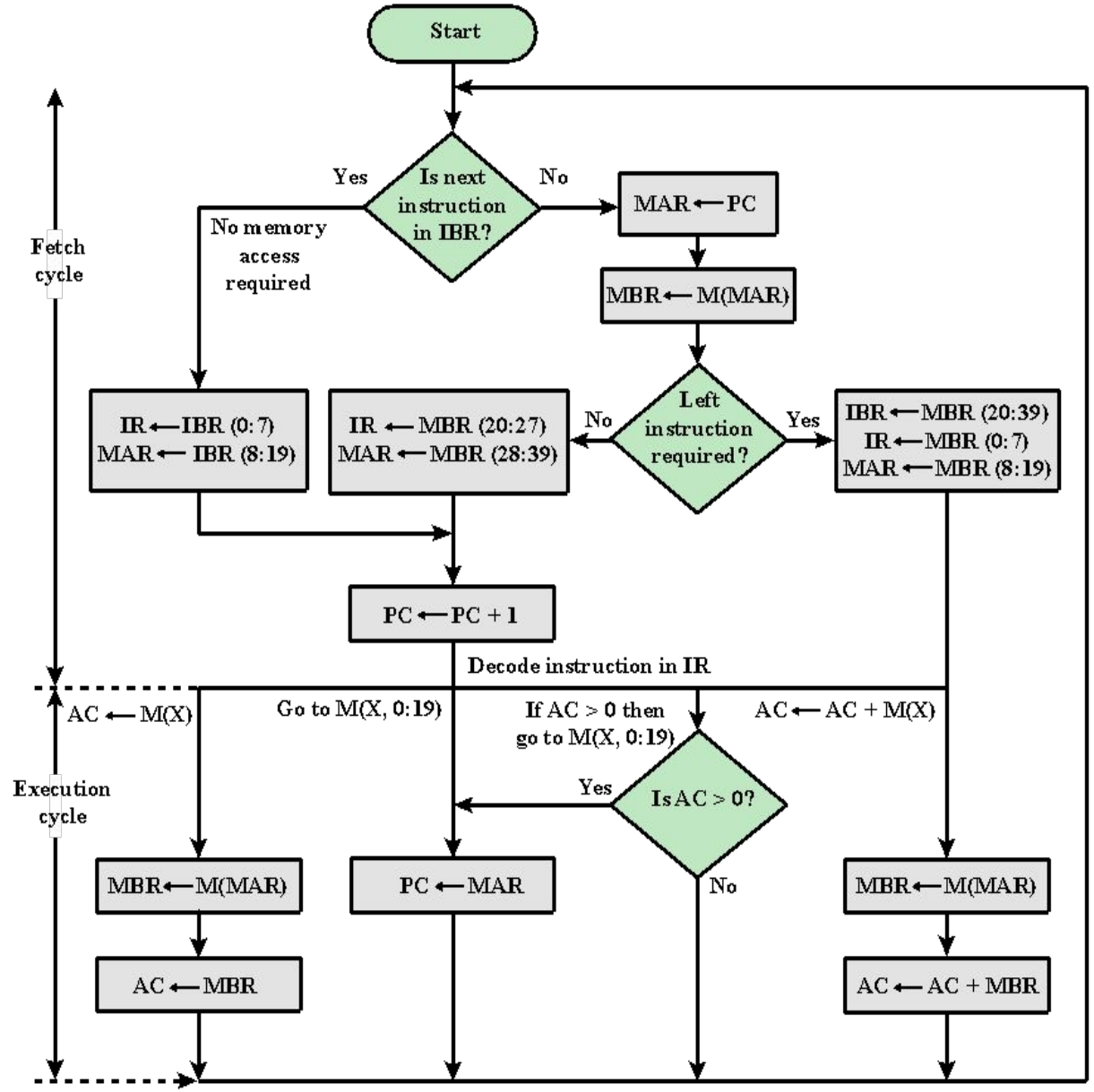


Figure 1.7 IAS Memory Formats

Registers

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
Instruction buffer register (IBR)	• Employed to temporarily hold 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 temporarily hold operands and results of ALU operations



M(X) = contents of memory location whose address is X
(i:j) = bits i through j

Figure 1.8 Partial Flowchart of IAS Operation

Instruction Type	Opcode	Symbolic Representation	Description
Data transfer	00001010	LOAD MQ	Transfer contents of register MQ to the accumulator AC
	00001001	LOAD MQ,M(X)	Transfer contents of memory location X to MQ
	00100001	STOR M(X)	Transfer contents of accumulator to memory location X
	00000001	LOAD M(X)	Transfer M(X) to the accumulator
	00000010	LOAD –M(X)	Transfer –M(X) to the accumulator
	00000011	LOAD |M(X)|	Transfer absolute value of M(X) to the accumulator
	00000100	LOAD –|M(X)|	Transfer –|M(X)| to the accumulator
Unconditional branch	00001101	JUMP M(X,0:19)	Take next instruction from left half of M(X)
	00001110	JUMP M(X,20:39)	Take next instruction from right half of M(X)
Conditional branch	00001111	JUMP+ M(X,0:19)	If number in the accumulator is nonnegative, take next instruction from left half of M(X)
		JUMP + M(X,20:39)	*If number in the accumulator is nonnegative, take next instruction from right half of M(X)*
Arithmetic	00000101	ADD M(X)	Add M(X) to AC; put the result in AC
	00000111	ADD |M(X)|	Add |M(X)| to AC; put the result in AC
	00000110	SUB M(X)	Subtract M(X) from AC; put the result in AC
	00001000	SUB |M(X)|	Subtract |M(X)| from AC; put the remainder in AC
	00001011	MUL M(X)	Multiply M(X) by MQ; put most significant bits of result in AC, put least significant bits in MQ
	00001100	DIV M(X)	Divide AC by M(X); put the quotient in MQ and the remainder in AC
	00010100	LSH	Multiply accumulator by 2; i.e., shift left one bit position
	00010101	RSH	Divide accumulator by 2; i.e., shift right one position
Address modify	00010010	STOR M(X,8:19)	Replace left address field at M(X) by 12 rightmost bits of AC
	00010011	STOR M(X,28:39)	Replace right address field at M(X) by 12 rightmost bits of AC

Table 1.1

The IAS Instruction Set

(Table can be found on page 17 in the textbook.)

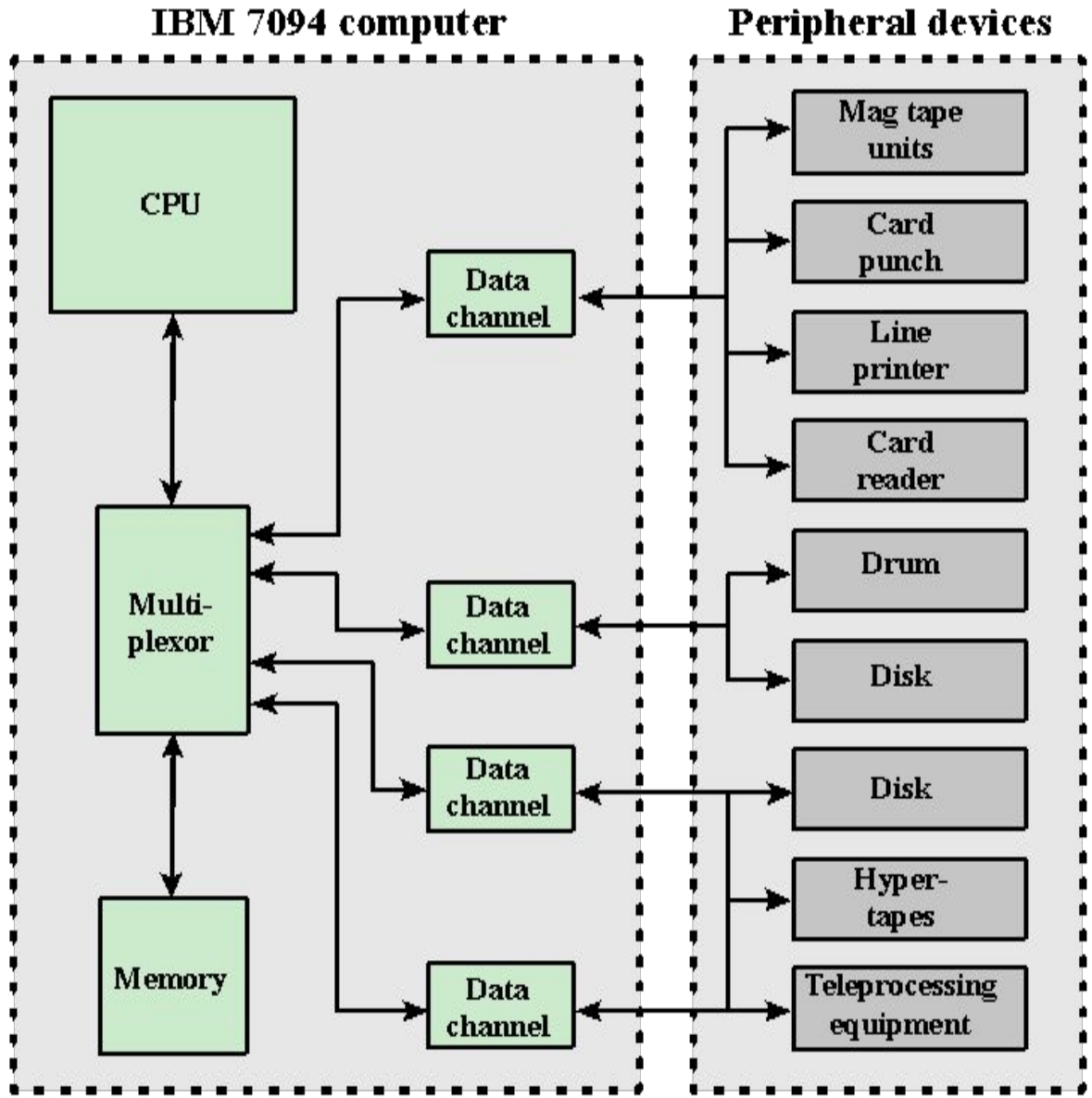


Figure 1.9 An IBM 7094 Configuration

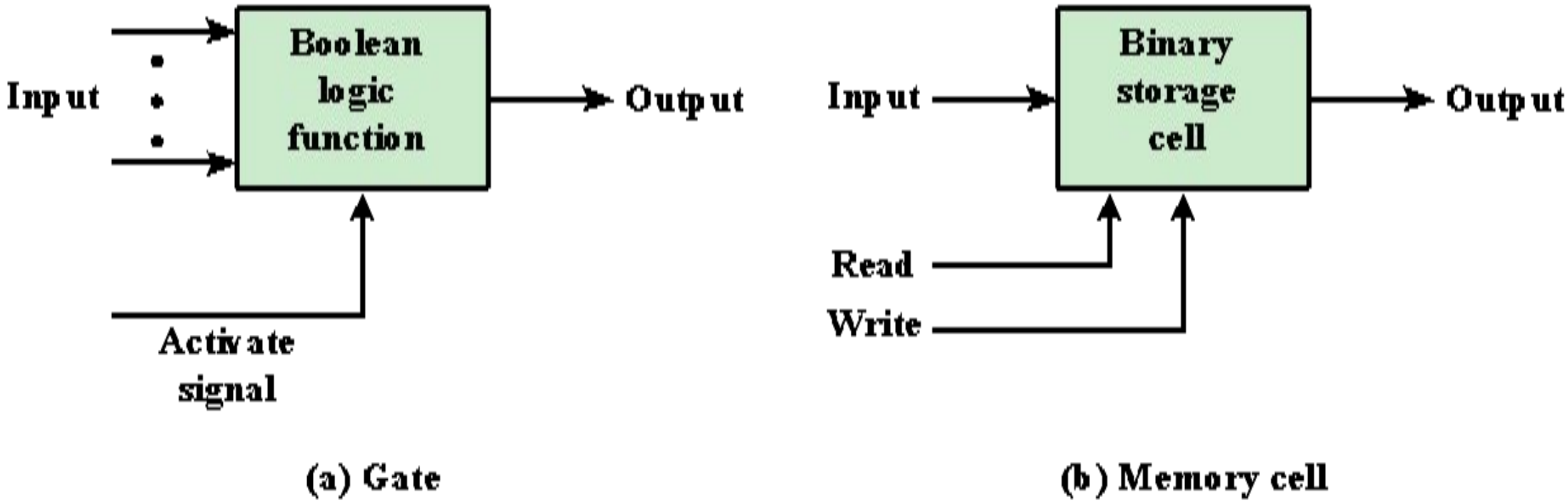


Figure 1.10 Fundamental Computer Elements

Integrated Circuits

- **Data storage** – provided by memory cells
- **Data processing** – provided by gates
- **Data movement** – the paths among components are used to move data from memory to memory and from memory through gates to memory
- **Control** – the paths among components can carry control signals

- A computer consists of gates, memory cells, and interconnections among these elements
- The gates and memory cells are constructed of simple digital electronic components

- Exploits the fact that such components as transistors, resistors, and conductors can be fabricated from a semiconductor such as silicon
- Many transistors can be produced at the same time on a single wafer of silicon
- Transistors can be connected with a processor metallization to form circuits

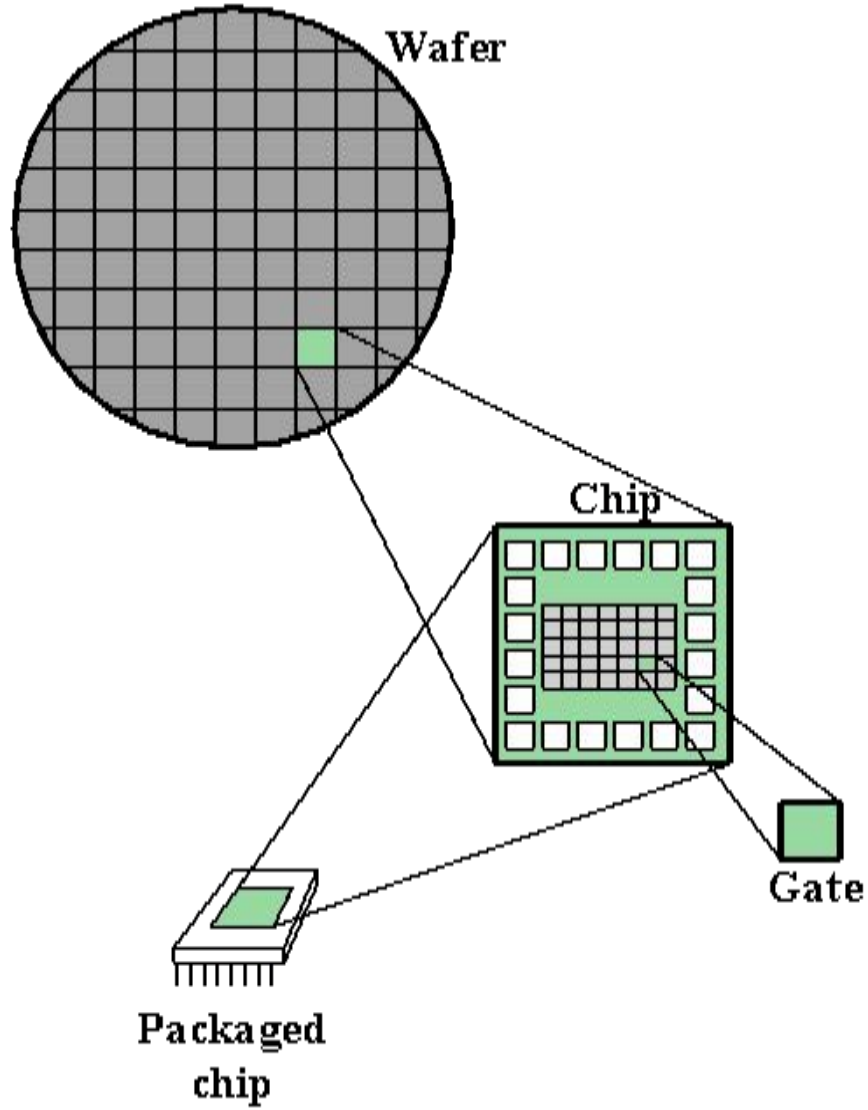


Figure 1.11 Relationship Among Wafer, Chip, and Gate

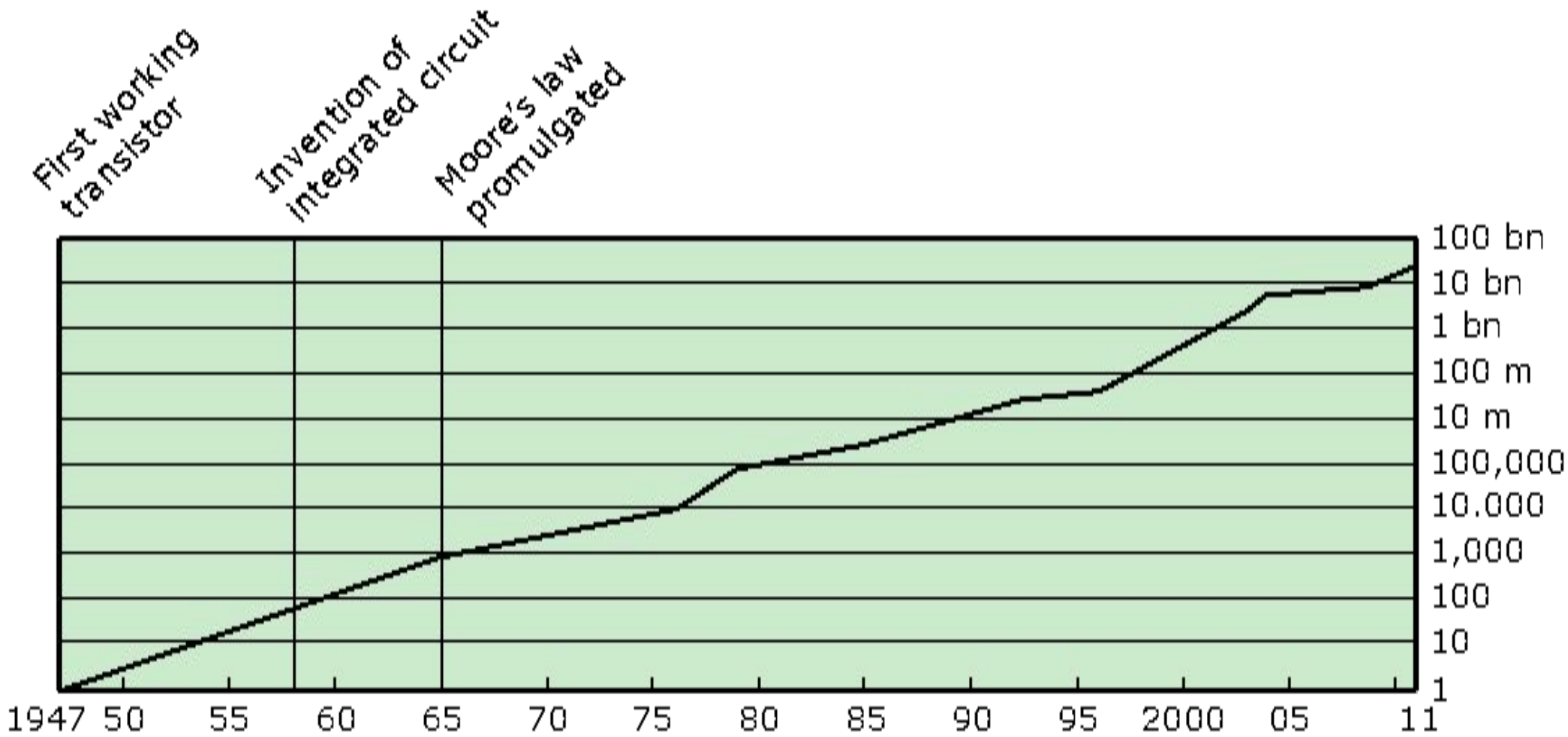


Figure 1.12 Growth in Transistor Count on Integrated Circuits (DRAM memory)

Moore's Law

1965; Gordon Moore – co-founder of Intel

Observed number of transistors that could be put on a single chip was doubling every year

The pace slowed to a doubling every 18 months in the 1970's but has sustained that rate ever since

Consequences of Moore's law:

- **The cost of computer logic and memory circuitry has fallen at a dramatic rate**
- **The electrical path length is shortened, increasing operating speed**
- **Computer becomes smaller and is more convenient to use in a variety of environments**
- **Reduction in power and cooling requirements**
- **Fewer interchip connections**

IBM System/360

- Announced in 1964
- Product line was incompatible with older IBM machines
- Was the success of the decade and cemented IBM as the overwhelmingly dominant computer vendor
- The architecture remains to this day the architecture of IBM's mainframe computers
- Was the industry's first planned family of computers
  - Models were compatible in the sense that a program written for one model should be capable of being executed by another model in the series

Family Characteristics

Similar or identical instruction set

Similar or identical operating system

Increasing speed

Increasing number of I/O ports

Increasing memory size

Increasing cost

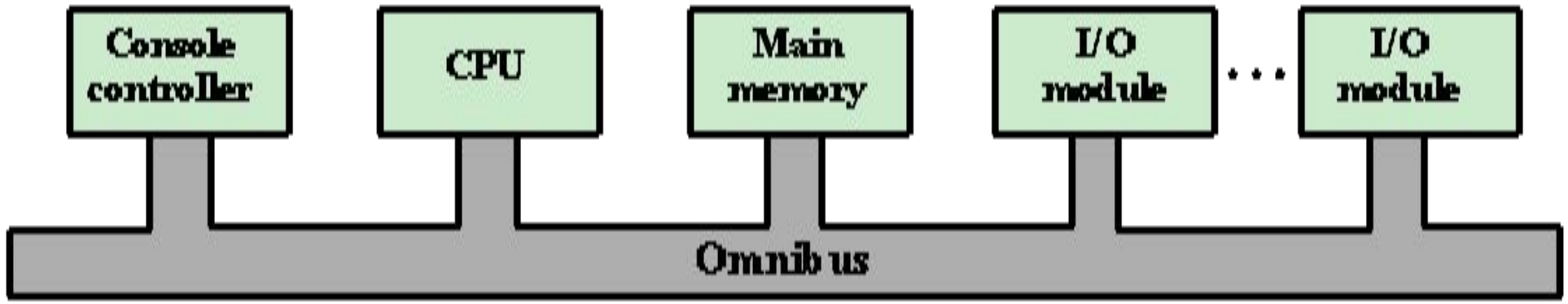


Figure 1.13 PDP-8 Bus Structure

Semiconductor Memory

In 1970 Fairchild produced the first relatively capacious semiconductor memory

- Chip was about the size of a single core
- Could hold 256 bits of memory
- Non-destructive
- Much faster than core

In 1974 the price per bit of semiconductor memory dropped below the price per bit of core memory

- There has been a continuing and rapid decline in memory cost accompanied by a corresponding increase in physical memory density
- Developments in memory and processor technologies changed the nature of computers in less than a decade

Since 1970 semiconductor memory has been through 13 generations

- Each generation has provided four times the storage density of the previous generation, accompanied by declining cost per bit and declining access time

Microprocessors

- The density of elements on processor chips continued to rise
  - More and more elements were placed on each chip so that fewer and fewer chips were needed to construct a single computer processor
- 1971 Intel developed 4004
  - First chip to contain all of the components of a CPU on a single chip
  - Birth of microprocessor
- 1972 Intel developed 8008
  - First 8-bit microprocessor
- 1974 Intel developed 8080
  - First general purpose microprocessor
  - Faster, has a richer instruction set, has a large addressing capability

Evolution of Intel Microprocessors

	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	8	6	3	6
Addressable memory	640 Bytes	16 KB	64 KB	1 MB	1 MB

(a) 1970s Processors

Evolution of Intel Microprocessors

	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

(b) 1980s Processors

Evolution of Intel Microprocessors

	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

(c) 1990s Processors

Evolution of Intel Microprocessors

	Pentium III	Pentium 4	Core 2 Duo	Core i7 EE 4960X
Introduced	1999	2000	2006	2013
Clock speeds	450 - 660 MHz	1.3 - 1.8 GHz	1.06 - 1.2 GHz	4 GHz
Bus width	64 bits	64 bits	64 bits	64 bits
Number of transistors	9.5 million	42 million	167 million	1.86 billion
Feature size (nm)	250	180	65	22
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	1.5 MB L2/15 MB L3
Number of cores	1	1	2	6

(d) Recent Processors

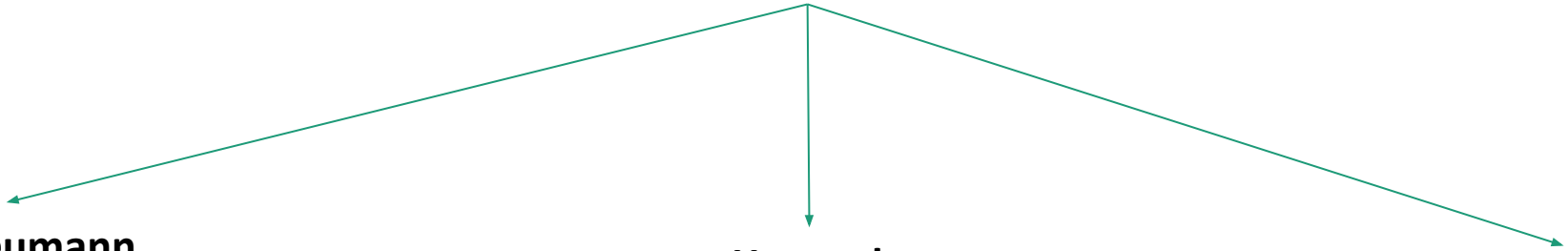
The Evolution of the Intel x86 Architecture

- Two processor families are the Intel x86 and the ARM architectures
- **Current x86** offerings represent the results of decades of design effort on **complex instruction set computers (CISCs)**
- An **alternative approach** to processor design **is the reduced instruction set computer (RISC)**
- **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**

Highlights of the Evolution of the Intel Product Line:

8080	8086	80286	80386	80486
• World's first general-purpose microprocessor • 8-bit machine, 8-bit data path to memory • Was used in the first personal computer (Altair)	• A more powerful 16-bit machine • Has an instruction cache, or queue, that prefetches a few instructions before they are executed • The first appearance of the x86 architecture • The 8088 was a variant of this processor and used in IBM's first personal computer (securing the success of Intel	• Extension of the 8086 enabling addressing a 16-MB memory instead of just 1MB	• Intel's first 32-bit machine • First Intel processor to support multitasking	• Introduced the use of much more sophisticated and powerful cache technology and sophisticated instruction pipelining • Also offered a built-in math coprocessor

Computer Architecture



Von Neumann

- Single Memory, 1 ACC

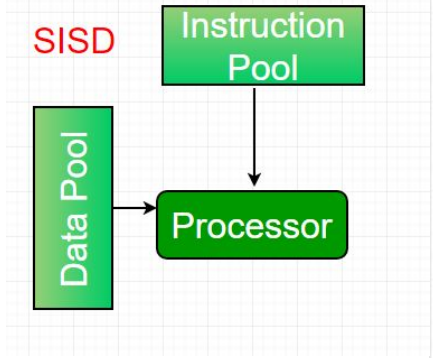
Harvard

- Instruction and Data Memories
- General Purpose Registers

Modified Harvard

- Instruction and Data Memories
- General Purpose Registers
- Cache

Computer Architecture | Flynn's taxonomy



Data Streams \ Instruction Streams	one	many
one	**SISD** traditional von Neumann single CPU computer	**MISD** May be pipelined Computers
many	**SIMD** Vector processors fine grained data Parallel computers	**MIMD** Multi computers Multiprocessors
	1 CU : N ALU	M CU : M ALU