2 Hardware

Chapter Objectives

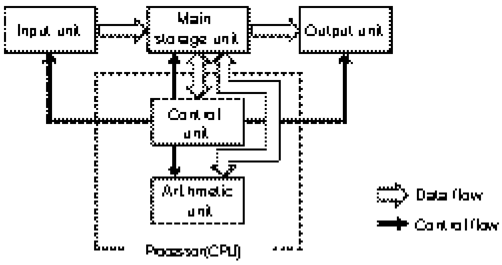
Among computer related technology, the progress of hardware technology is particularly remarkable.
In this chapter, the learning objective is to understand the mechanism and functions of each of the five main units that are basic to computer hardware. To:

① Understand the roles and functions of the computer's five main units,
② Understand the basic operations and the registers used to read, decode and execute the instructions and data stored in the main storage unit by the processor (processing unit), which is composed of the control unit and the arithmetic unit,
③ Understand the basic approach and configuration circuits of the arithmetic unit that performs arithmetic operations and logical operations,
④ Understand the mechanism and functions of the main storage unit and the auxiliary storage devices used to store data, and know their types and characteristics,
⑤ Understand the types and mechanism of the input/output units as well as the input/output control system and the input/output interface,
⑥ Understand computer types and characteristics.

Introduction

The functions of the hardware composing a computer can be divided broadly into the following five categories:
· Input
· Storage
· Operation
· Control
· Output
The following are the units that implement the above-mentioned functions:
· Input unit: This unit inputs the data and programs for computer processing. It is equivalent to the human eyes and ears.
· Storage unit: This unit stores the input data and programs. It is equivalent to the memory section of the human brain.
· Arithmetic unit: This unit conducts calculation and decision on the stored data according to the instructions of the program. It is equivalent to the thinking section of the human brain.
· Control unit: This unit controls the input unit, storage unit, arithmetic unit and the output unit. It is equivalent to the human central nervous system.
· Output unit: This unit outputs the results of computer processing in a format that can be understood by humans. It is equivalent to the human hands and mouth.
These five units are called the "computer five main units" (Figure 2-1-1).
Since the control unit and the arithmetic unit are handled as one unit, they are called the processor (processing unit) or central processing unit (CPU). The general term "peripheral devices" is used to refer to the input unit, the output unit and the auxiliary storage devices that are outside the processor and exchange data with the main storage unit. Likewise, the storage units are divided into main storage unit and auxiliary storage device, depending on their functions.

Figure 2-1-1
Computer five main units



2.1 Information element

2.1.1 Integrated circuit

In today's computers, an integrated circuit (IC) that integrates semiconductors to a high level is used. According to the integration level, ICs are classified as in Figure 2-1-2.

Figure 2-1-2
IC classification according to their integration level

IC	Integration level
SSI (Small Scale Integration)	10^1–10^2
MSI (Medium Scale Integration)	10^2–10^3
LSI (Large Scale Integration)	10^3–10^4
VLSI (Very Large Scale Integration)	10^5–

Note: The integration level indicates the range of the number of gates (number of transistors) contained in 1 IC.

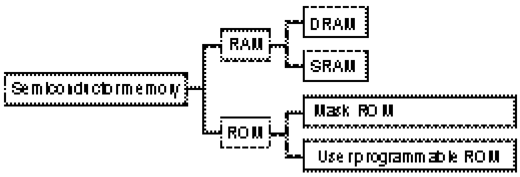
Likewise, according to their structure, ICs can be classified as follows:

- Bipolar IC: The speed and power requirements, as well as the costs, are high. It is used as a logic element.
- CMOS IC: The speed and power requirements, as well as the costs, are low. It is used as a storage element.

2.1.2 Semiconductor memory

Logic elements are used in logical operations while storage elements are used in data and instruction storage. Here the storage elements will be explained. (The logical circuit will be explained in detail in the next section, 2.2.) The storage element is called semiconductor memory (or IC memory) and is broadly divided into RAM and ROM.

Figure 2-1-3
RAM and ROM



(1) RAM (Random Access Memory)

A RAM is semiconductor memory in which data writing and reading is possible. When the computer is turned off, the stored data is lost. This property is called volatility. Since most main storage units are composed of RAMs, the processor can be made to read and write information from the main storage unit at random by specifying the address.
RAMs are classified into DRAMs and SRAMs.

① DRAM (Dynamic RAM)

A DRAM represents bits, and stores information depending on whether the part called capacitor is being charged (status "1") or is not being charged (status "0").
Since the circuits are simple and small, RAMs of large capacity can be created at low cost. However, since the charge stored in the capacitor is lost after a lapse of time, the memory needs to be rewritten (recharged) at regular intervals. This operation is called refreshing. Once, DRAMs were used in the main storage unit, but currently they are also used in storage units, etc., contained in the input/output units of printers and other devices.

② SDRAM (Synchronous DRAM)

Due to the progress of IC technology, and the consequent substantial improvement of the performance of processors, the operating speed of the DRAMs that composed the storage unit could not keep up with the operating speed of the processors. For that reason, an external clock signal that indicates the processor operation timing is now set in the DRAM and through synchronization with this signal, complicated address specifications are reduced and simplified, enabling the development of DRAMs that operate at high speeds. These types of DRAMs are called synchronous DRAMs (SDRAM).

③ SRAM (Static RAM)

SRAMs are created with a circuit called the flip-flop. The flip-flop settles the output according to the previous input and the current input, and can preserve the status "1" and "0" inside the circuit. Since data is not lost unless the computer is turned off, memory refreshing is not necessary. However, since SRAM circuits are complicated, the memory capacity is smaller than that of DRAMs and the cost is higher. However, since its processing speed is high, it is used in devices such as the registers contained in main storage units and processors.

(2) ROM (Read Only Memory)

The ROM is semiconductor memory for read use only. Since programs and data are stored in the ROM from the beginning, the stored information is not lost even if the computer is turned off. This property is called nonvolatility.
ROMs are classified into mask ROMs and user programmable ROMs.

① Mask ROM

Since programs and data are already written in the Mask ROM before it is shipped by the manufacturer, the user cannot add any programs or data. Mask ROMs are used in the memories of game cassettes and IPL (Initial Program Loader), a program used to start the computer, etc.

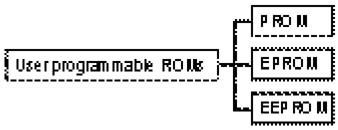
② User programmable ROM

The user programmable ROM is a type of ROM, but since at the time it is shipped by the manufacturer it has nothing stored in it, the user can write data into it once. The following types of user programmable ROM exist (Figure 2-1-4).

- PROM (Programmable ROM): Once data has been written, it cannot be erased.
- EPROM (Erasable PROM): It can be erased with ultraviolet light and rewritten.
- EEPROM (Electrically Erasable PROM): It can be erased through the application of electrical voltage and rewritten.

EEPROM is used in a storage medium called flash memory, which is used in the registration of image data of digital cameras, etc. Likewise, it is also used in the storage section of IC cards, etc.

Figure 2-1-4
User programmable ROMs



2.2 Processor architecture

2.2.1 Processor structure and operation principles

(1) Processor structure

Among the five main units that compose a computer, the control unit and the arithmetic unit are handled as one unit and are called processor (processing unit). The processor is also called central processing unit (CPU), and as the backbone of the computer, it plays the important roles indicated below.

① Control unit

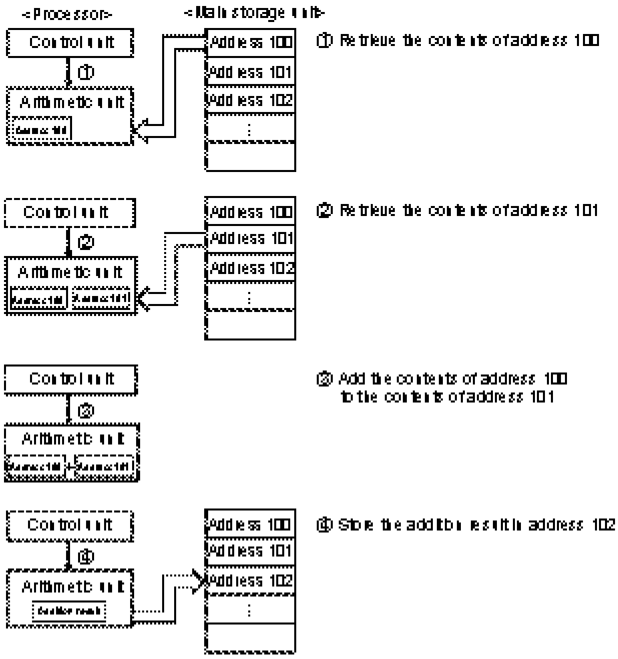
The control unit is the unit that controls all the operations of the computer. It retrieves, decodes and executes, one by one, in order, the instructions stored in the main storage unit.
The following are the main functions of the control unit:

- Retrieval of the instructions stored in the main storage unit
- Decoding of the retrieved instructions using the instruction decoder
- According to the decoding, transmission of the specifications required for the execution of the instructions to each unit

Through the repetition of these operations, the control unit controls each unit, and implements the functions of each of the units as a computer system. The system by which instructions are executed in this way, one by one, is called the sequential control system. The design of this sequential control system and the stored program system (Please refer to main storage unit in 2.3.1) was based on the concepts of

John von Neumann. Computers of this kind are called Neumann computers.
In Figure 2-2-1, as an example to explain the mechanism of the sequential control system, the process of the "addition of the contents of address 100 and the contents of address 101 and the storage of the result in address 102" is represented.

Figure 2-2-1
Mechanism of the sequential control system



② Arithmetic unit

The official name of the arithmetic unit is arithmetic and logic unit (ALU). This unit performs arithmetic operations, logical operations, comparison, branch, and other processes on the data assigned to be subject to processing. The main instructions are shown in Figure 2-2-2.

Figure 2-2-2
Functions of the arithmetic unit

Basic operations	Basic instructions
Arithmetic operations	Addition, subtraction, multiplication and division
Logical operations	Logical sum (OR), logical product (AND), negation (NOT)
Comparison	Comparison instruction (size comparison)
Branch	Branch instruction (change of the sequence of instruction execution according to the conditions)

Depending on the representation method of data assigned to be subject to operations, arithmetic and logic unit has functions performing fixed point operation, floating point operation, and decimal operation.

(2) Processor operation principles

① Instruction readout and decoding

The data and programs retrieved from the main storage unit are transferred to the processor through the data bus. Then the data subject to processing is temporarily stored in the "general-purpose register," while a part of the program indicating the procedure of the process is transferred to the "instruction register."

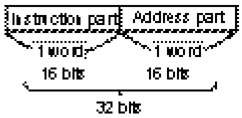
a. Instruction and instruction format

- Instruction
  The program is a set of instructions that indicates "do …" to the computer. Since inside the computer, data is represented in the binary system, instructions are also represented in the binary system. The instructions represented in the binary system are called machine language instructions. Regardless of

the program language in which a program is written, at the end it is converted into language that can be understood by the computer, machine language, in order to be decoded and executed. Machine language instructions and instruction formats differ depending on the computer, but, in general terms, they are composed of the following parts.

- **Instruction part:** Indicates instructions and operations
- **Address part:** Specifies the address and register of the main storage unit subject to processing

Figure 2-2-3
Example of the instruction structure



● Instruction format

In practice, instruction formats differ depending on the computer. There are instructions that have several address parts, and according to the structure of the address part, there are four address formats, from zero-address format to three-address format.

- **Zero-address format**

The zero-address format performs operations using a dedicated register called a stack pointer. Currently, zero-address format computers are not used. The stack pointer is the register that stores the address to be returned to (return address) after execution completion.

Figure 2-2-4 Zero-address format

- **Single-address format**

The single-address format performs operations between the content of the main storage unit specified in the address and the accumulator data (Figure 2-2-5). The accumulator stores operation values and operation results. There are cases where general-purpose registers are also used as accumulators.

Figure 2-2-5 Single-address format

- **Two-address format**

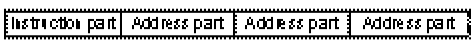
The two-address format specifies two addresses and uses the address data specified on the main storage unit.

Figure 2-2-6 Two-address format

- **Three-address format**

The three-address format specifies two addresses to be used for the operation, and the address where the operation result is to be stored.

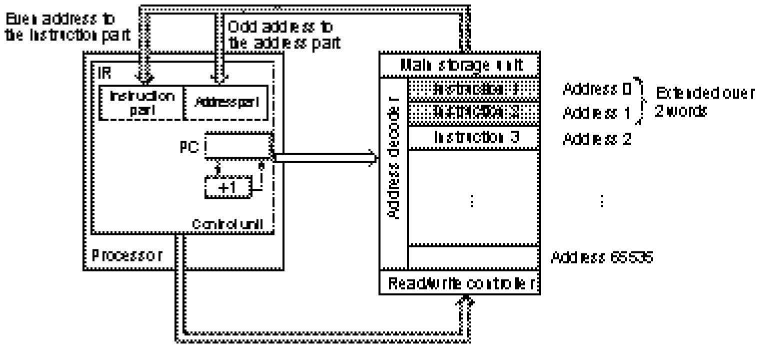
Figure 2-2-7
Three-address format



b. Instruction readout

The instruction received from the main storage unit is stored in the instruction register (IR).
The length of one word of the main storage unit is 16 bits. It is supposed that one instruction has 32 bits in the computers used. One instruction is stored in two words. Therefore, the content of the address of the main storage unit accessed is sent to the processor twice.
In practice, it is determined beforehand that in one instruction the instruction part is stored in an even address while the address part is stored in an odd address.

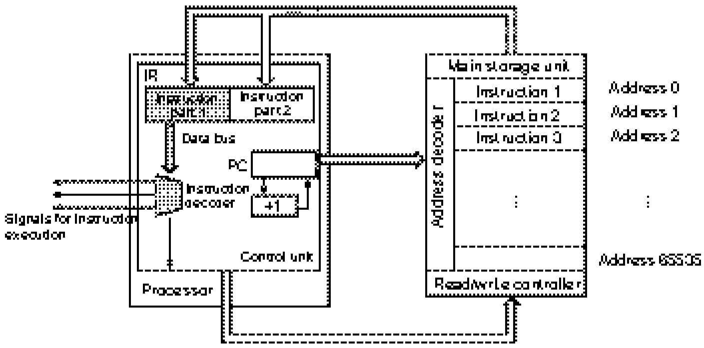
Figure 2-2-8 Instruction loading



c. Instruction decoding

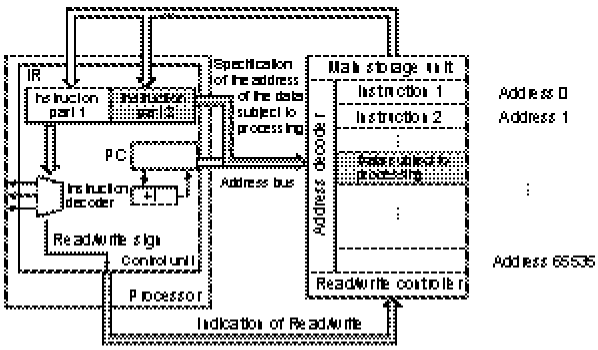
The content of the instruction part of the instruction register is transferred to a device called the decoder. The decoder decodes the type of work indicated by the instruction and sends the signals for the execution of the operation to each unit.

Figure 2-2-9
Instruction decoder



On the other hand, the content of the address part of the instruction register is transferred to the address bus. The content of the address of the main storage unit specified by the address bus corresponds to the data subject to processing. According to the instruction of the instruction part, a read/write signal is sent from the control unit to the data, subject to processing on the main storage unit.

Figure 2-2-10
Address part and data subject to processing



② Instruction execution

Once the instruction content and the address of the data subject to processing are obtained, the instruction is executed. Using the example of assembler language in which there is a one-to-one correspondence with the machine language, the instruction execution control and each type of register will be explained below.

a. Storing retrieved data

If, as a result of decoding the instruction part and the address part using the instruction decoder, the instruction is found to say "Retrieve and transfer to the processor the contents of address 100 of the main storage unit," a place to store the retrieved contents will be needed. Therefore, a general-purpose register is set in the arithmetic unit of the processor in order to store the retrieved data. In this example, it is assumed that there are five registers, and, for convenience, the numbers 0 to 4 will be assigned to them. Then, using the initials of each of the general-purpose registers, they will be represented as GR0, GR1, GR2, GR3 and GR4.

Figure 2-2-11 General-purpose register

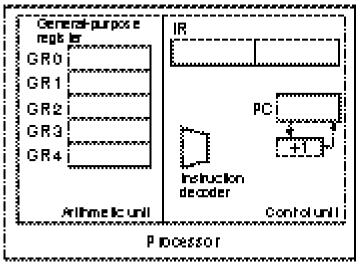
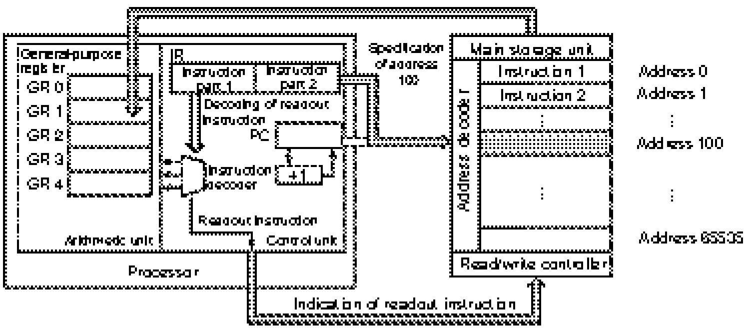


Figure 2-2-12 shows the mechanism by which the contents of address 100 of the main storage unit passes through the data bus to be stored in general-purpose register GR1.

Figure 2-2-12 Storage in the general-purpose registers



b. Instruction execution

If, as a result of decoding the instruction part and the address part of the instruction register, the instruction is found to say "Add the contents of address 100 of the main storage unit to the GR1 contents and store them in GR1," the retrieved contents of address 100 have to be added to the GR1 contents. The unit that performs this kind of addition and subtraction of numeric values is the ALU (Arithmetic and Logic Unit).

The ALU has the following arithmetic mechanism.

- Fixed point operation mechanism to perform operations of integer data
- Floating point operation mechanism to perform operations of floating point data

} For scientific and engineering calculations

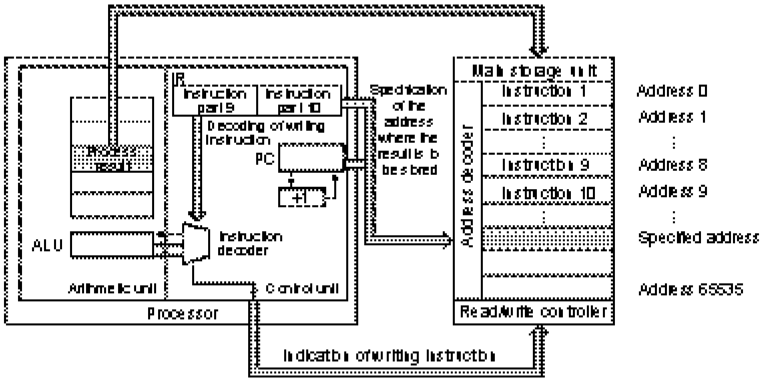
- Decimal operation mechanism to perform operations of binary-coded decimals in packet format .... For commercial data processing

It should be noted that besides arithmetic operations such as addition and subtraction, the operation mechanism of the ALU performs logical operations such as logical products, logical sums and shifts. For a detailed explanation of the logical operations, please refer to Chapter 1 and Section 2.2.

c. Processing subsequent to the instruction execution

Based on the instructions and data retrieved from the main storage unit, the result of the process performed using the operation mechanism and the register contained in the processor is transferred to the main storage unit through the data bus. Then the address where the result is to be stored is specified by the program instruction.

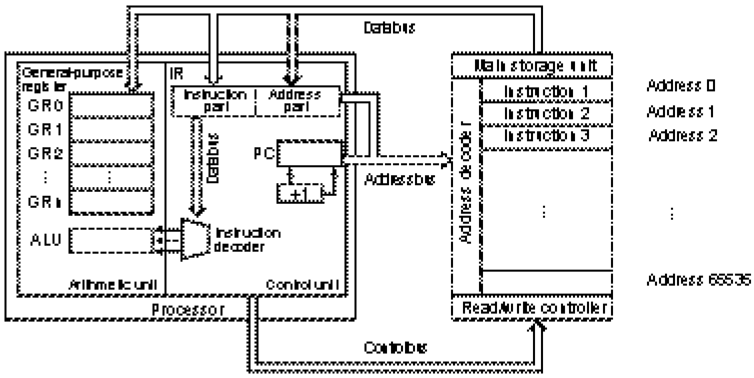
Figure 2-2-13 Storage of the process result



d. Flow of the instruction from its decoding to its execution and hardware structure

Figure 2-2-14 shows the hardware structure from the instruction readout to its decoding and execution.

Figure 2-2-14 Hardware structure



e. Various registers

Up to this point, the roles played by the instruction register, the general purpose register, etc., have been explained, but, besides these registers, the following registers exist:

· Program counter
· Accumulator
· Index register
· Base address register
· Program Status Word (PSW)
· Flag register
· Complement register

- Program Counter (PC)

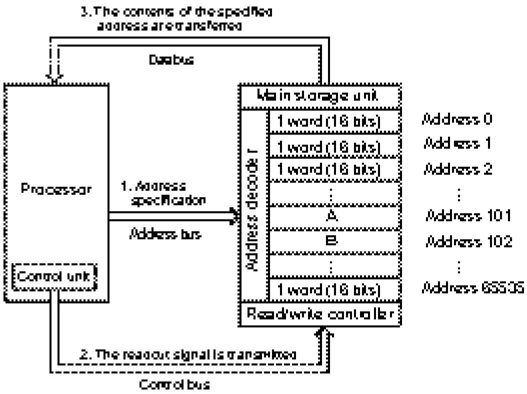
In Figure 2-2-15, considering the procedure in which instruction "A" stored in address 101 of the main storage unit is loaded to the processor, the following can be observed:

1. The processor specifies address 101 with the address bus
2. The control unit sends the readout sign to the main storage unit
3. The main storage unit transfers the contents of address 101 to the processor using the data bus.

At the beginning, the processor specified address 101, but under whose instructions? There is

actually a storage unit that exclusively performs this kind of instruction inside the processor. It is called the program counter and is composed of 16 bits. The program counter is also called the instruction address register, instruction counter or sequential control counter.
The devices that, as is the program counter, are set inside the processor and temporarily store data are known generally as registers. Among the registers, there are specialized registers whose application is set in advance, as is the program counter's, and general purpose registers whose application is freely decided by the program.

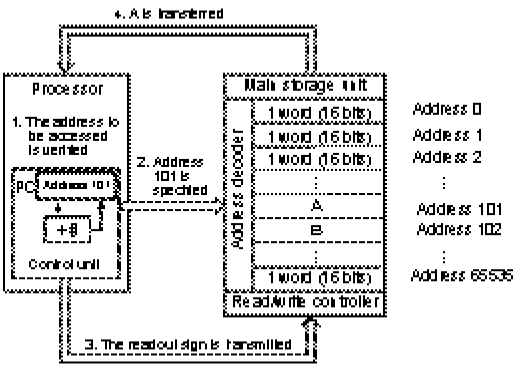
Figure 2-2-15
Address reading



Computer hardware is set in such a way that when the computer is turned on, the content of the program counter is immediately read and the address of the main storage unit to be accessed is verified. Likewise, every time this program counter is referred to, the content stored is automatically "+∝ (instruction word length)."
Taking into account the role of the program counter, and if we consider the procedure in which the processor loads instruction "A" stored in address 101 of the main storage unit, the following can be observed:

1. The content stored in the program counter is referred to and the address of the main storage unit to be accessed is verified. After it is referred to, "∝" is automatically added to the content of the program counter.
2. The processor specifies address 101 with the address bus
3. The control unit sends the readout signal to the main storage unit
4. The main storage unit transfers the contents of address 101 A to the processor using the data bus

Figure 2-2-16
Role of the program counter

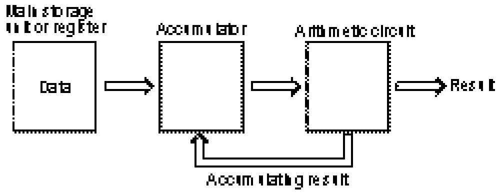


- Accumulator

The accumulator is the register used exclusively to store operation results and operation values. Since it stores accumulating results, it is also called the accumulating device. There are cases where the general-purpose register is used as a substitute for the accumulator.

When the accumulator is used, it is called accumulator mode, when the general-purpose register is used, it is called general-purpose register mode.

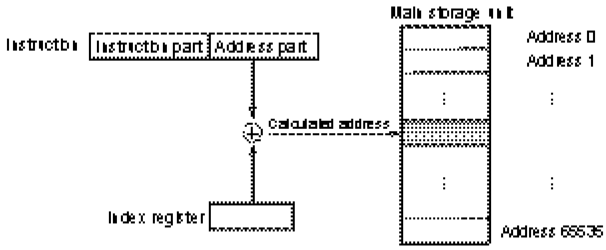
Figure 2-2-17
Accumulator



- Index register

When an address in the main storage unit is specified, the act of changing the address of the address part of the instruction is called address modification. The register used to perform this change is the index register.

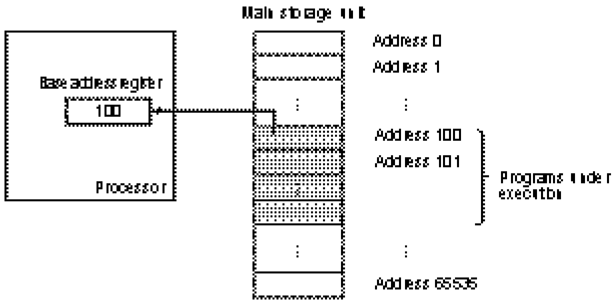
Figure 2-2-18
Index register



- Base address register

The base address register is the register that stores the program top address.

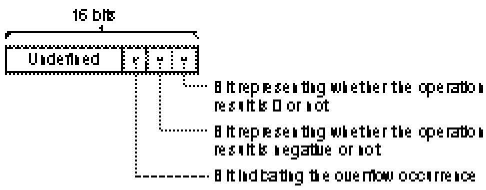
Figure 2-2-19
Base address register



- Flag register

The flag register stores information related to the operation result (if it is positive or negative or 0), to the existence of carry, overflow, etc.

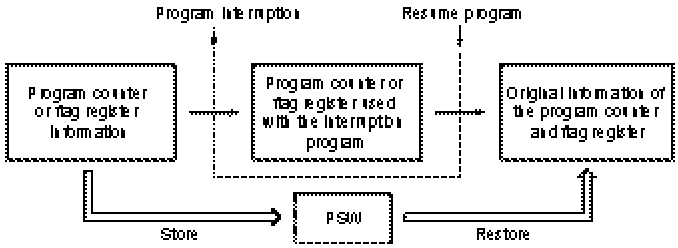
Figure 2-2-20
Example of a flag register



- PSW (Program Status Word)

The program counter, flag register and other information are registered in the PSW. In cases where an event that interrupts the program (interruption) in the processor occurs, the program execution can be resumed using the PSW information. Interruption is explained in Chapter 3 Section 3.1.

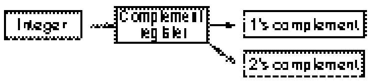
Figure 2-2-21
PSW



- Complement register

  The complement register generates integer complements in order to perform operations in the addition circuit.

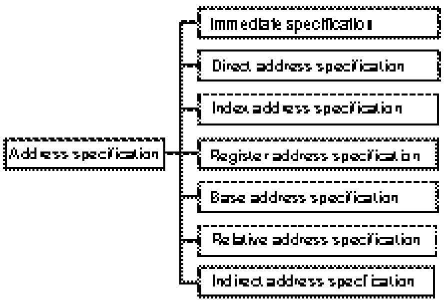
Figure 2-2-22
Complement register



(3) Address specification mode

The address part of the instruction specifies the main storage unit address and the register subject to processing. This specification method is called the address specification method.
At the instruction execution, the value of the address part of the instruction is not used as the address subject to processing as it appears; the actual address is specified after performing calculations between the specified register and addresses. The act of obtaining the address through calculation is called "address modification" and the actual address obtained is called the "effective address." The types of address specification modes are listed in Figure 2-2-23.

Figure 2-2-23
Types of address specification modes



① Immediate specification

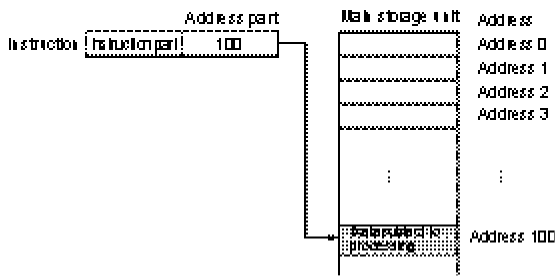
In the immediate specification, the data itself is contained in the address part. Since it is not necessary to access the main storage unit address, it can be immediately executed.

Figure 2-2-24
Immediate specification

② Direct address specification

In the direct address specification, the address of the data subject to processing is contained in the address part.

Figure 2-2-25
Direct address specification

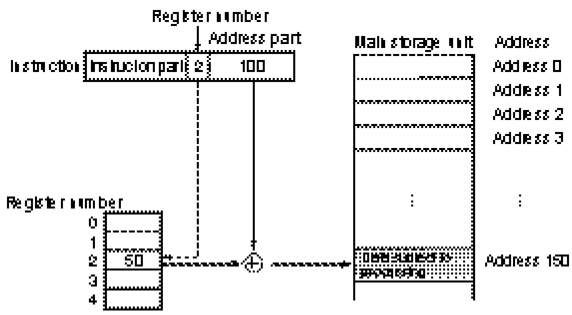


③ Index address specification

In the index address specification, the address part is divided into the section that specifies the number of the index register and the constant section, and the effective address is the result of the following addition:

(Content of the register content specified with the register number) + (Address constant)

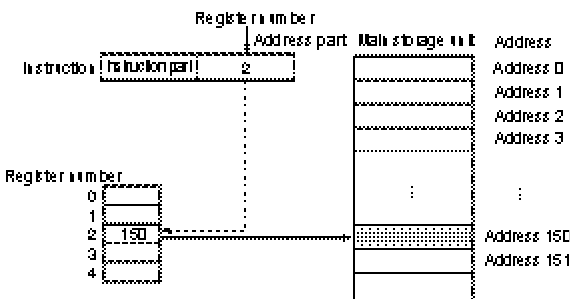
Figure 2-2-26
Index address specification



④ Register address specification

In the register address specification, the register number is stored in the address part and the address is stored in the register of that number.

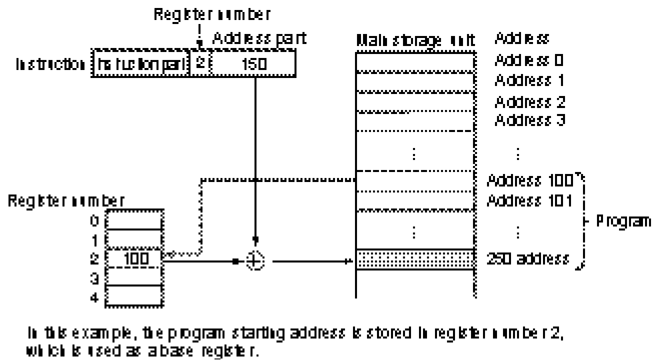
Figure 2-2-27
Register address specification



⑤ Base address specification

In the base address specification, the program starting address is stored in the base register. The result of the addition of the address contained in this base register and the address constant becomes the effective address.

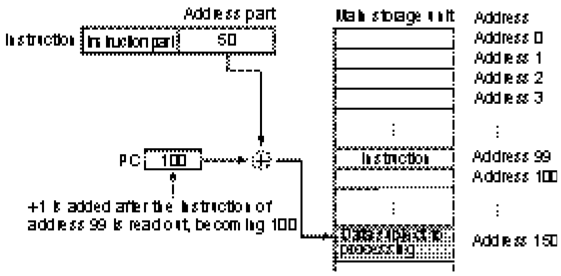
Figure 2-2-28 Base address specification



⑥ Relative address specification

In the relative address specification, the result of the addition of the address of the instruction being executed at the present time (value of the program counter) and the address of the address part become the effective address.

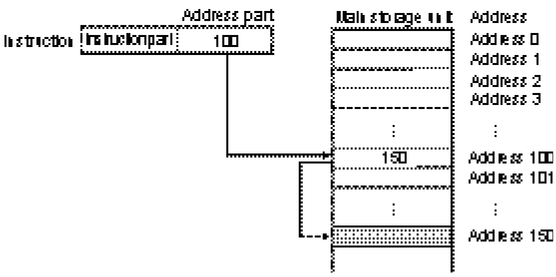
Figure 2-2-29
Relative address specification



⑦ Indirect address specification

In the indirect address specification, the address of the data subject to processing is contained in the address specified in the address part (Figure 2-2-30). There are cases where indirect address specification is performed on two or three levels.

Figure 2-2-30
Indirect address specification



(4) Instruction set

When the computer executes a job requested by the user, the hardware performs the process using several instructions needed from a group of instructions built into that computer. The set of instructions is defined as the interface of the software and the hardware of a specific computer, and, depending on the computer, the types and number of instructions differ. This group of instructions (the total of the instructions) is called the instruction set. As a result, computer software packages with identical instruction sets are basically compatible.

(5) Execution control of the instruction

The execution of a program consists of the repetition of the readout of the instruction from the main storage unit, and the decoding and execution of that instruction by the control unit. If we arrange the operations performed by the processor during program execution, we can divide them as follows:

- Instruction readout
- Instruction execution

① Instruction cycle and execution cycle

The series of operations consisting of the readout of the instruction stored in the main storage unit, its storage in the instruction register contained in the processor, and the instruction decoding using the instruction decoder, is called the instruction cycle. Likewise, the series of operations consisting of the reading out of the data subject to processing from the main storage unit, and writing and executing the instruction, is called the execution cycle.

a. Instruction cycle

The instruction cycle consists of the following two consecutive operations:

- According to the value of the program counter, the instruction to be executed is read out from the address of the main storage unit, where it was stored, to be stored in the instruction register.
- The instruction part of the instruction register is decoded using the instruction decoder, and the address of the data subject to processing is calculated based on the address part of the instruction register.

The instruction cycle is also called I cycle, and it is also called F (fetch) cycle.

b. Execution cycle

The execution cycle consists of the following two consecutive operations:

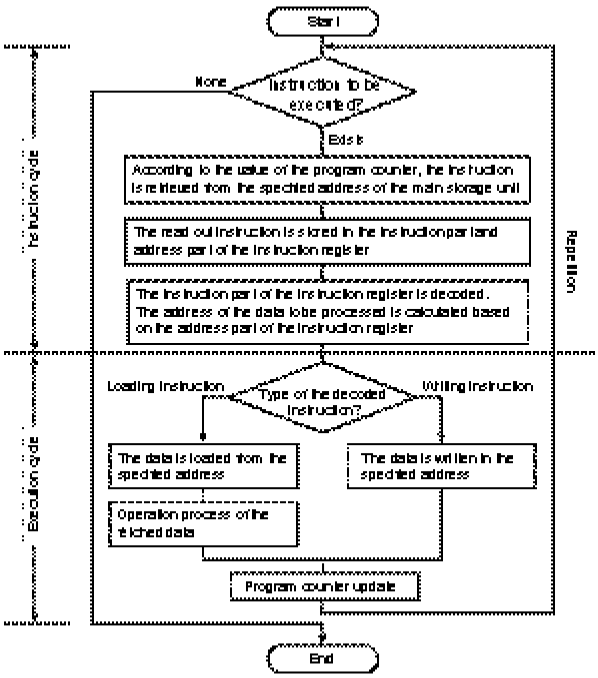
- If the decoded instruction is a readout instruction, the data subject to processing is read out from the specified address of the main storage unit; if it is a writing instruction, data is written in the specified address of the main storage unit.
- In the case of readout instructions, the read out data is used to perform the operation process.

Taking the initial of execution, the execution cycle is also called E cycle.

c. Instruction cycle and execution cycle operations

Figure 2-2-31 shows the flow figure of the operations of the instruction cycle and execution cycle in a clearly understandable way.

Figure 2-2-31 Flow figure of the operations of the instruction cycle and execution cycle



Note : There are cases where the program counter update is performed immediately after the instruction readout, and there are cases where it is performed after the instruction execution is completed.

The processor reads out, in order, the program instructions stored in the main storage unit and executes the program by repeating the instruction cycle and the execution cycle.

(6) Hardwired-logic control and microprogramming control

The instructions set in the computer are executed using logical circuits composed of several logic elements. In other words, logical circuits are the result of hardwiring among the logic elements; for that reason they are called hardwired-logic control system or wiring logic control system. Since the different instructions are implemented by the hardware, they have the advantage that the operation speed is fast. Opposite to this system, there is one that executes the instructions with the firmware.
As computer performance improves, instructions with more complicated functions become feasible. The higher the function level of the instructions, the more complicated the control procedure becomes. Therefore, instead of executing the instructions with hardware of complicated wiring, an execution method using easily modifiable firmware was designed. This method is called the microprogramming control system. Compared to the hardwired-logic control system, the operation speed of the microprogramming control system is slow, but the hardware is simpler and corrections (debugging) are easily performed. The microprogram, which is a string of patterns that determine whether the logic gate is to be on or off, is stored in a special memory called control storage inside the control unit. Instructions are followed by reading out the microprogram sequentially.

2.2.2 Operation mechanism

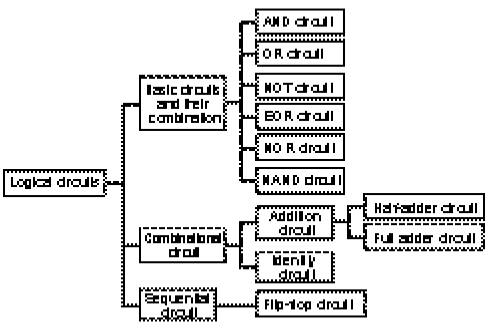
The procedure of the execution of logic operations studied in Chapter 1 inside the computer will be explained using real logical circuits.
In the arithmetic unit there are numeric operation circuits that handle numeric values and logical circuits that perform logical operations. The following three operations are basic in logical operations:
· Logical product operation (AND operation)
· Logical sum operation (OR operation)
· Negation operation (NOT operation)
Through the combination of circuits that perform these three operations, a wide range of logical circuits is implemented.

Figure 2-2-32
Logical operations

Logical operations	Operation symbols
Logical product (AND)	$\wedge$ or $\cdot$
Logical sum (OR)	$\vee$ or $+$
Negation (NOT)	or $\neg$
Exclusive logical sum (EOR)	$\veebar$ or $\oplus$
Negative logical sum (NOR)	
Negative logical product (NAND)	

Likewise, according to the combination of logical circuits, circuits can be classified as follows:
· Combinational circuits: Addition circuits, identity circuits, etc., that establish the output according to current input.
· Sequential circuits: Flip-flop circuits, etc., that establish the output according to current and past inputs.
The organization of these logical circuits is shown in Figure 2-2-33.

Figure 2-2-33
Logical circuits



(1) Basic logical circuits

The three operations "AND," "OR" and "NOT" are basic logical operations. The circuits that perform these three operations, AND circuits, OR circuits and NOT circuits will be explained below.

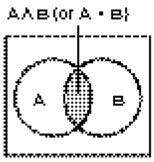
① AND circuit

AND circuits are the circuits that perform AND operations (logical product operations), as the one shown in Figure 2-2-34. In these circuits, if both A and B input values are not "1," "1" is not input. The table shown in Figure 2-2-34 is called the "truth table," and in this case, for the input "1" (true) or "0" (false) of A and B, the operation results "1" or "0" are indicated. Likewise, the Venn diagram, which clearly represents the operation result, is also displayed.
Besides "A AND B," AND operations are represented as "A · B" or as "A ∧ B"

Figure 2-2-34
Truth table and Venn diagram of AND operations

A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

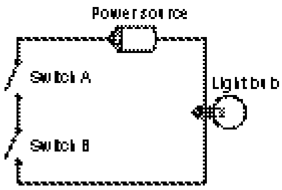
Truth table



Venn diagram

Figure 2-2-35 represents a comparison between the AND circuit that performs AND operations and a switch and a light bulb. Here, by establishing a correspondence between the switch "opens" and "1," and between "closes" and "0," as well as between the light bulb "lights" and "1" and "does not light" and "0," a truth table can be created.

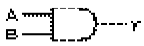
Figure 2-2-35 AND circuit of a switch and a light bulb



Switch A	Switch B	Light bulb
Opens (0)	Opens (0)	Does not light (0)
Opens (0)	Closes (1)	Does not light (0)
Closes (1)	Opens (0)	Does not light (0)
Closes (1)	Closes (1)	Lights (1)

The electric circuit is often represented using the US army MIL symbol (US MILitary standard, MIL-STD). Figure 2-2-36 shows the AND circuit represented with the MIL symbol.

Figure 2-2-36 AND symbol



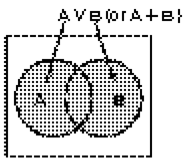
② OR circuit

OR circuits are the circuits that perform OR operations (logical sum operations) as the one shown in Figure 2-2-37. If either the A or B input value is "1," "1" is input.
Besides "A OR B," OR operations are represented as "A + B" or as "A ∨ B"

Figure 2-2-37
Truth table and Venn diagram of OR operations

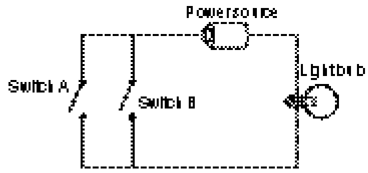
A	B	A OR B
0	0	0
0	1	1
1	0	1
1	1	1

Truth table



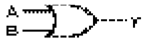
Venn diagram

Figure 2-2-38 OR circuit of a switch and a light bulb



Switch A	Switch B	Light bulb
Opens (0)	Opens (0)	Does not light (0)
Opens (0)	Closes (1)	Lights (1)
Closes (1)	Opens (0)	Lights (1)
Closes (1)	Closes (1)	Lights (1)

Figure 2-2-39 OR symbol



③ NOT circuit

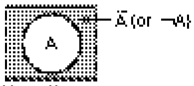
NOT circuits are the circuits that perform NOT operations (negation operations) as the one shown in Figure 2-2-40. The opposite of input value is output. The negation of "1" is "0" and the negation of "0" is "1."

Besides "NOT A," NOT operations are represented as "$\overline{A}$ " or as "¬ A."

Figure 2-2-40 Truth table and Venn diagram of NOT operations

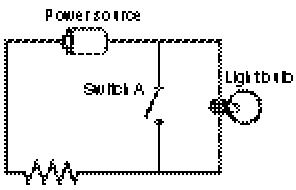
A	NOT A
0	1
1	0

Truth table



Venn diagram

Figure 2-2-41 NOT circuit of a switch and a light bulb



Switch A	Light bulb
Opens (0)	Lights (1)
Closes (1)	Does not light (0)

Figure 2-2-42 NOT symbol

(2) Combination of the basic circuits

Through the combination of the basic circuits, EOR circuits, NOR circuits and NAND circuits can be composed.

① EOR circuit (Exclusive logical sum operation circuit)

Figure 2-2-43 shows the truth table, MIL symbol and Venn diagram of EOR operations.

Besides "A EOR B," EOR operations are represented as "A ⊕ B" or as "A ⊻ B."

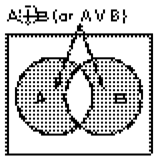
It should be noted that "A ⊕ B" is an operation that means the same as "$\overline{A} \cdot B + A \cdot \overline{B}$."

Figure 2-2-43 Truth table, EOR symbol and Venn diagram of EOR operations

A	B	A EOR B
0	0	0
0	1	1
1	0	1
1	1	0

Truth table

EOR symbol

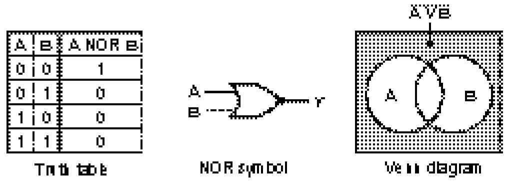


Venn diagram

② NOR circuit (Negative logical sum operation circuit)

NOR operations are the negation of OR operations. NOR circuits result of the combination of a NOT circuit in the output side of an OR circuit.

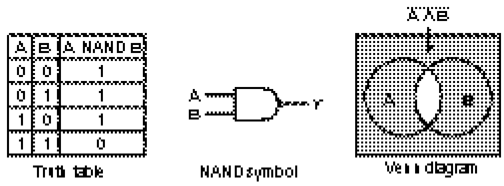
Figure 2-2-44 Truth table, NOR symbol and Venn diagram of NOR operations



③ NAND circuit (Negative logical product operation circuit)

NAND operations are the negation of AND operations. NAND circuits result in the combination of a NOT circuit in the output side of an AND circuit.

Figure 2-2-45 Truth table, NAND symbol and Venn diagram of NAND operations



④ Addition circuit

Through the combination of several basic circuits and combinational circuits, circuits that perform 1-digit binary additions called addition circuits can be created. There are two types of addition circuits, half-adder circuits and full adder circuits.

a. Half-adder circuit (HA)

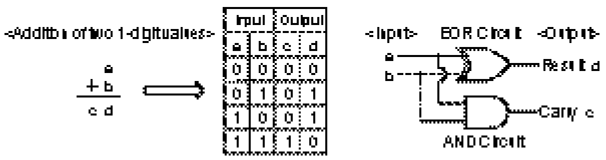
The addition of the 1-digit binaries A and B, A+B can be performed in the following four ways:

$$\begin{array}{r} 0 \\ +\ 0 \\ \hline 0 \end{array} \qquad \begin{array}{r} 0 \\ +\ 1 \\ \hline 1 \end{array} \qquad \begin{array}{r} 1 \\ +\ 0 \\ \hline 1 \end{array} \qquad \begin{array}{r} 1 \\ +\ 1 \\ \hline 10 \end{array}$$

↑
Carry

The circuit that performs these binary operations is created by the combination of one AND circuit and one EOR circuit. This circuit is called the half-adder circuit. (Figure 2-2-46)

Figure 2-2-46 Truth table of the half-adder circuit and half-adder circuit



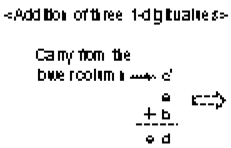
b. Full adder circuit (FA)

The addition of the 1-digit binaries A, B and C, A+B+C can be performed in the following eight ways:

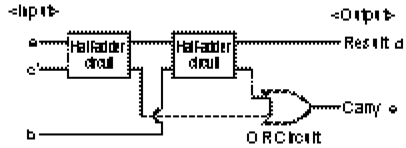
0	0	0	0	1	1	1	1
0	0	1	1	0	0	1	1
+ 0	+ 1	+ 0	+ 1	+ 0	+ 1	+ 0	+ 1
0	1	1	10	1	10	10	11

The circuit that performs these binary operations is created by the combination of two half-adder circuits and one OR circuit. This circuit is called the full adder circuit.

Figure 2-2-47 Truth table of the full adder circuit and full adder circuit



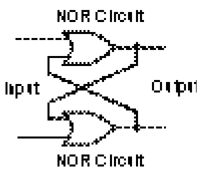
Input			Output	
c'	a	b	e	d
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1



(3) Sequential circuit

The sequential circuit is a circuit in which the output is established according to the current input and the status preserved (past input). The sequential circuit, whose status changes with time, is composed of a flip-flop circuit and is used in registers, etc.

Figure 2-2-48
Flip-flop circuit



2.2.3 Processor performance

The performance of the processor, which can be considered as the central nervous system of the units that compose the computer system, is measured using the number of instructions that can be executed in a unit of time as an index. These indexes are indicated below.

(1) MIPS

MIPS is an acronym of Million Instructions Per Second, and indicates in million units the number of instructions that can be executed in one second. In other words, a 1 MIPS processor is a processor that can execute one million instructions per second. Basically, the larger the number of instructions that can be executed, the higher the value. The term MIPS is mainly used to indicate the performance of processors of high-end mainframe computers. However, it is meaningless to use this index to compare processors of different types of machines that execute different instruction contents.

(2) Clock

In order to set the pace in which the micro-instructions, which are basic operations, are executed, the processor has a clock inside. A quartz crystal oscillator that pulses in regular intervals when electrical current passes through is used in this clock. The time taken for this oscillator to pulse once (one cycle) is called clock. The basic operations of the processor are performed according to this clock. The number of clocks varies according to the instruction.

The clock reciprocal number is called clock frequency. Clock frequency is used as an index to measure the performance of a personal computer.

Example Performance of a processor with a clock frequency of 500 MHz

500 MHz = 500 × 10^6 Hz = 500,000,000 Hz (times/second); 500 hundred million pulses per second

$$\frac{1}{0.5\times10^{9}} = 2\times10^{-9} = 2 \text{ nano (seconds/times)};$$ 1 pulse for every 2 nanoseconds

(3) CPI (Cycles Per Instruction)

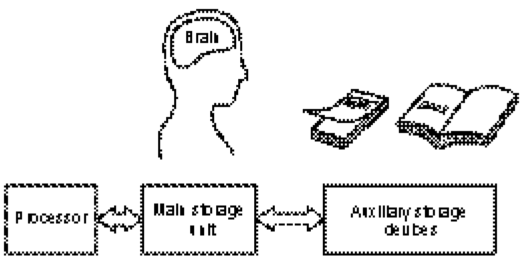
A CPI is the number of clocks required to execute one instruction. This index indirectly indicates the execution time of one instruction.

2.3 Memory architecture

2.3.1 Memory types

The storage function, which is the most important characteristic of the computer, is made possible by the storage units. According to the application, the storage units are divided into main storage unit and auxiliary storage devices.

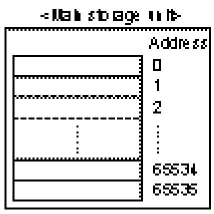
Figure 2-3-1
Main storage unit and auxiliary storage devices



(1) Main storage unit

The main storage unit, which is directly connected to the processor by a signal line called bus, is a device that stores the programs and data to be executed by the processor.
The place where data is stored is generally called memory and it has a series of consecutive addresses. By specifying one of these addresses, information is retrieved from or stored in the main storage unit. The act of exchanging data with the main storage unit performed in the above-mentioned cases is called access. In this way, the system that stores in advance the program to be executed in the main storage unit is called the stored-program system (or internally programmed system) and it is a basic approach in current computers.

Figure 2-3-2
Main storage unit address concept



The main storage unit is composed of semiconductor elements called RAMs (Random Access Memory). A RAM's property is such that when the computer is turned off, the contents stored are lost. Therefore, if there is data to be saved after the process is finished, it is stored in the auxiliary storage devices.

(2) Auxiliary storage devices

The auxiliary storage devices are devices that play the supporting role of making up for the shortage of storage capacity of the main storage unit. They are also called external storage units. The auxiliary storage devices are not included among the five main units of the computer, but they are indispensable for current computers. Large volumes of data and programs are stored/saved in the auxiliary storage devices and when the data or program required to perform a process is not found in the main storage unit, it is transferred (copied) from the auxiliary storage devices to the main storage unit in order to perform the process. Likewise, the data to be saved after the process is completed is transferred to the auxiliary storage devices and saved there. Since the auxiliary storage devices have the property that, even when the computer is turned off, the contents stored are not lost, they can be used as input/output units of large volumes of data.

· The following are the main auxiliary storage devices.
· Magnetic tape unit
· Magnetic disk unit
· Floppy disk unit (Flexible disk unit)
· Optical disk unit
· Magneto-optical disk unit

2.3.2 Memory capacity and performance

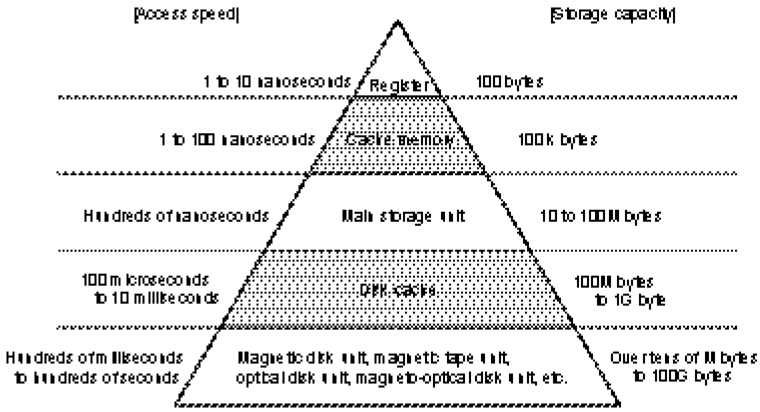
(1) Memory hierarchical structure

The computer memory is composed of the register inside the processor, the main storage unit, the auxiliary storage devices, etc. The storage capacity and the processing speed of each of these devices differ. As is shown in Figure 2-3-3, the access speed is as follows:

(High speed) Register inside the processor > Main storage unit > Auxiliary storage devices (Low speed)

This access speed difference is absorbed by a device called the buffer.

Figure 2-3-3 Memory hierarchical structure



(2) Access time

The access time and cycle time indicate the operation speed of the storage units.

The access time is the time elapsed from when the processor sends the read/write instruction to the storage unit until the data delivery/acceptance is completed.

For the processor to access the main storage unit data, the following three stages are necessary:

① The time during which the processor requests the data readout

② The time during which the processor selects the main storage unit address with the address bus

③ The time during which the data of the selected address is transferred through the data bus.

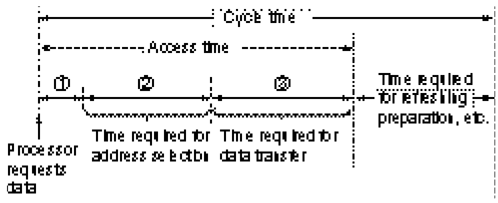
In other words, ①+②+③ represent the time elapsed from when the data access request is sent until the data transfer is completed. This lapse of time is called the access time.

(3) Cycle time

Among the storage elements of the storage unit, when data is to be stored in the capacitor, there are some whose memory fades with time, as the DRAM. In this case, the refreshing operation that rewrites data at regular intervals becomes necessary. For that reason, after the data transfer is completed, a preparation time in order to receive the next request becomes necessary. The lapse of time that includes the point up to this preparation is called cycle time.

Figure 2-3-4

Access time and cycle time



2.3.3 Memory configuration

As was mentioned above, the memory used in the computer can be classified into hierarchies. To provide for the occurrence of malfunctions or failures, these devices are equipped with data error detection and error correction functions. These functions are implemented by several Error Correcting Codes (ECC).

(1) Magnetic disk

The series of errors caused by a small scratch, etc., on a magnetic disk are called burst errors. The Cyclic Redundancy Check code (CRC code) is adopted in the disk unit to detect these burst errors. Error detection is possible with the CRC code system.

(2) Magnetic tape

The magnetic tape indicates 1-byte data in the transverse direction of the tape. In order to detect bit errors in this transverse direction, a parity check system, which can detect odd numbers of bit errors by appending vertical parity bits, is adopted. In addition, CRC code is adopted to detect burst errors in a transverse direction.

(3) Main memory

In the main memory, due to the high probability of the occurrence of non-consecutive random errors, the Hamming code, which can detect single-bit errors and double-bit errors, is adopted.

It should be noted that, generally speaking, the main memory error detection is performed in general-purpose computers but it is not performed in personal computers.

(4) Memory protection system

Since various information is handled in a computer, depending on the characteristics of that information, a function that limits the users is necessary. This function is called memory protection and it protects the instructions and data stored in the main memory, auxiliary storage devices and other memories under specific conditions. When the memory is accessed, operations like the ones mentioned below are performed:

· Read
· Write
· (Instruction) execute

The right to perform these operations is called access right. Data has read/write rights, but instructions do not have a right to write. On the other hand, instructions have a right to execute, but data do not. When an illegal access that violates these access rights occurs, the control is transferred to the OS as a result of the interruption handling routine.
Likewise, as protection mechanisms of the main memory implemented by the hardware, the protective boundary register system, in which a dedicated register specifies the accessible domains, the TLB (Translation Look-aside Buffer) system, which applies the memory protection function in a virtual address space, etc., exist.

2.4 Auxiliary storage devices

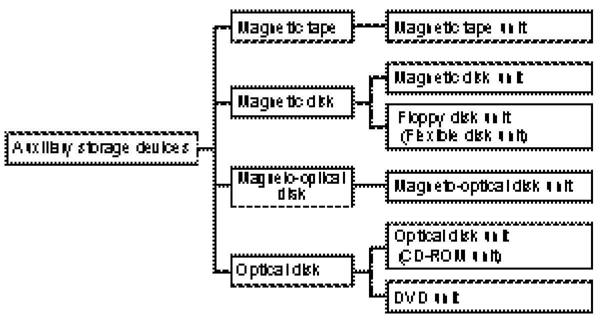
2.4.1 Types and characteristics of auxiliary storage devices

As was mentioned above, computer storage units are divided as follows:

· Main storage unit
· Auxiliary storage devices

The main storage unit is equivalent to the human brain, while auxiliary storage devices are equivalent to notebooks and texts. Auxiliary storage devices are devices that store and save programs and data while they are not being executed. Likewise, as when one reads a text and writes down the necessary information, or when one writes in a letter the things to be transmitted to another person, these auxiliary storage devices also play the role of input devices and output devices.
There are two types of auxiliary storage device: devices that store data magnetically, as the magnetic tape unit, the magnetic disk unit, the floppy disk unit (flexible disk unit), and the magneto-optical disk unit, and devices that store data optically as the optical disk unit (Figure 2-4-1).
The main storage unit stores programs and data to be used by the processor for instruction execution, but it has a big problem: stored content is lost when the computer is turned off. On the other hand, compared to the main storage unit, the operating speed of auxiliary storage devices is low, but they can store a large volume of data and, even if the computer is turned off, the stored data is retained semi-permanently.
It should be noted that besides these devices, there is also a semiconductor disk unit that is, for example, the flash memory used as an auxiliary storage unit in digital cameras and notebook personal computers. This unit is composed of semiconductor(s) (EEPROM(s)), it does not operate mechanically, and it electrically performs data reading/writing processes at high speed. However, since it cannot store large volumes of data, it is used as the storage unit of small devices with low power requirements.
Here, the operation principles and characteristics of the typical auxiliary storage devices will be explained.

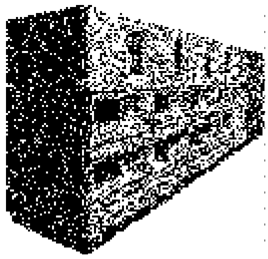
Figure 2-4-1
Diverse auxiliary storage devices



(1) Magnetic disk unit

Magnetic disk unit is devices that store data using magnetic disks. It is the auxiliary storage device most widely used in today's computer systems. Magnetic disks for personal computers or workstations are also called fixed disks or hard disks but the mechanism is the same.

Figure 2-4-2
Magnetic disk unit

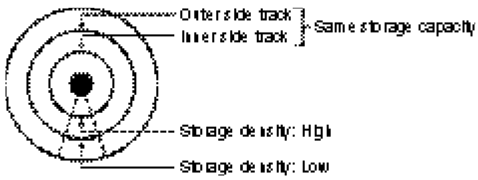


① Magnetic disk

a. Track

The magnetic disk is a circle-shaped magnetic body in which data is recorded along rings called tracks. There are several tracks concentrically set on the magnetic disk. The length of the outer tracks and that of the inner tracks differ, because of the difference of the storage capacity, the volume of data stored is the same in every track. (Figure 2-4-3).

Figure 2-4-3
Data recording side
of the magnetic disk

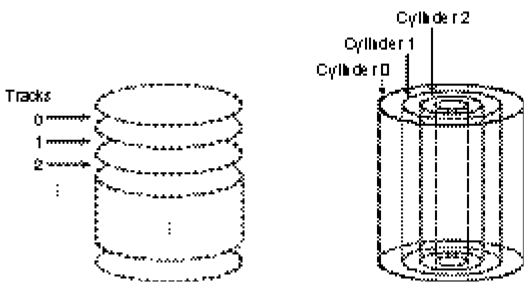


The storage density of the disk is based on the average track length and the storage capacity of the magnetic disk is determined by the number of tracks and the storage density of one disk.

b. Cylinder

In a magnetic disk unit, which is composed of multiple magnetic disks, the group of tracks with the same radius on each of the disks is set as one data storage area. This storage area is called a cylinder. When data is stored in a cylinder, if, for example, the data cannot be completely stored on track 0 of cylinder 1, it can be stored on track 1, track 2, etc. of the same cylinder. Therefore, since data access can be performed without moving the access arm (that is, the magnetic head), it is extremely efficient. To put it in another way, the cylinder is a group of tracks that can be read and written by multiple magnetic heads if the access arm of the magnetic disk unit is fixed.

Figure 2-4-4
Tracks and cylinders



c. Storage capacity

The storage capacity of the magnetic disk can be determined as follows:
Storage capacity of 1 track × Track number of 1 cylinder × Cylinder number of the magnetic disk

Example

Given a magnetic disk with the following specifications, the storage capacity of this magnetic disk is calculated:

[Magnetic disk specifications]

- Cylinder number: 800 cylinders
- Track number/cylinder number: 19 tracks
- Storage capacity/track: 20,000 bytes

The storage capacity per cylinder is as follows:

20,000 bytes/track $\times$ 19 tracks/cylinder = 380,000 bytes/cylinder = 380 kB (kilo bytes)

Since the number of cylinders on this disk is 800, the storage capacity of the magnetic disk is as follows:

380 kB/cylinder $\times$ 800 cylinders = 304,000 kB = 304 MB (Mega bytes)

An example of the calculation of storage capacity when blocking is performed is shown below.

Example

Given a magnetic disk with the following specifications, the number of cylinders required when 80 thousand records of 200 bytes each are stored in a sequential access file of 10 records/block per magnetic disk is calculated. It should be noted that block recording cannot be extended over multiple tracks.

[Magnetic disk specifications]

- Cylinder number: 400 cylinders
- Track number/cylinder number: 19 tracks
- Storage capacity/tracks: 20,000 bytes
- Inter-block gap (IBG): 120 bytes

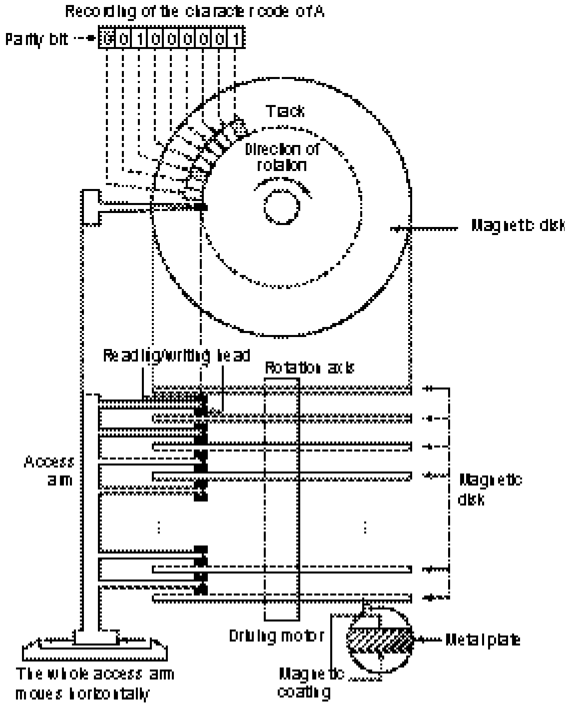
1. First, the number of blocks of the whole file is calculated.
   Since the number of records is 80,000 and the blocking factor is 10, the number of blocks is determined as follows:
   80,000 records $\div$ 10 records/block = 8,000 blocks
2. The length of 1 block, including the inter-block gap is calculated.
   200 bytes/record $\times$ 10 records/block + 120 bytes/block = 2,120 bytes/block
3. The number of blocks that can be recorded in 1 track is calculated.
   20,000 bytes/track $\div$ 2,120 bytes/block = 9.43… blocks/track
   Since a block cannot be recorded across multiple tracks, the decimals are omitted, and the number of blocks that can be recorded in 1 track becomes 9 blocks/track.
4. The number of tracks required for the whole file is calculated.
   8,000 blocks $\div$ 9 blocks/track =888.88… tracks
   Rounding it up to the next whole number, it becomes 889 tracks.
5. The number of cylinders required to record the whole file is
   889 tracks $\div$ 19 tracks/cylinder = 46.78…cylinders
   Rounding it up to the next whole number, it becomes 47 cylinders.

② Magnetic disk unit structure and operation principles

The magnetic disk unit has multiple magnetic disks, which it rotates at high speeds in order to record data along concentric tracks. On each recording side, an access arm with a magnetic head moves forward and backward to reach the track position where data is to be read or recorded.

Compared to the sequential access of the magnetic tape unit, in which access can only be performed in order from the beginning, in the magnetic disk unit, besides sequential access, direct access to the desired recording position can also be performed. Auxiliary storage devices in which this direct access can be performed are called direct access storage devices (DASD).

Figure 2-4-5 Structure of the magnetic disk unit



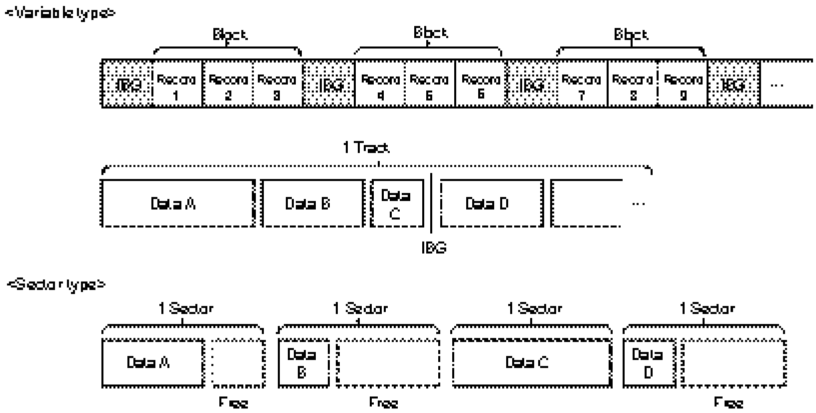
a. Variable type and sector type

By recording method, magnetic disk unit is classified into "Variable type" and "Sector type."

- Variable type
  In the variable type unit, data reading and writing is performed on a block basis, as in the magnetic tape. A block is a group of data called a record and there is an IBG between blocks. In the unit, there is no gap between data (or IBG). Reading and writing of any number of bytes can be started from any track position.

- Sector type
  In the sector type unit, one track is divided into approximately 20 small units called sectors. Data reading and writing is performed on a sector basis. The reading/writing position is specified with the sector number of the selected track.

Figure 2-4-6 Variable type and sector type



Generally, the variable type is used in magnetic disks, and the sector type is used in floppy disks and hard disks.

b. Parity check

When data is recorded on a magnetic disk, data is written on the track bit by bit using the magnetic head. The same method is used to read data. When this process is performed, as in the magnetic tape, in order to detect reading or writing errors, a parity bit (1 bit) is appended to perform the parity check.

c. Defragmentation

In personal computer hard disks, data is stored and deleted repeatedly. Since it is improbable that all the data to be stored will have the same size, a small volume of data can be stored after a big volume of data is deleted, or vice versa. As a consequence, there would be free sectors scattered about and a drop in access efficiency. This status is called fragmentation; in order to solve it, a function called defragmentation is implemented in the OS.

③ Magnetic disk unit performance

The performance of the magnetic disk unit is measured according to access time and storage capacity. Since the storage capacity was already explained in ①, here, the access time significance and the calculation method will be explained.

a. Access time

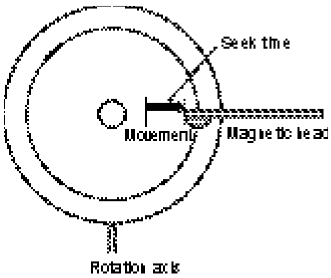
Access is the generic term for the act of reading specific data from the magnetic disk and writing it on a specific cylinder or track. Access time is calculated through the addition of the following:

- Seek time
- Search time
- Data transfer time

● Seek time

In order to access the target data, the magnetic head has to be moved to the position of the track where the target data is stored. The time it takes to move the magnetic head is called seek time.

Figure 2-4-7
Seek time

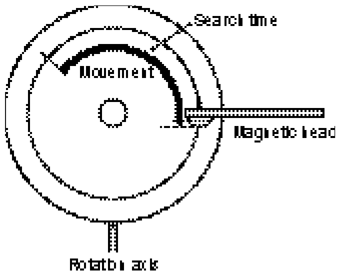


Since seek time differs depending on the distance between the position of the target track and the current position of the magnetic head, an average value is used as the actual seek time. This value is called average seek time.

● Search time

The search time is the lapse of time until the target data reaches the magnetic head position. (Figure 2-4-8).

Figure 2-4-8
Search time



As with average seek time, depending on the data position, there are cases where the search time is 0, as well as cases where there is a wait of 1 revolution. Therefore, 1/2 revolution of the magnetic disk is used as the search time. This value is called average search time.

- Data transfer time
  The time elapsed between when the magnetic head data access starts and when the transfer is completed is called data transfer time.

Therefore, the time elapsed between when the magnetic disk unit starts the data access and when the data transfer is completed, that is, the access time, is calculated as follows:
Seek time + Search time + Data transfer time
Strictly speaking, as in the above-mentioned formula, the time elapsed between when the access request occurs and the magnetic disk unit starts operating is the access time.

Access time of the magnetic disk unit = Average seek time + Average search time + Data transfer time

Example

Given a magnetic disk unit with the following specifications, the access time of this magnetic disk when a record of 9,000 bytes is processed is calculated.

[Magnetic disk unit specifications]

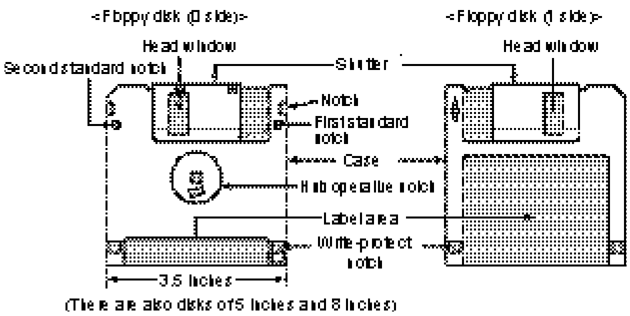
- Capacity per track: 15,000 bytes
- Magnetic disk rotation speed: 3,000 revolutions/minute
- Average seek time: 20 milliseconds

1. First, the average search time is calculated.
   Since the rotation speed of the magnetic disk is 3,000 revolutions/minute, through the following operation,
   3,000 revolutions/minute $\div$ 60 seconds/minute = 50 revolutions/second,
   it is determined that the magnetic disk makes 50 revolutions per second. Therefore, the time required to make 1 revolution is as follows:
   1 revolution $\div$ 50 revolutions/second = 0.02 seconds/revolution = 20 milliseconds
   Since the average search time is the time required to make 1/2 revolution, it is as follows:
   20 milliseconds $\div$ 2 = 10 milliseconds
2. Since in 1 revolution, the information contained in 1 track passes through the magnetic head, considering that the disk makes 50 revolutions per second, the data transfer speed is as follows:
   Data transfer speed = 50 tracks/second $\times$ 15,000 bytes/track = 750×10^3 bytes/second
   Based on this data transfer speed, the time to transfer 9,000 bytes of data can be calculated as follows.
   $(9 \times 10^3$ bytes$) \div (750 \times 10^3$ bytes/second$)$ = 0.012 seconds = 12 milliseconds
3. Therefore, the access time is as follows:
   Average seek time + Average search time + Data transfer time
   = 20 milliseconds + 10 milliseconds + 12 milliseconds = 42 milliseconds

(2) Floppy disk unit

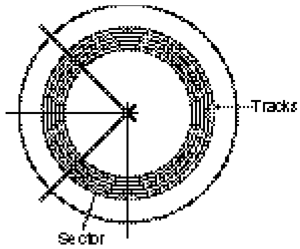
The floppy disk unit is also called a flexible disk unit. In floppy disk units data random access is possible, and, since the floppy disk itself, which is a storage medium, is low-priced and easy to carry about, its use has widely spread. As an auxiliary storage device of personal computers, it is the most ordinarily used device.

Figure 2-4-9
Floppy disk
(Flexible disk)



The recording method of the floppy disk is the sector method, and as it is shown in Figure 2-4-10; the track is divided into sectors, and the data is recorded on a sector basis.

Figure 2-4-10
Data recording side of the floppy disk



① Floppy disk

a. Types

Among floppy disks, there are magnetic disks that measure 8 inches, 5 inches and 3.5 inches, but, the most common disks today are 3.5 inch-disks, while 8- and 5-inch disks are almost never used. There are also the following 2 types of 3.5-inch floppy disks, depending on the storage density.

- 3.5 inch 2 HD (double side High Density)
  Storage capacity: 1.2 to 1.4 megabytes (MB)
- 3.5 inch 2 DD (double side Double Density)
  Storage capacity: 640 to 730 kilobytes (kB)

Figure 2-4-11
Example of the specifications of a floppy disk (2HD)

	1.4MB	1.2MB
Sides available for use	2	2
Track number/side	80	77
Sector number/track	18	8
Storage capacity (B)/sector	512	1,024

Likewise, there is a floppy disk whose storage capacity is 120MB (UHD) and a disk called Zip whose storage capacity is 100MB. Both of them are compatible with the 3.5-inch disk (2DD/2HD), but they have not come into wide use.

b. Storage capacity

The calculation of the access time of floppy disk units is the same as that for magnetic disk units. Therefore, here, the storage capacity of the sector method will be explained.
As was shown in Figure 2-4-11, among floppy disks, the sides available for use, the number of tracks per side, the number of sectors per track, etc. differ.
The storage capacity of a floppy disk is calculated using the following values:
Storage capacity per sector × Number of sectors per track × Number of tracks per side ×
Number of sides (One side or both sides)

Example

Given a floppy disk with the following specifications, the storage capacity is calculated.
[Specification of a floppy disk unit]

- Sides available for use: 2 sides
- Track number/side: 80 tracks
- Sector number/track: 9 sectors
- Storage capacity/sector: 1,024 bytes

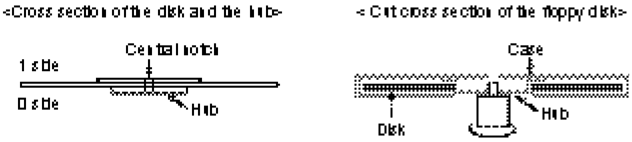
The storage capacity of 1 track is as follows:
1,024 bytes/sector × 9 sectors/track = 9,216 bytes/track
Therefore, the storage capacity of 1 side is as follows:
9,216 bytes/track × 80 tracks = 737,280 bytes ≤ 737kB
And, since the sides available for use of the floppy disk are 2 (sides), the following is the storage capacity:

737kB × 2 = 1,474kB
Approximately 1.474MB

② Floppy disk unit structure and operation mechanism

Basically, the floppy disk unit has the same structure as the magnetic disk unit. However, only 1 floppy disk is used and the sector method, in which the track is divided into sectors, is the recording method.
The number of tracks and the division of the sectors depends on the operating system used. Therefore, when the user uses a floppy disk, it has to be initialized in the format specified by the operating system. This process is called formatting.
When the floppy disk cartridge is installed in the floppy disk unit, the disk contained in the cartridge rotates. The magnetic head directly traces the magnetic disk surface of the disk and, in order to read/write information, the data access time is longer than that of the magnetic disk unit and the magnetic tape unit.

Figure 2-4-12 Floppy disk structure



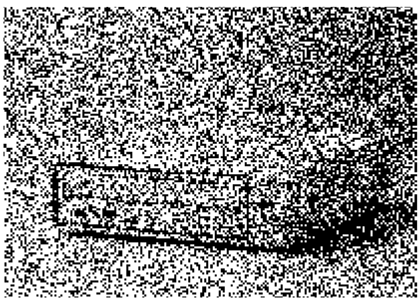
(3) Optical disk (CD, DVD) unit

Besides the magnetic disk unit, the magnetic tape unit and the floppy disk unit, there are various other kinds of auxiliary storage devices. Optical disk units, magneto-optical disk units, DVD units, etc. are used to store/save image processing data of extremely large volume or as storage devices of large volume packaged software. These devices can store large volumes of data through a mechanism that reads out information using light reflection.
In addition to floppy disk units and hard disk units, as auxiliary storage devices, today's standard personal computer systems are also equipped with CD-ROM units. The role played by the CD-ROM as a medium to supply software packages to the general marketplace, and as a multimedia storage medium, is extremely important.

① Optical disk

The surface of the optical disk is covered with a hard plastic that makes it resistant to scratches and dust. Furthermore, since a laser beam is used to read out data, the head does not touch the recording surface directly, so no friction is caused. Among optical disks, CD-ROM use in particular is expanding rapidly.

Figure 2-4-13
CD-ROM unit



Among optical disks, there is the music CD (Compact Disc), the CD-G (CD-Graphic) for image data, the CD-I (CD-Interactive) for interactive applications, the CD-R (CD-Recordable), etc. And, as a computer storage medium, the CD-ROM (CD-Read Only Memory) is widely used.
Furthermore, as an optical disk that supports the multimedia era, the DVD, which has great capacity and high image quality and is capable of storing animated images and audio, exists.
Here, the CD-ROM and the DVD specifically, will be explained.

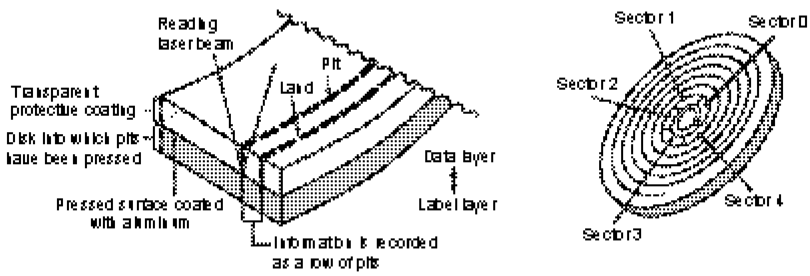
② CD-ROM

The CD used as a computer storage medium is the CD-ROM. The external appearance, diameter, thickness, etc. of the CD-ROM is the same as that of a CD (diameter: 12 cm, thickness: 1.2 mm, single disk diameter: 8 cm), but the error correction function, file system, logical format, etc. differ. Since the CD-ROM logical format uses the international industrial standard ISO 9660, it has high compatibility. However, since the CD-ROM is a read-only disk, data can be read out but cannot be written.

a. Structure

The CD-ROM, which is a disc-shaped storage medium, does not have a concentric-track structure as does the magnetic disk or floppy disk. Tracks of continuous sectors are connected in a spiral as in vinyl records and the data is stored from the inner side to the outer side. Figure 2-4-14 shows a magnification of the data recording surface of the CD-ROM.

Figure 2-4-14 CD-ROM data recording surface



The CD-ROM stores "0" and "1" information using the pits and lands of the data recording layer. In order to read out data, a laser beam is applied and the optical head reads out the changes in intensity of the reflected light.

b. Storage capacity

By creating a master disk with a negative replica of these pits and lands and pressing it against plastic disks, a large quantity of CD-ROMs can be replicated at high speed and low cost.
1 CD-ROM (12 cm) has a storage capacity of approximately 600MB, which makes it an indispensable storage medium to process the enormous volume of information of multimedia data.

③ CD-ROM unit structure and performance

a. Structure

Basically the structure of the CD-ROM unit is the same as that of the magnetic disk unit. The difference is that data is not read out using a magnetic head, but an optical head that detects the laser beams.

b. Performance

The CD-ROM unit performance is measured according to the head seek time and the data transfer rate.

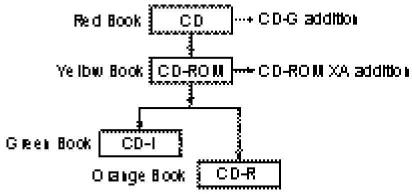
- Seek time
  The CD-ROM seek time is extremely slow compared to that of the magnetic disk unit. While the seek time of the magnetic disk unit is measured in tens of milliseconds, it is measured in hundreds of milliseconds in the CD-ROM unit. This is due to the use of a heavy lens in the read head and to the CD-ROM structure (the data storage format uses a spiral track as in a vinyl record).

- Transfer rate
  The data transfer rate is expressed in numeric values that represent how much data can be transferred in comparison with audio CDs. The audio CD player can read out approximately 150k bytes of data in 1 second, which is an extremely low rate compared to computer processing speed. Therefore, units with transfer speeds 2 times or 3 times as fast as the transfer rate for audio CDs began to be developed and today the transfer rate has reached levels of 10 times and 20 times as fast.

④ Optical disk specifications

The optical disk, which was born from the audio CD and is widely used as a computer storage medium, has multiple variations that make the best use of its high storage capacity, portability, mass production through press replication processing, and other advantages. The standard specifications of these optical disks have been established and the basic standard of each of them is called red book, yellow book, etc. These names were given after the color of the cover of the binder in which the standard specifications were kept.

Figure 2-4-15
Optical disks



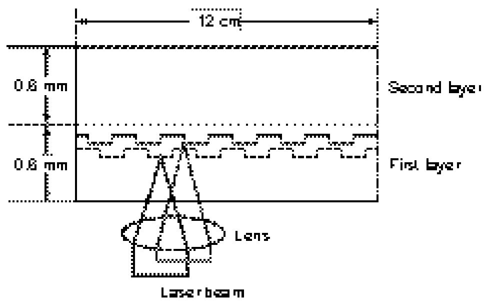
The outline of each standard is indicated below.

- Red Book
  The Red Book is the basic CD standard and describes the physical specifications of the CD. The standard of the CD-G, which made possible the storage of CG (Computer Graphics) in the audio CD, etc., has also been added.
- Yellow Book
  The Yellow Book is the basic CD-ROM standard and describes the physical format of the CD-ROM. As an extension to the Yellow Book, the CD-ROM XA, which made possible extended audio playback and multiple graphics recording, is also specified and its specification becomes the bridge between the CD-ROM and the CD-I.
- Green Book
  The Green Book describes the specifications of the CD-I (CD-Interactive), which is capable of storing audio, images, CGs, characters, programs, data, etc.
- Orange Book
  The Orange Book defines the physical structure of the CD-R (CD-Recordable), a writable CD. Among the CD-Rs, the CD-WO (Write Once), a recordable type in which once information is written, the content cannot be rewritten, and the CD-MO (Magneto Optical) a re-writable type which can be rewritten exist. This CD-R is used in photo CDs (camera film images recorded in a CD).

⑤ DVD

The DVD (Digital Versatile Disk or Digital Video Disk) is an optical disk capable of storing approximately 2 hours of animated images and audio data. The external appearance of DVD disks is the same as that of CD-ROMs, 12 cm of diameter and 1.2 mm of thickness. However, while the recording side of the CD-ROM consists of one side (1 layer), the DVD has a maximum of 2 layers, and data can be stored on both sides.

Figure 2-4-16
DVD structure



At present, DVD-ROMs are commercialized and can be played on DVD players. Likewise, the use of DVD-ROM units in personal computers is expanding.
DVD-ROM storage capacity is as follows:

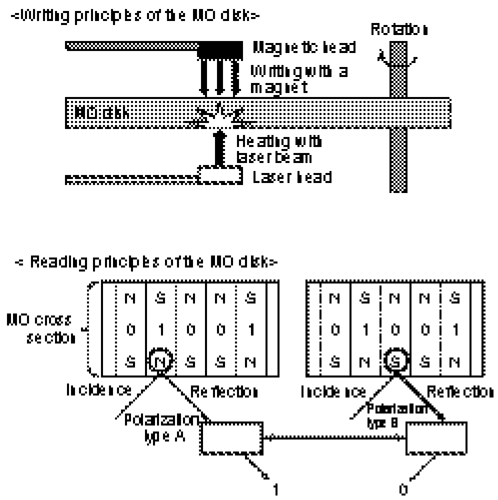
- Single layer single sided recording: 4.7 Gbytes
- Dual layer single sided recording: 8.5 Gbytes
- Single layer dual sided recording: 9.4 Gbytes
- Dual layer dual sided recording: 17 Gbytes

The DVD uses a compression method of animated images called MPEG2, which enables playback of extremely clear images. Due to its large capacity and high image quality, the DVD is attracting attention as a computer auxiliary storage medium/device. The standards of the read-only DVD-ROM, the recordable DVD-R and the re-writable DVD-RAM have been established.

(4) Magneto optical disk (MO) unit

The magneto optical disk unit has almost the same structure as the magnetic disk unit. While data can be only read from the CD-ROM unit, data can be read from and written onto the magneto optical disk unit. The main characteristic of the magneto optical disk is that the data reading and recording methods differ. Data recording is performed by applying the laser beam to the magnetized recording side to heat it then record high density information using the magnetic head. Data reading is performed focusing the laser beam on the magnetic disk and reading out the polarization direction of the reflected light. In other words, data writing is performed using a magnet while data reading is performed using a beam.
Figure 2-4-17 shows the writing and reading principles of the magneto optical disk unit. In this diagram, when the magnetization of the magneto optical disk from top to bottom is from N to S the value is "0" and when it is from S to N, "1" is the read out value.

Figure 2-4-17
Data reading and writing operation of the magneto optical disk unit



The magneto optical disk shipped today as a standard is the 3.5-inch disk, with a storage capacity of 128 MB or 230 MB. As a substitute for the floppy disk, the magneto optical disk has come into wide use as a computer auxiliary storage medium.

(5) Semiconductor disk unit

The semiconductor disk unit is a storage unit of high speed and large capacity, which uses flash memories and other devices. In most cases, it is used in high-end mainframe computers as a storage unit positioned between the main storage unit and the auxiliary storage devices. It has the advantage that, despite having several G bytes of storage capacity, its access time is 1/100 that of the magnetic disk unit.

2.4.2 RAID types and characteristics

Since computers have largely penetrated into our daily life, playing a critical role, high reliability is required together with high performance. Therefore, in order to achieve high reliability, a great variety of technologies are used. The method to duplicate system components to allow continued operation in case of a failure of a certain component is called fault tolerance technology. RAID (Redundant Arrays of Inexpensive Disk) is one such technology.
RAID is a method that consists of the parallel use of multiple hard disks (SCSI drives, etc.) in networks, etc. and has a high fault tolerance in the event that a failure occurs in more than one drive. There are 5 levels of RAID, which are used according to the objective.

(1) RAID 0

In RAID 0, data is distributed to more than 1 drive, but there is no spare drive.

(2) RAID1

In RAID 1, the same content is recorded on 2 hard disks with the same capacity. One of them automatically continues operating and the other is used as backup. This RAID 1 is called disk mirroring or disk duplexing.

(3) RAID 2

In RAID 2, bit interleave data is distributed to and recorded onto multiple drives, and the parity and error correction information is recorded in an extra drive.

(4) RAID 3

In RAID 3, bit interleave data is distributed to and recorded onto multiple drives, but only 1 drive is used as the parity drive.

(5) RAID 4

In RAID 4, data is not recorded by bits, but by sectors, and a separate drive is used as the parity drive for error detection.

(6) RAID 5

In RAID 5 the data is distributed and recorded by sectors and the parity information is added as separate sectors in the same way as ordinary data.

Among the above-mentioned RAIDs, the most used is RAID 5, which does not need a parity drive. A dedicated disk for the error correcting code (parity information) is required in RAID 2 and RAID 4. However, even if RAID technology is adopted, since it is only a countermeasure in the event that failure occurs in the disk itself, data backup at regular intervals is indispensable.

2.5 Input/output architecture and devices

Since there are many mechanical operations in the input devices and the output devices, a wide gap between the operation speed of these devices and that of the processors which perform electronic operations only, is generated. If, ignoring this operation speed gap, the processor and the input or output device are connected, the operation speed of the whole computer system will become slow. And as a consequence, the computer characteristic of high-speed processing becomes ineffective.
In order to solve this problem, input/output control and interruption are performed.

2.5.1 Input/output control method

When data is exchanged between the processor or the main storage unit and the auxiliary storage devices, input devices, output devices, etc., the following control methods are provided:

· Direct control method
· DMA method
· Input/output channel control method

(1) Bus

The bus is a bunch of signal lines that connects units. In computers with a 16-bit word length, a bunch of 16

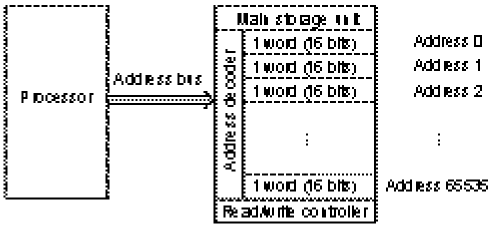
signal lines constitute a bus.
Access and information exchange are performed by a processor and a main storage unit using the following buses:

- Address bus
- Control bus
- Data bus

① Address bus

The address bus connects the main storage unit and the processor. This bus is used for the specification of the main storage unit address by the processor.

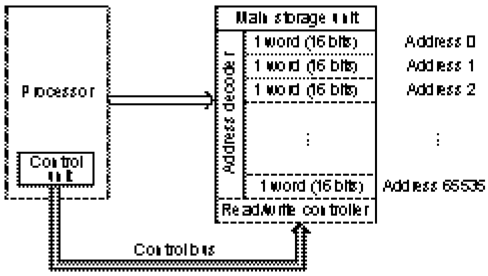
Figure 2-5-1
Address bus



② Control bus

The control bus connects the control unit and the main storage unit. This bus is used for the transmission of the instruction signal to the main storage unit from the control unit. (Figure 2-5-2).

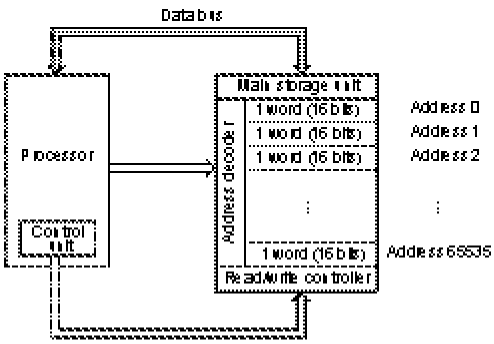
Figure 2-5-2
Control bus



③ Data bus

The data bus connects the main storage unit and the processor and is used to exchange data. Only this bus is used to exchange data between the main storage unit and the processor in both directions.

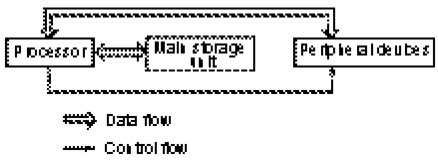
Figure 2-5-3



(2) Direct control method

The direct control method is the method by which the processor directly controls the input/output operations of the peripheral devices, and the data exchange is performed through the processor.
The structure of this method is simple, but it has a big drawback, which is that the processor cannot proceed to perform the next operation until the input/output operation is completed. For that reason, since processor efficiency is low, this method is not so widely used.

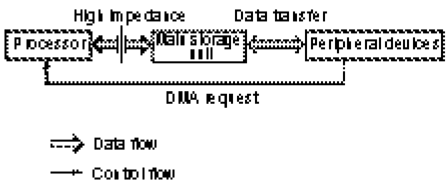
Figure 2-5-4



(3) DMA (Direct Memory Access) method

When a request signal is issued from an input device, output device or any a peripheral device such as an input device or output device, the connections between the processor and the main memory unit and between the processor and the peripheral device are set to the high impedance status and data transfer is performed between the main memory unit and the peripheral device. During this input/output process, the processor performs other processes, and it is not involved in the input/output process at all. This control method is called DMA method and is widely used as the input/output control system of personal computers.

Figure 2-5-5
DMA method



2.5.2 Input/output interfaces

An interface is an agreement for the connection of multiple devices and for the operation of these devices by humans. Among these, the interface related to the data input/output is called input/output interface.
The input/output control method explained above in Section 2.5.1 would not function correctly if the input/output interface were not established.
According to the transfer method, the input/output interface is divided as follows:

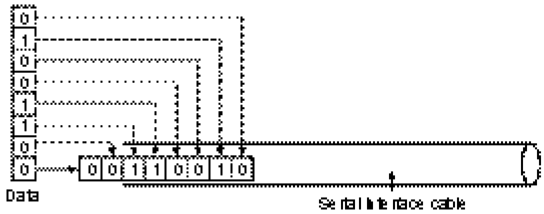
- Serial interface
- Parallel interface

(1) Serial interface

The interface that supports serial data exchange between the computer and the input device/output device is called the serial interface. The serial transfer is the transfer method conducted by lining up data of 8-bit or 16-bit processing units in one row and transferring one bit at a time (Figure 2-5-6). The data transfer rate is slower than that of the parallel interface, but it has the advantage that only one transmission channel is required. Since during a serial transfer there is no signal delay, long-distance transfers can also be performed.
The following serial interfaces are widely used:

- RS-232C (Recommended Standard-232C)
- USB (Universal Serial Bus)

Figure 2-5-6
Serial transfer



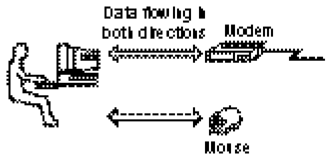
① RS-232C

The RS-232C is an interface that connects the computer, and the modem that converts digital signals into analog signals, or vice versa (Figure 2-5-7). This interface was standardized by EIA (Electronic Industries Association) and the physical connector format, pin number, pin role, etc. are strictly established.

<Characteristics>

- Transfer units: the start bit that indicates the start of 1-byte data: 1 bit, the top bit that indicates the end: 1 bit, the parity bit used for error detection: 1 bit. A total of 11 bits.
- Data exchange can be performed bi-directionally.
- The mainstreams in transfer rates are 28.8 kbps and 33.6 kbps.
- Besides the modem, it is widely used to connect image scanners, mice and other peripheral devices and personal computers.
- Data flow is bi-directional.

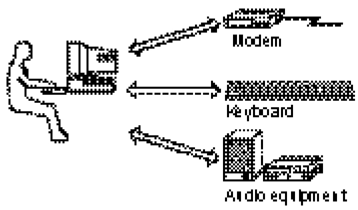
Figure 2-5-7
RS-232C interface connection example



② USB

The USB is a new interface standard by which, besides the keyboard, modem and other peripheral devices, audio signals, image data and other input/output device data can be processed indistinctly with one connector (Figure 2-5-8). According to the USB specification, when a peripheral device supported by the USB is connected, the personal computer automatically is configured. The connection of cables has also been simplified and its use as an input/output interface for multimedia systems is attracting attention.

Figure 2-5-8
USB interface connection example



③ IEEE1394

IEEE1394 is a serial interface used to send animated image data in real time. Since real time transfer is supported, animated images can be smoothly represented. Therefore, IEEE1394 is used as a multimedia interface supporting connections such as those between digital video cameras and personal computers. The maximum data transfer rate is 400 Mbps and a connection of a maximum of 63 nodes can be performed.

④ IrDA (Infrared Data Association)

The IrDA is an interface for wireless (infrared) data transmission. It has the advantage that, since connection cables are not used, layout modifications inside the office can be easily performed. There are several IrDa versions, and the transmission speed ranges between 2.4 kbps and 4.0 Mbps. These versions are equipped in PDA (Personal Digital Assistants) and notebook-type personal computers.

(2) Parallel interface

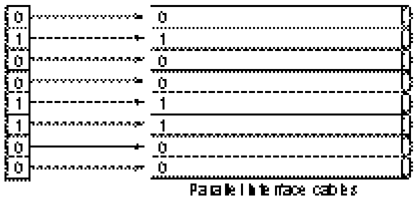
In parallel interfaces, instead of transferring data in sequence, 1 bit at a time, as in serial interfaces, data is transferred in parallel using 8 or 16 cables (Figure 2-5-9). Compared to serial interfaces, the data transfer rate in parallel interfaces is high. However, since multiple transmission channels are required, the transmission channel maintenance cost becomes high.

The following parallel interfaces are widely used:

- Centronics interface
- SCSI (Small Computer Systems Interface)
- GPIB (General Purpose Interface Bus)

Figure 2-5-9

Parallel transfer



① Centronics interface

The Centronics interface is a printer interface developed by the U.S. company, Centronics Data Computer (Figure 2-5-10).

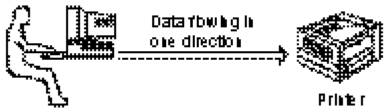
It is not an interface formally standardized by an international industrial standard organization, but, since it has been adopted by a very large number of manufacturers as the interface to connect printers and personal computers, in practice, the Centronics interface has become the (*de facto* standard printer interface).

<Characteristics>

- 8-bit parallel transfer is possible.
- Limited to one-direction data transfer.
- Limited to peer-to-peer connections.
- The transfer rate is 150 kbps

Figure 2-5-10

Centronics interface connection example



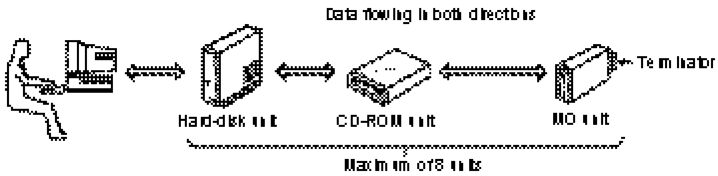
② SCSI

The SCSI was approved as a personal computer standard interface by ANSI (American National Standards Institute).

<Characteristics>

- 8-bit parallel transfers can be performed bi-directionally.
- The transfer rate ranges between 1.5 and 4 Mbps but the transfer rate of SCSI-2, an extensive enhancement of SCSI, is 20 Mbps.
- Up to 8 auxiliary storage devices, such as the hard disk unit and the CD-ROM unit, can be connected one after another. This is called daisy chain. An ID (a number to distinguish the devices) is assigned to the connected devices and a resistor, called a terminator, that indicates the termination, is attached (Figure 2-5-11).
- The pin number is 50 (or 25).
- The data flow is bi-directional.

Figure 2-5-11 SCSI connection example (daisy chain)



③ GPIB

The GPIB was originally approved as a standard interface to connect microcomputers and measurement instruments, but it is currently an interface with a wide range of uses that connects the microcomputer and its peripheral devices.
This interface was standardized as IEEE-488 by the U.S. Institute of Electrical and Electronics Engineers (IEEE).

<Characteristics>

- 8-bit parallel transfers are possible.
- It is composed of 24 signal lines.
- The transmission distance is within 20 m.
- The data transfer rate ranges between 1 kbps and 1 Mbps
- Connection of up to 15 devices is possible.

Figure 2-5-12 synthesizes the above-mentioned input/output interfaces.

Figure 2-5-12 Types of input/output interfaces

	Name	Transfer rate	Connected devices	Content	Industrial standard
Serial transfer	RS-232C	· 28.8kbps · 33.6kbps · 56kbps	· Modem · Printer · Mouse · Plotter, etc.	· Connector format and role · Pin number and role	EIA standard
	USB	· 12Mbps	· Keyboard · Modem · Speaker, etc.	· Multimedia support · Audio, images, etc. can be processed with one connector · Cable connection simplification	—
	IEEE1394	· 400Mbps	· Digital video camera	· Multimedia support · Real-time function · Possibility to connect up to 63 nodes	IEEE standard
	IrDA	· 2.4kbps — 4.0Mbps	· Hard disk · Printer · Modem · Mouse	· Infrared data transmission	IrDA standard
Parallel transfer (8 bits)	Centronics interface	· 150kbps	· Printer · Plotter · Digitizer, etc.	· Wide use as printer standard interface	De facto standard developed by Centronics Data Computer Corp.
	SCSI	· 1.5—4Mbps	· Auxiliary storage devices	· Possibility to connect up to 8 devices in a daisy chain	ANSI standard
	GPIB	· 1kbps — 1Mbps	· Measurement instruments · Peripheral devices	· Developed by the U.S. company, Hewlett-Packard · Possibility to connect up to 15 devices	IEEE-488

2.5.3 Types and characteristics of input/output devices

While the data we handle is made up of characters, numeric values (decimals), symbols, etc., only binary digits can be handled by the computer. Therefore, the data and information subject to process must be converted into a format that can be processed by the computer before being transferred to the processor. The devices equipped with this function are generally known as input devic es.

Likewise, if we see the binary results processed by the computer, it will not be easy to understand their meaning. Therefore, the content processed using binary digits has to be converted into a format that can be understood by humans. The devices that perform this kind of function are generically known as output devices.

Figure 2-5-13
Roles of input devices and output devices

The input device is a device exclusively used to transfer information to the computer, and the output device is a device that represents the result of the computer process in a format that can be understood by us. But there is also a device equipped with both functions. It is called the input/output device.

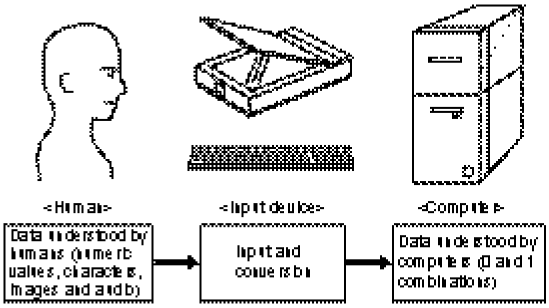
(1) Input devices and output devices

The device that enters data and programs into the computer is called the input device, and the device that represents/outputs computer data and programs is called the output device.

① Input device

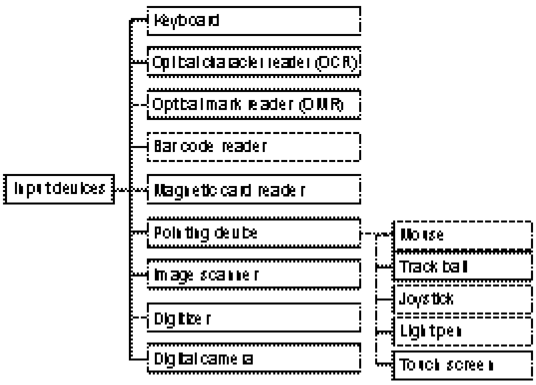
An input device is a device that converts data that can be understood by humans such as numeric values, characters, images and audio, into a data format (0 and 1 combinations) that can be understood by computers, and loads it into the computer main storage unit.

Figure 2-5-14
Input device's role



The early computers were limited to processing characters and numeric values, but with the progress of information technology today, computers can also process image and audio data. The different types of input devices that can process all these kinds of information are shown in Figure 2-5-15.

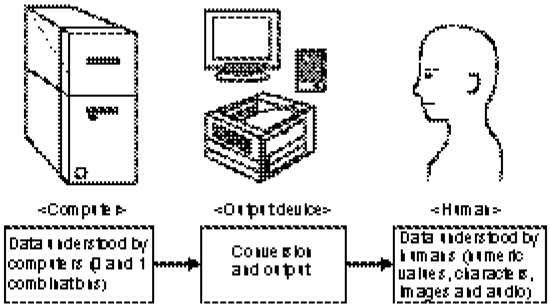
Figure 2-5-15
Various input devices



② Output device

Output device is the general term for the devices that convert the data processed in the computer (which processes all the data using 0s and 1s to produce results which are combinations of 0s and 1s) into data that can be understood by humans such as numeric values, characters, images, still images, animated images and audio, and output it.

Figure 2-5-16
Output device's role



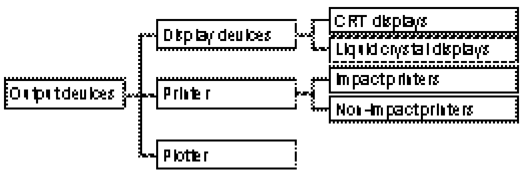
As in the input devices, there are different kinds of output modes for the output devices (Figure 2-5-17). For example, if the output is divided into "Display" and "Printing," it can be classified into the following two types:

- Display devices: The output is displayed on a television screen.
- Printer: The output is printed on the surface of a piece of paper.

Furthermore,

- Output into a display device is called "Soft copy"
- Output into a printer is called "Hard copy"

Figure 2-5-17
Various output devices



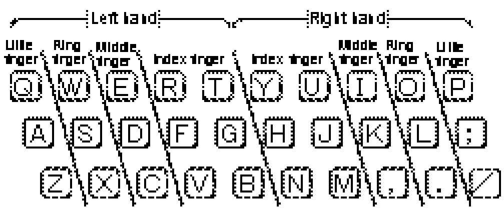
(2) Keyboard

The keyboard, which is the input device we find most familiar, inputs the code corresponding to the key of the character or symbol we press in the processing unit. A keyboard layout is specified by a JIS (Japanese Industrial Standard). However, in order to improve the efficiency of Japanese input, some word processor manufacturers have developed unique keyboard layouts of their own.

Figure 2-5-18
Keyboard

Figure 2-5-19 shows the correct finger position to be assumed to press the keys. Once one gets used to it, it becomes easy to press the correct keys without looking at the keyboard. This typing method is called touch typing.

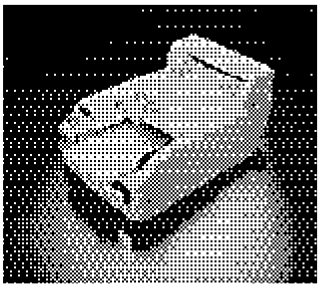
Figure 2-5-19
Touch typing



(3) Optical character reader (OCR)

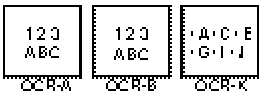
The optical character reader is a device that, based on the intensity of the reflected light, reads out characters and symbols and inputs them (Figure 2-5-20).

Figure 2-5-20
Optical character reader (OCR)



At the beginning, the optical character reader could only read easily identifiable special printed characters and JIS OCR fonts (Figure 2-5-21). However, at present, the character pattern recognition has improved and even handwritten characters can be recognized.

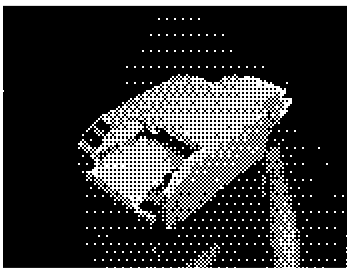
Figure 2-5-21
OCR fonts



(4) Optical mark reader (OMR)

The optical mark reader is the device that reads and inputs data according to the marks made on marksheets. Alphanumeric characters are printed on marksheets; the part to be input is marked with a pencil, etc. The difference with the optical character reader is that this device does not directly recognize the patterns of characters or numeric values, but reads them out based on the marked position instead.
The information reading principle is the same as that of the optical character reader. Based on the reflected light, this device judges whether or not marks exist and inputs the character or numeric value corresponding to the marked position. Therefore, there are cases where reading errors occur or reading cannot be performed – when marksheets are dirty or folded.

Figure 2-5-22
Optical mark reader (OMR)



Since the mark reading position is set through the program, the pattern of the marksheet can be freely designed. In practice, marksheets are used in different fields, and are also used as answer sheets in the Information Processing Engineer Examination.

Figure 2-5-23
Marksheet example

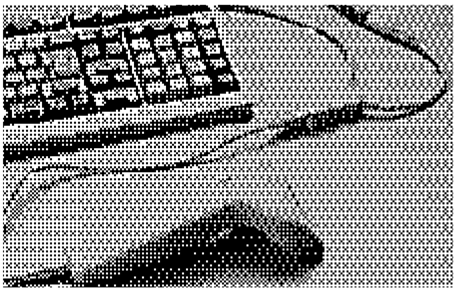
(5) Bar code reader

The bar code reader is the device that reads and inputs the bar code attached to diverse products. The following types of bar code readers exist:

- Pen type
- Touch type
- Laser type

When the pen-type device is used, the bar code has to be traced with LED (light emitting diode). With the touch-type device, the LED only has to be focused on the bar code (Figure 2-5-24). Likewise, since it is not necessarily to directly touch the bar code with the laser-type device, it is widely used in convenience stores and supermarkets.

Figure 2-5-24
Bar code reader



Generally, in account processing using bar codes, not only product identification and accounting are performed, but also, based on the information input, stock control and order control are performed.

(6) Magnetic card reader

The magnetic card reader is a device that reads and inputs the information needed from a magnetic card. There are different types of readers depending on the magnetic card to be read. Automatic train ticket gate machines are also magnetic card readers.
The magnetic card is a paper or plastic card which has a magnetic stripe on the surface to store information such as numeric values and characters.
At present, as it is said, we live in a "card society" and magnetic card use has widely expanded as a paying method that replaces cash in our daily life. Among the most familiar cards, we have the following:

- Phone cards
- Cash cards
- Credit cards
- Tickets for automatic ticket gates

Magnetic cards have become indispensable in our daily life. There is also the IC card, which has increased the storage capacity of magnetic cards and incorporated information processing functions. It is more expensive than regular magnetic cards, but it is superior in security and functional aspects.

(7) Pointing device

"Pointing device" is the generic term for the devices that input positional information on the screen of a display device.
With the expansion of computer use, different kinds of pointing devices have appeared. Among the main pointing devices, the following can be mentioned.

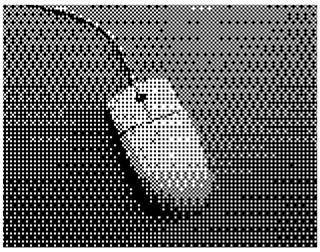
- Mouse
- Track ball
- Joystick
- Light pen
- Touch screen

Without the troublesome operations on keyboards, etc., using any of these devices, anybody can easily input data while watching the screen of the display unit.

① Mouse

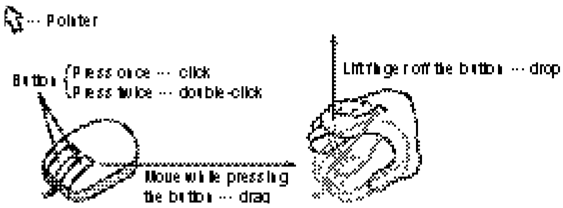
Along with the keyboard, the mouse is the most used input device. It was named mouse due to the similarity of its external appearance to a mouse.

Figure 2-5-25
Mouse



The mouse has a mechanism by which, when it is moved, the ball on the underside rolls, and the screen pointer moves according to the rolled distance and direction. When the pointer has been moved to the aimed position, by pressing the button of the mouse, the positional information is entered. This operation is called clicking. Likewise, as it is shown in Figure 2-5-26, besides clicking, there are other button operations such as double clicking, which means pressing the button two times, and dragging, which is the specification of an area by moving the mouse while holding the button down, etc.

Figure 2-5-26
Mouse operations and pointer

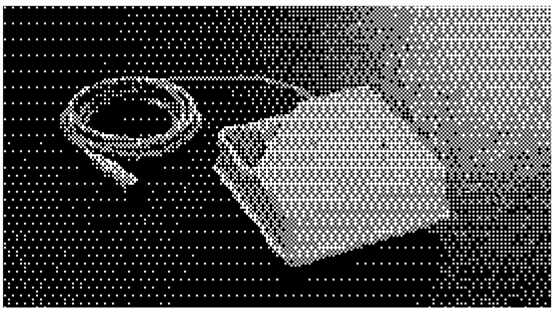


The biggest characteristic of the mouse is that, unlike the keyboard, it does not input data directly to the computer; instead, by pointing at the icons and windows indicating the operation locations which appear on the screen, it indicates and inputs operations to the computer. In other words, the mouse supports the GUI (graphical user interface) environment.

② Track ball

The principle is the same as that of the mouse, but, since the track ball is moved directly with the fingers, it does not require the moving space needed by the mouse. For that reason, it is often equipped in lap-top and notebook personal computers.

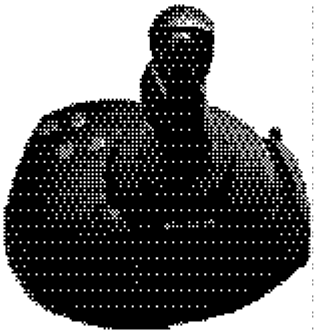
Figure 2-5-27
Track ball



③ Joystick

With the joystick, the stick is moved back and forth as well as to the right and left, and the pointer moves according to the direction and the angle in which the stick is moved. It can perform the same operations as the mouse, but, since indications have to be performed with buttons, etc. besides the stick, it is not so easy to handle as the mouse, which can be manipulated with one hand. For that reason, joysticks are widely used for game software manipulation.

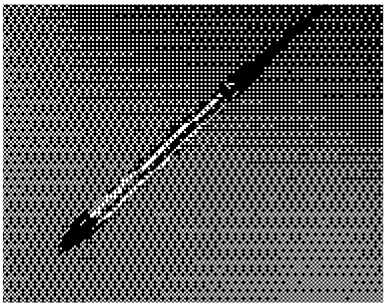
Figure 2-5-28
Joystick



④ Light pen

The light pen is a device that inputs the coordinate information by pointing and tracing on the screen of the display device directly.
Since the optical sensor at the point of the light pen detects the position of the information on the screen and inputs it, the responsiveness is high.
As the uses of the light pen, data entry on palm top personal computers entry, and the entry of handwritten characters into a word process can be mentioned.

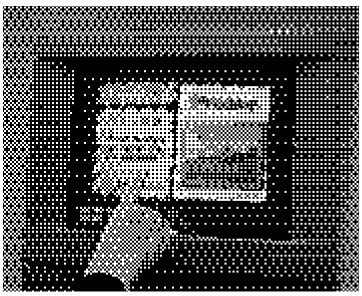
Figure 2-5-29
Light pen



⑤ Touch screen

The touch screen, which is also called a touch panel, takes advantage of the static electricity that passes through the human body. By directly touching with the finger the screen of the display device, the positional information is entered. In this mechanism, a transparent panel is attached to the screen surface, and the sensor on the panel senses changes in the voltage and detects the touched position.
Due to the dimensions of the area touched with the finger, detailed manipulations and instructions can not be performed, but since it can be easily manipulated by anybody, it is widely used in the automatic teller machines (ATMs) of banks, automatic ticket vending machines at train stations, reception/information at hospitals, etc.

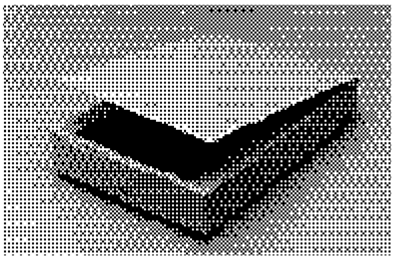
Figure 2-5-30
Touch screen



(8) Image scanner

The image scanner is a device that reads and inputs figure and picture data from a sheet of paper with the same principle as a fax. The mechanism consists of decomposing a figure or image into a dot image, composed of small dots, and focussing light on it of order to load the intensity of the light reflected as electronic codes into the computer.
The devise which moves the reading mechanism over a fixed piece of paper is usually called the image sensor.

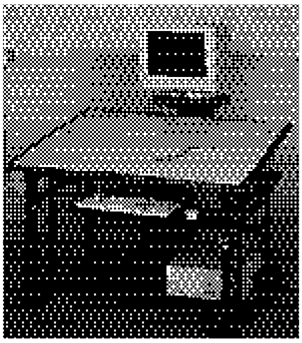
Figure 2-5-31
Image scanner



(9) Digitizer

The digitizer is a device that, by tracing a plane panel figure with a pen or cursor, detects the coordinates position and, based on this consecutive coordinate information, inputs the figure. This device is used by the CAD (Computer Aided Design) application, in which the input of figures of high precision is required. Small-sized devices are sometimes called tablets for making a distinction.

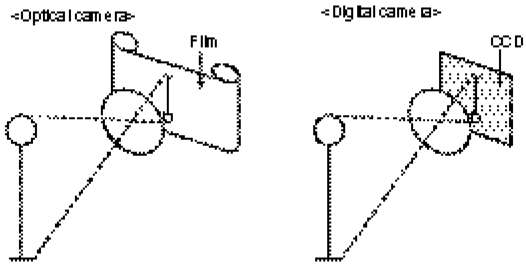
Figure 2-5-32
Digitizer



(10) Digital camera

The digital camera is a camera that can input the picture taken to the computer as data. While optical cameras record images through the chemical change of the sensitized material of the film surface, digital cameras, using the image sensor of a semiconductor element called CCD (Charge Coupled Device), convert optical pictures into digital data and record this data as image files.
A semiconductor memory called flash memory is widely used as the storage medium.

Figure 2-5-33
Optical camera and digital camera mechanism



(11) Display device

In ordinary computer systems, operations are conducted verifying on the spot the input data and process results displayed on the screen. The display device is one of the devices which are indispensable for human use of computers. Displays are roughly divided into the following two types:

- Character displays: Capable of displaying characters only.
- Graphics displays: Capable of displaying characters and graphics.

Likewise, according to the colors that can be displayed, displays are divided as follows:

- Black and white displays
- Color displays, etc.

At present, color graphics displays are the standard. Furthermore, according to the structure of the display screen, display devices can be classified as follows:

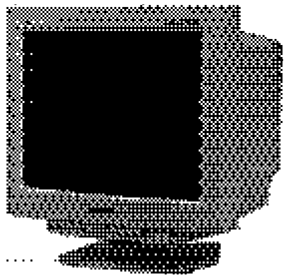
- CRT displays
- Liquid crystal displays

Here, CRT displays and liquid crystal displays will be explained.

① CRT display

The display device that has the same structure as the television, and uses the cathode-ray tube, is called CRT (cathode-ray tube) display.

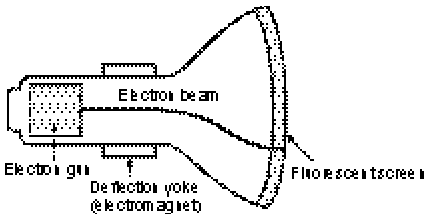
Figure 2-5-34
CRT display



a. Mechanism

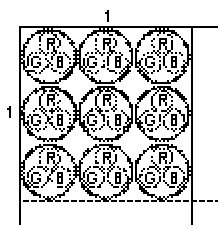
As it is shown in Figure 2-5-35, in the CRT display, when struck by the electron beam, the fluorescent screen emits light, which is displayed on the screen.

Figure 2-5-35
CRT structure



Color display is generally used in CRT displays. Color images are represented by striking the dots that contain the "three primary colors of light," R, G and B (Red, green and blue) with the electron beam.

Figure 2-5-36
Color screen diagram magnification



Besides the above mentioned, the screen display is equipped with an important function called the screen saver. In the CRT display, when the same screen is displayed for a long period of time, the image of that screen is burnt into the fluorescent screen of the cathode-ray tube. In order to prevent this, an animated image is displayed on the screen. This software is called screen saver.

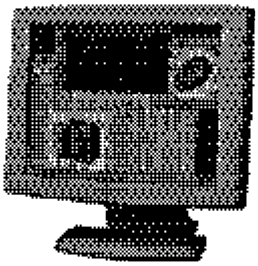
b. Resolution

The screen size is represented by the diagonal length of the screen. According to this, there are screens of 15 inches, 17 inches, 21 inches, etc.
The screen resolution is represented by the value of the number of dots which can be represented in 1 screen (width × height), and resolutions of 640 × 480, 800 × 600, 1024 × 768, 1280 × 1024, etc. Today, as a result of the expansion of multimedia, 1280 × 1024 resolution has become a *de facto* standard due to its capacity to process high image quality. Likewise, the CRT display called multi scan monitor, in which the resolution can be switched according to necessity, is expanding.

② Liquid crystal display

The liquid crystal display is a display device widely used in the display screen of calculators, etc. (Figure 2-5-37). The liquid crystal material used has the property of aligning in one direction when voltage is applied, changing from non-transparent to transparent. The liquid crystal display takes advantage of this property, and by controlling whether or not light passes through it with the voltage applied, the appropriate display is produced.
Currently, the majority of liquid crystal displays are also color displays that use R, G, B color filters.
Unlike CRT displays that require a specific depth, liquid crystal displays are thin, and moreover, have low power requirements. Due to these reasons, they are widely used in lap top and notebook personal computers.

Figure 2-5-37
Liquid crystal display



The following two types of liquid crystal display exist:

a. Passive matrix type

The system in which multiple liquid crystal pixels are controlled by one semiconductor is called the passive matrix type. This system is adopted by the STN (super twisted nematic) liquid crystal display. Currently, the DSTN (Dual scan STN) liquid crystal display, which divides the liquid crystal panel into upper and lower sides enabling double scanning, is expanding.

b. Active matrix type

The system in which one liquid crystal pixel is controlled by one semiconductor is called the active matrix type. This system is adopted by the TFT (Thin Film Transistor) liquid crystal display. The TFT liquid crystal display uses a transistor as a switch to apply voltage. The screen contrast, response speed, viewing angle, etc. are dramatically superior to the STN liquid crystal display. However, due to the complex structure, the production cost is high.

(12) Printer

The printer is the oldest computer output device and, today, it is much more widely used.
There are many types of printers. According to the printing methods, printers are classified as follows:

- Impact printers: Print by mechanically hitting pre-formed characters against an ink ribbon.
- Non-impact printers: Print using heat, ink, laser, etc.

Likewise, according to the printing unit, printers are classified as follows:

- Serial printers: Print 1 character at a time, as typewriters.
- Line printers: Print 1 line at a time.
- Page printers: Print 1 page at a time.

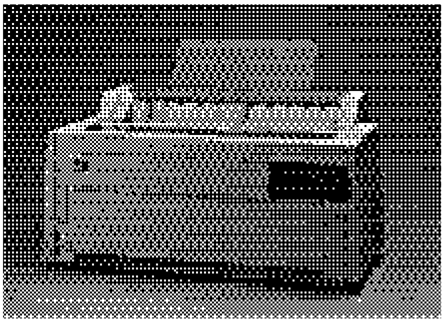
Here, among the different types of printers, the printers indicated below will be explained:

Serial printer	Dot impact printer	Impact printer
	Thermal transfer printer	Non-impact printer
	Thermal printer	
	Ink-jet printer	
Page printer	Laser printer	
Line printer	Line printer	Impact printer

① Dot impact printer

The dot impact printer is the printer that prints by striking a head against an ink ribbon, which, in turn, hits the paper. Alphanumeric characters are sets of dots, and since printing is performed by striking a head containing multiple small pins, dot impact printers are noisy. This is a drawback: however, they are convenient for performing multiple printing at once using carbon copies.
Compared to thermal transfer printers, etc., the quality of the printed characters is not so good. The density of the dots composing a character (width × height) determines the print resolution. The number of dots forming one character varies from 9 × 7, 16 × 16, 24 × 24. The higher these values, the better the resolution of the printed characters. Likewise, the characters that can be printed vary. Only alphanumeric characters can be printed with a 9 × 7 resolution, while kanji can also be printed with 16 × 16 and 24 × 24 resolution.

Figure 2-5-38
Dot impact printer



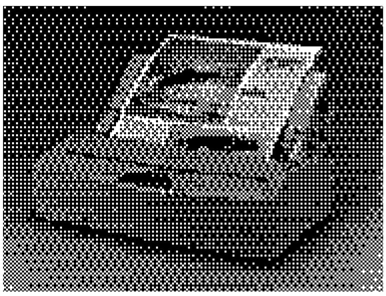
② Thermal transfer printer

The thermal transfer printer is a printer in which the print head heats and melts the ink of the ink ribbon to print the dot-composed character on normal paper. Since this printer uses a non-impact method, the noise level is lower than that of dot impact printers.
On the other hand, the thermal printer uses thermal paper as printer paper. Since thermal paper fades with time, it is not suitable for long-term conservation. Furthermore, the fact that the running cost becomes high due to the high price of thermal paper is a drawback.

③ Ink-jet printer

The ink-jet printer is a printer in which, according to the form of the dot-composed character, tiny ink nozzles in the print head squirt ink onto the paper. Color ink of 3 colors "Cyan: C, Magenta: M and Yellow: Y) or 4 colors" "3 colors + Black: K" are used in color printing. Today, the use of color ink-jet printers as personal computer printers has expanded.

Figure 2-5-39
Ink-jet printer



④ Laser printers

The laser printer is a page printer that, using toner (powder ink), creates the printing image of one page on the photoreceptive drum and transfers it to the paper through the application of laser beams.
The printing principle is the same as that of copy machines, and the character size, space between the lines, etc. can be selected freely. Figures, images, etc. can also be printed and, print quality as well as printing speed are high. For that reason, it is the mainstream printer for business use.

Figure 2-5-40
Laser printer

2.6 Computer types and architectural characteristics

2.6.1 Computer types

Computers used in a great variety of fields will be explained below.

(1) Personal computer

As the name implies, personal computers are computers that were developed for personal use, commonly called PCs for short. Based on their external appearance, different types of personal computers have multiplied. These personal computers can be classified as follows:

- Desk-top type, which can be placed on a desk (Figure 2-6-1)
- Lap-top type, which can be placed on one's lap
- Notebook type, the size of A4 or B5 paper, thin and light (Figure 2-6-2)

Likewise, expansion of the palm-top type (Figure 2-6-3) ultra small-sized personal computers which can be held in one's palm, is starting.
On the other hand, according to the place where they are set up, and the main use purpose, computers can be classified as follows:

- Home: Used as word processors and to play games as home and hobby computers.
- Enterprise: Word processor, spreadsheet software and database software are used for business.
  Used in software development.
- School and enterprise: Used in CAI (Computer Aided Instruction) application for education.

Likewise, considering the use mode, up to now, the stand-alone system was used in most computers, but recently, the network system in which personal computers are connected by communication lines is becoming the mainstream.

Figure 2-6-1
Desk-top type

Figure 2-6-2
Notebook type

Figure 2-6-3
Palm-top type

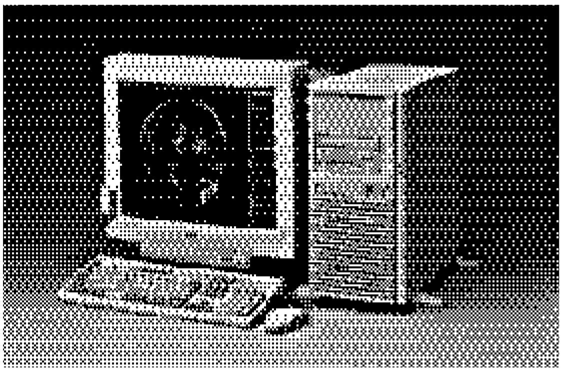
(2) Workstation

Due to the expansion of use of personal computers, enterprises are adopting the system of one computer per person. However, personal computers lack the capacity to perform technological calculation processing, software development, etc. In order to solve this problem, computers called engineering workstations (EWS) were created. Compared to personal computers, workstations are capable of performing high quality image processing, etc. with high speed (Figure 2-6-4).

The main applications of these workstations are listed below:

- Research and development fields:
  High-speed processing of complex scientific and engineering calculations.
- Product design/manufacturing fields:
  Used in CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), etc. application.
- Software development field:
  Use of CASE tools (Computer Aided Software Engineering tool), etc.
- Communication network field:
  Used as client machines or server machines in distributed processing systems.

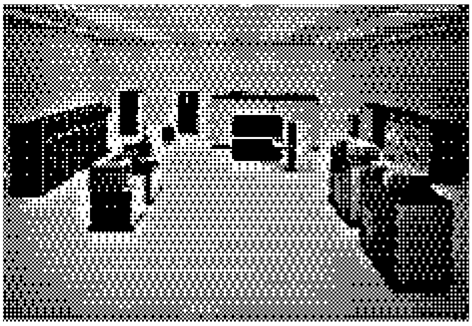
Figure 2-6-4
Workstation



(3) General-purpose computer

The general-purpose computer is a computer which, literally, can be used for multiple purposes, capable of performing both office work as well as scientific and engineering calculations. Since it is the mainframe of a great number of computers used in an enterprise, it is also called mainframe (Figure 2-6-5).
The computers that conduct enterprise core business system processing, an automatic ticketing processing, bank services, etc. are all general-purpose computers.
Since most general-purpose computers are large sized, due to the high heat generation, it is necessary to install them in an air-conditioned room called a computer room.

Figure 2-6-5
General-purpose computers



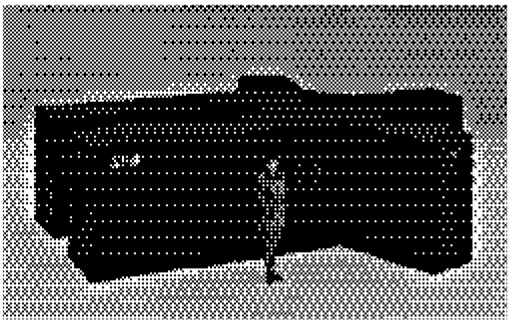
(4) Supercomputer

There is no precise definition of supercomputers. Commonly, computers capable of performing enormous and complex calculations at extremely high speeds are called supercomputers. In other words, it can be said that supercomputers are computers whose design attaches importance to high-speed calculation.
Supercomputers are computers that compile computer high-speed technology using forefront semiconductor element technology as well as vector processors that perform floating point operations and vector operations, etc. However, their use purposes are limited. Among the main purposes, the following can be mentioned:

- Weather forecast
- Simulation of nuclear power generation
- Orbit calculation of artificial satellites

As a manufactured product, the U.S. Cray Inc.'s Cray supercomputer is famous. In Japan NEC's SX and Fujitsu's FACOM VP are produced.

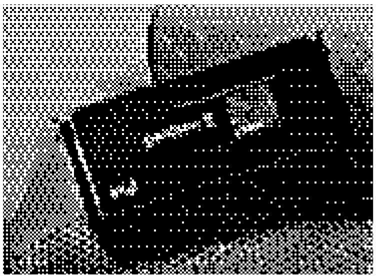
Figure 2-6-6
Supercomputer



(5) Microcomputer

Microcomputers are small-sized computers into which a microprocessor is built. The computers that are imbedded into machines, especially household appliances such as washing machines, air conditioners and AV appliances, in order to control the machine operation are called microcomputers. These microcomputers are electronic parts with bare integrated circuits. According to the purpose, information on the temperature and number of revolutions can be entered using a sensor. Since their function is to repeat the same operation, control data is recorded in ROMs (Read Only Memory). Likewise, since the output devices are motors or electric switches, they are also called actuators.

Figure 2-6-7
Microcomputer



(6) Process control computer

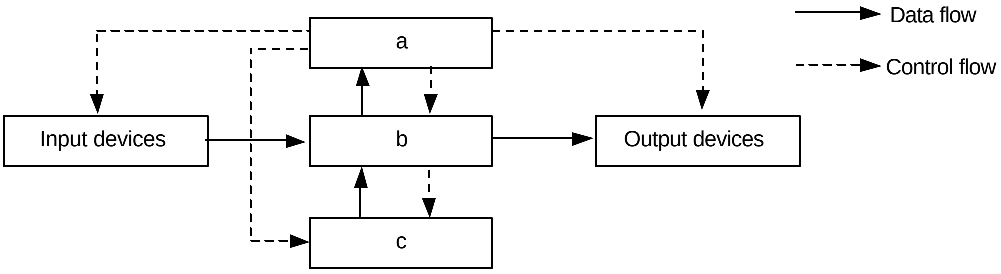
Process control computers are computers that control the different types of machines in steel mills, automobile plants, petroleum refineries, etc. Chemical plants, etc. are entirely automated with process control computers. When the supervising computer detects an abnormality, it immediately controls each machine and adjusts the production process.

In addition to this, centralized control and automation have been achieved through the use of process control computers in power system control, general building security systems, highway traffic control, etc.

Exercises

Q1

What is the combination of words that should fill in the blanks of the diagram representing the computer basic configuration?



	a	b	c
A	Arithmetic unit	Main storage unit	Main storage unit
B	Main storage unit	Control unit	Arithmetic unit
C	Control unit	Arithmetic unit	Main storage unit
D	Control unit	Main storage unit	Arithmetic unit

Q2

What is the appropriate explanation of a DRAM?

A. DRAM represents 1 bit depending on whether the capacitor is charged or not. It is commonly used as a main storage unit.
B. Data is written at the time it is manufactured. It is used as a microprogramming storage memory.
C. Data can be written using a special device and erased with ultraviolet light.
D. It is composed of flip flops. The speed is high but the manufacturing cost is high as well. It is used in cache memories, etc.

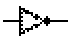
Q3

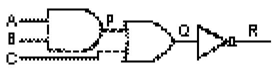
Regarding the index modification of the machine language instruction, which of the following would be the effective address?

Address in which the instruction is stored: 1000
Value of the instruction language: 100
Value of the index register: 10

A. 10 B. 100 C. 110 D. 1100 E. 1110

Q4

Given the following circuit, when the input values are A=1, B=0, C=1, what is the appropriate output value for P, Q and R? Here  **represents an AND gate,**  **represents an OR gate and**  **represents a NOT gate.**



	P	Q	R
A	0	1	0
B	0	1	1
C	1	0	1
D	1	1	0

Q5 **When the sum of 1-bit values A and B is represented in 2-bit values, which of the following corresponds to the combination of the logical expression of the higher bit D and the lower bit S? Here, "·" represents the logical product (AND), "+," the logical sum (OR) and $\overline{A}$, the negation (NOT) of A.**

A	B	Sum of A and B	
		C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

	C	S
A	$A \cdot B$	$(A \cdot \overline{B}) + (\overline{A} \cdot B)$
B	$A \cdot B$	$(A + \overline{B}) + (\overline{A} + B)$
C	$A + B$	$(A \cdot \overline{B}) + (\overline{A} \cdot B)$
D	$A + B$	$(A + \overline{B}) + (\overline{A} + B)$

Q6 **In a computer with 3 types of instruction sets, which of the following corresponds to the MIPS value when their respective execution speed and frequency rate are as follows?**

Instruction set	Execution speed (microseconds)	Frequency rate
A	0.1	40%
B	0.2	30%
C	0.5	30%

A. 0.25 B. 0.8 C. 1.25 D. 4

Q7 **A given program executes instructions a, b, c and d in the following order:**

a → a → b → a → c → d

The CPI required to execute each instruction is indicated in the following table. If 1 clock cycle of the CPU is 10 nanoseconds, how many nanoseconds will the CPU execution of this instruction string require?

Instruction	CPI
a	6
b	2
c	4
d	8

A. 20 B. 32 C. 200 D. 320

Q8 **Which of the following is the method of the ordinary computer basic architecture that loads programs and data together in a computer storage device and sequentially reads and executes them?**

A. Address method
B. Virtual storage method
C. Direct program control method
D. Program storage method

Q9 **Given the following magnetic disk unit specifications and conditions of the data subject to storage, how many tracks does the necessary area have when the blocking factor is 20? Here, the area is assigned by track and the file organization is sequential.**

Magnetic disk unit specifications

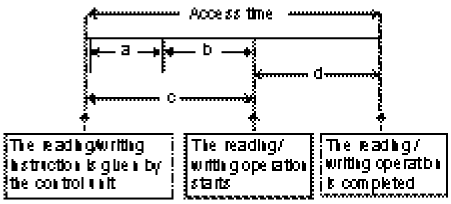
Storage capacity per track	25,200 Bytes
Inter-block gap	500 Bytes

Conditions of the data subject to storage

Record length	200 Bytes
Number of records	10,000 Records

A. 80 B. 83 C. 89 D. 100

Q10 **The following diagram represents the access time of the magnetic disk unit. Which is the a, b, c and d correct combination?**



	a	b	c	d
A	Seek time	Search time	Latency	Data transfer time
B	Seek time	Latency	Search time	Data transfer time
C	Latency	Seek time	Data transfer time	Search time
D	Latency	Data transfer time	Seek time	Search time

Q11 **Given the magnetic disk unit with the following performance, what is the average access time in milliseconds required to read the 2,000-byte-length-block data recorded in this magnetic disk?**

Magnetic disk unit performance

Storage capacity per track (bytes)	20,000
Revolution speed (revolution/minute)	3,000
Average seek time (milliseconds)	20

A. 30 B. 31 C. 32 D. 42

Q12 **Regarding the optical disk characteristics, which of the following descriptions is correct?**

A. CD-ROMs have large storage capacity, but since high-level technology is required for their manufacture, compared to magnetic disks, the cost is higher for the same amount of information.
B. In the magneto optical disk, which is one of the rewritable storage media, data is recorded by changing the medium magnetization direction.
C. In the recordable optical disk, in which data is recorded by making microscopic holes in the medium, data can be rewritten as many times as required.
D. Since the access mechanism of magneto optical disks is very similar to that of magnetic disks, the average access time is also of the same level.
E. Since magneto optical disks are susceptible to heat, light and dust, compared to magnetic disks, the magneto optical disk's durability is lower.

Q13 Which of the following is the most appropriate explanation of mirroring, which is one of the methods used to improve the magnetic disk unit reliability?

A. By giving a mirror-like finish to the disk surface the resistance at the time the disk rotates is reduced.
B. The data block and the parity block are stripped and stored across multiple disks.
C. Besides the disks that record the data, another disk for parity recording is used.
D. Identical data is recorded simultaneously in separate disks.

Q14 Which is a feasible combination of interfaces for connecting the peripheral devices indicated below? Here ATA/ATAPI-4 represents the interface that is normally called IDE.

	Hard disk, CD-ROM	Modem	Keyboard
A	ATA / ATAPI-4	GPIB	SCSI
B	GPIB	SCSI	RS-232C
C	SCSI	RS-232C	USB
D	USB	IrDA	ATA / ATAPI-4

Q15 If an image, whose height and width in pixels is 480 dots and 640 dots, respectively, is represented in 256 types of colors: approximately how many kilo bytes would be required in order to save this data in a storage device? It should be noted that no compression process is performed.

A. 170 B. 310 C. 480 D. 9,840 E. 78,650

Q16 Which of the following printers uses a heating element to melt the ink of the ink ribbon and is capable of printing on normal paper?

A. Ink-jet printer
B. Thermal printer
C. Dot impact printer
D. Thermal transfer printer
E. Laser printer