Computer Organization

Presented By:

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Text books

•Carl Hamacher, Zvonko Vranesic, Safwat Zaky, **Computer Organization**, 5th Edition, Tata McGraw Hill, 2002.

•William Stallings: **Computer Organization & Architecture**, 9th Edition, Pearson, 2015.

Course Topics

Introduction (Module 1): Basic Structure of Computers: Basic Operational Concepts, Bus Structures, Performance –Processor Clock, Basic Performance Equation, Clock Rate, Performance Measurement, Machine Instructions and Programs: Memory Location and Addresses, Memory Operations, Instructions and Instruction Sequencing, Addressing Modes, Assembly Language, Basic Input and Output Operations, Stacks and Queues, Subroutines, Additional Instructions, Encoding of Machine Instructions.

Input/Output Organization(Module 2): Input/Output Organization: Accessing I/O Devices, Interrupts – Interrupt Hardware, Direct Memory Access, Buses, Interface Circuits, Standard I/O Interfaces – PCI Bus, SCSI Bus, USB.

Memory System(Module 3): Memory System: Basic Concepts, Semiconductor RAM Memories, Read Only Memories, Speed, Size, and Cost, Cache Memories – Mapping Functions, Replacement Algorithms, Performance Considerations.

Arithmetic (Module 4): Arithmetic: Numbers, Arithmetic Operations and Characters, Addition and Subtraction of Signed Numbers, Design of Fast Adders, Multiplication of Positive Numbers, Signed Operand Multiplication, Fast Multiplication, Integer Division.

Basic Processing Unit:(Module 5): Basic Processing Unit: Some Fundamental Concepts, Execution of a Complete Instruction, Multiple Bus Organization, Hard-wired Control, Micro programmed Control. Pipelining: Basic concepts of pipelining

Module 1
Basic Structure of Computers

Learning Objectives

- Understand the basics of computer organization: structure and operation of computers and their peripherals
- Understand the concepts of programs as sequences or machine instructions.
- To analyse various addressing modes and machine instructions
- Assembly language
- To study basic IO operations and Stack operations

What is a computer?

- a computer is a sophisticated electronic calculating machine that:
  - Accepts input information,
  - Processes the information according to a list of internally stored instructions and
  - Produces the resulting output information.
- Functions performed by a computer are:
  - Accepting information to be processed as input.
  - Storing a list of instructions to process the information.
  - Processing the information according to the list of instructions.
  - Providing the results of the processing as output.
- What are the functional units of a computer?

Information Handled by a Computer

- Instructions specify commands to:
  - Transfer information within a computer (e.g., from memory to ALU)
  - Transfer of information between the computer and I/O devices (e.g., from keyboard to computer, or computer to printer)
  - Perform arithmetic and logic operations (e.g., Add two numbers, Perform a logical AND).
- A sequence of instructions to perform a task is called a program, which is stored in the memory.
- Processor fetches instructions that make up a program from the memory and performs the operations stated in those instructions.
- What do the instructions operate upon?

Information in a computer -- **Data**

- Data are the "operands" upon which instructions operate.
- Data could be:
  - Numbers,
  - Encoded characters.
- Data, in a broad sense means any digital information.
- Computers use data that is encoded as a string of binary digits called bits.

Functional Units

Functional Units

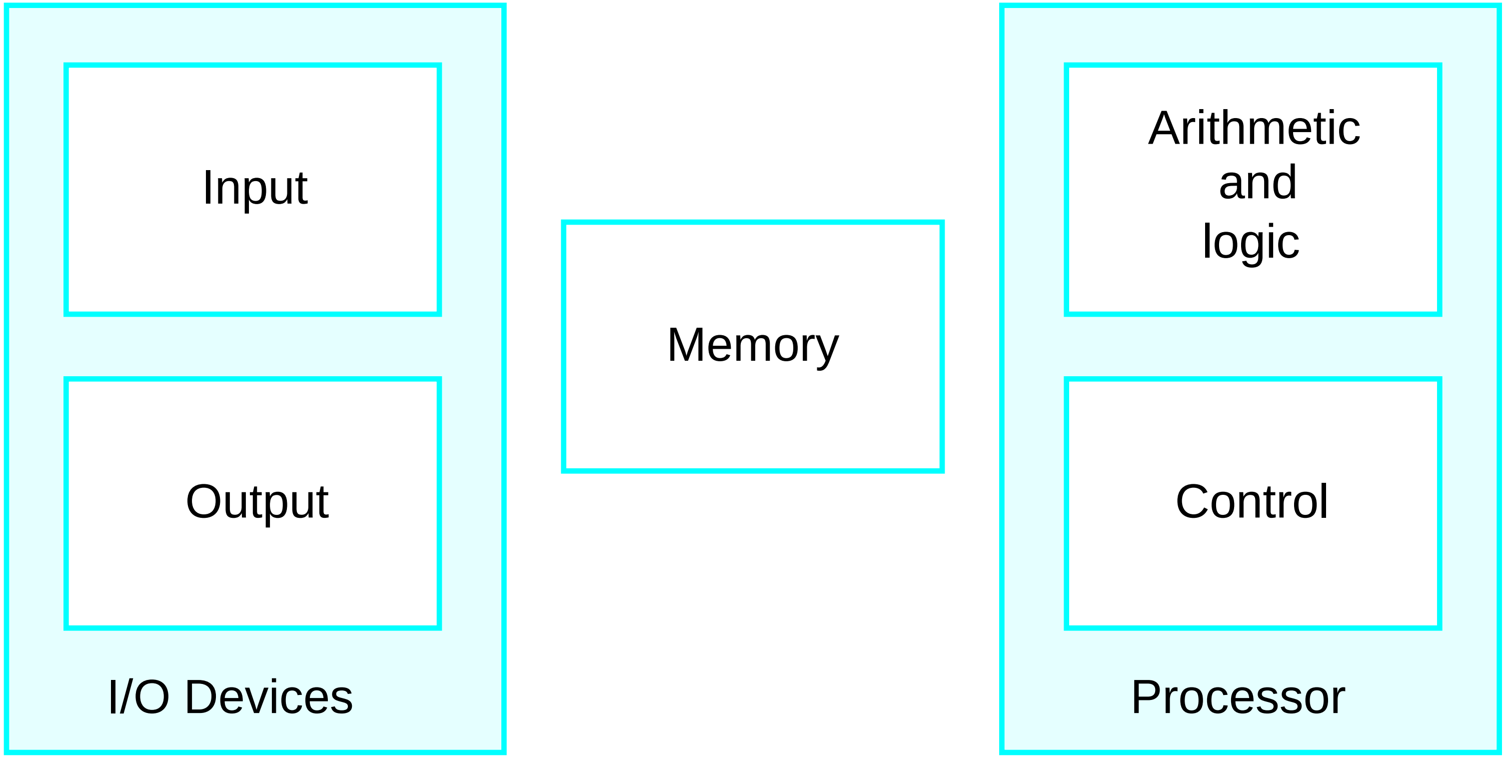
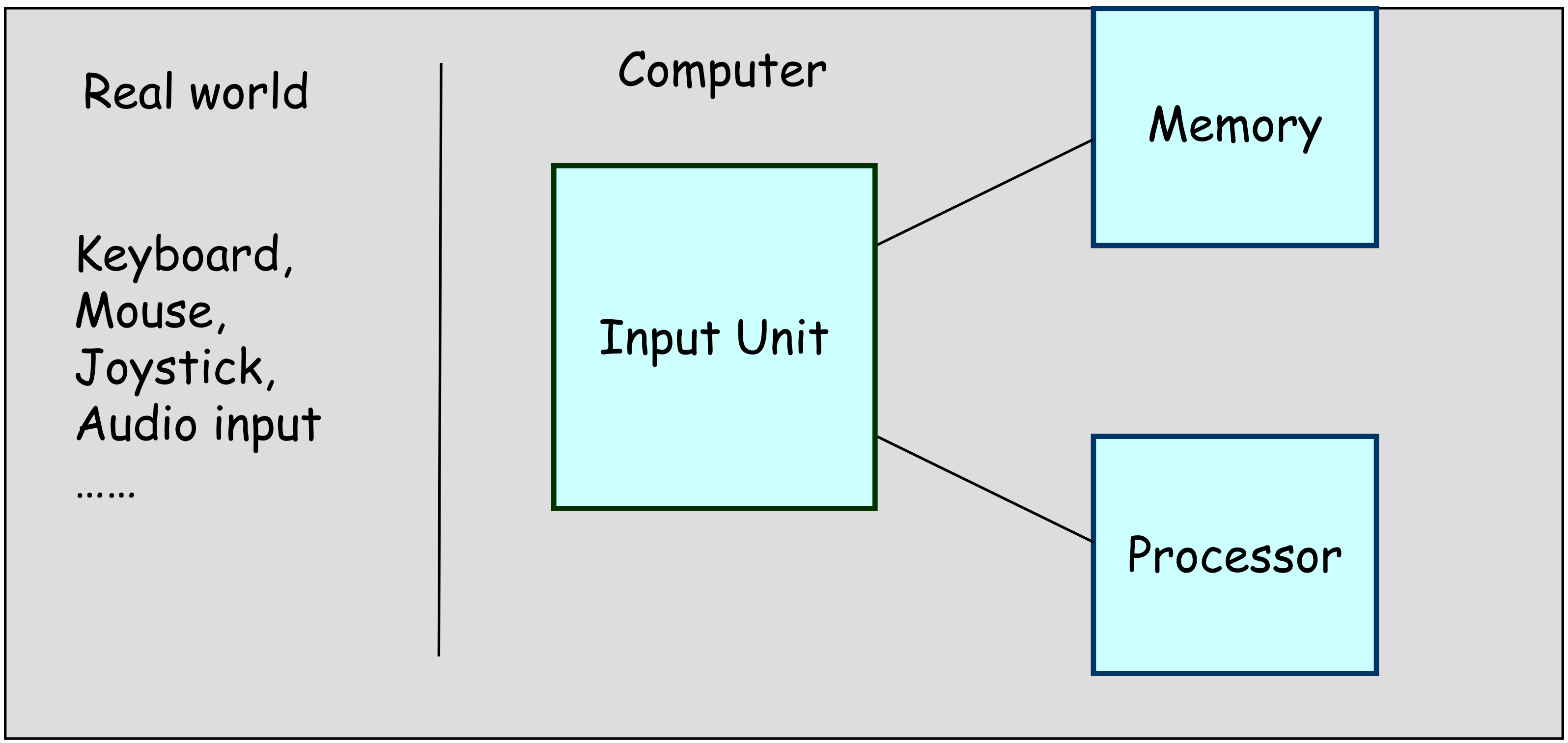


Figure 1.1. Basic functional units of a computer.

Input unit

Binary information must be presented to a computer in a specific format. This task is performed by the input unit:

- Interfaces with input devices.
- Accepts binary information from the input devices.
- Presents this binary information in a format expected by the computer.
- Transfers this information to the memory or processor.



Memory unit

- Memory unit stores instructions and data.
  - Recall, data is represented as a series of bits.
  - To store data, memory unit thus stores bits.
- Processor reads instructions and reads/writes data from/to the memory during the execution of a program.
  - In theory, instructions and data could be fetched one bit at a time.
  - In practice, a group of bits is fetched at a time.
  - Group of bits stored or retrieved at a time is termed as "word"
  - Number of bits in a word is termed as the "word length" of a computer.
- In order to read/write to and from memory, a processor should know where to look:
  - "Address" is associated with each word location.

Memory unit (contd..)

- Processor reads/writes to/from memory based on the memory address:
  - Access any word location in a short and fixed amount of time based on the address.
  - Random Access Memory (RAM) provides fixed access time independent of the location of the word.
  - Access time is known as "Memory Access Time".
- Memory and processor have to "communicate" with each other in order to read/write information.
  - In order to reduce "communication time", a small amount of RAM (known as Cache) is tightly coupled with the processor.
- Modern computers have three to four levels of RAM units with different speeds and sizes:
  - Fastest, smallest known as Cache
  - Slowest, largest known as Main memory.

Memory unit (contd..)

- Primary storage of the computer consists of RAM units.
  - Fastest, smallest unit is Cache.
  - Slowest, largest unit is Main Memory.
- Primary storage is insufficient to store large amounts of data and programs.
  - Primary storage can be added, but it is expensive.
- Store large amounts of data on secondary storage devices:
  - Magnetic disks and tapes,
  - Optical disks (CD-ROMS).
  - Access to the data stored in secondary storage in slower, but take advantage of the fact that some information may be accessed infrequently.
- Cost of a memory unit depends on its access time, lesser access time implies higher cost.

Arithmetic and Logic Unit (ALU)

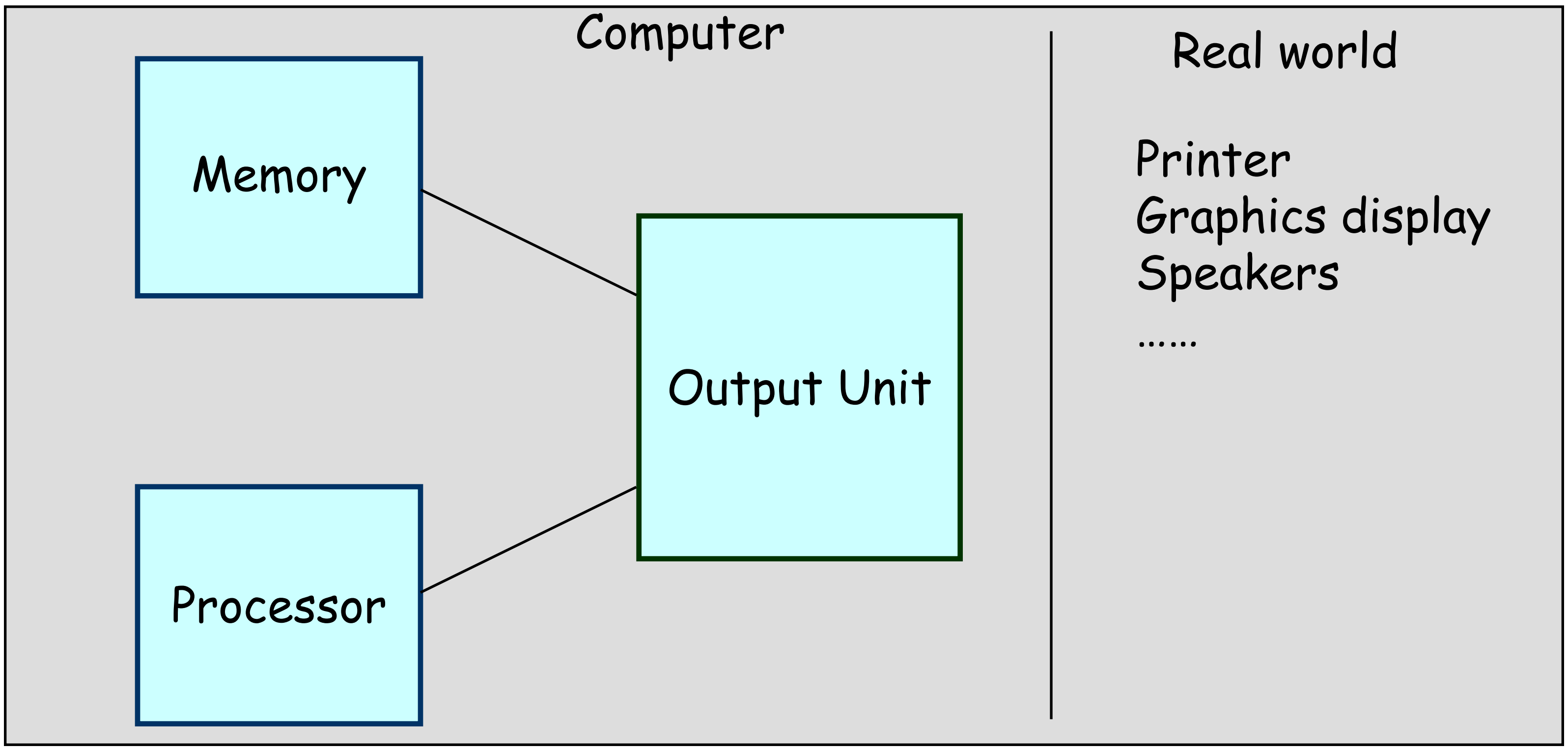
- Most computer operations are executed in ALU of the processor.
  - Arithmetic operations such as addition, subtraction.
  - Logic operations such as comparison of numbers.
- In order to execute an instruction, operands need to be brought into the ALU from the memory.
  - Operands are stored in general purpose registers available in the ALU.
  - Access times of general purpose registers are faster than the cache.
- Results of the operations are stored back in the memory or retained in the processor for immediate use.

Control Unit

- All computer operations are controlled by the control unit.
- The timing signals that govern the I/O transfers are also generated by the control unit.
- Control unit is usually distributed throughout the machine instead of standing alone.
- Operations of a computer:
  - Accept information in the form of programs and data through an input unit and store it in the memory
  - Fetch the information stored in the memory, under program control, into an ALU, where the information is processed
  - Output the processed information through an output unit
  - Control all activities inside the machine through a control unit.
- Operations of Input unit, Memory, ALU and Output unit are coordinated by Control unit.
- Instructions control "what" operations take place (e.g. data transfer, processing).
- Control unit generates timing signals which determines "when" a particular operation takes place.

Output unit

- Computers represent information in a specific binary form. Output units:
  - Interface with output devices.
  - Accept processed results provided by the computer in specific binary form.
  - Convert the information in binary form to a form understood by an output device.



Basic Operational Concepts

- Activity in a computer is governed by instructions.
- To perform a task, an appropriate program consisting of a list of instructions is stored in the memory.
- Individual instructions are brought from the memory into the processor, which executes the specified operations.
- Data to be used as operands are also stored in the memory.

A Typical Instruction

Add LOCA, R0

- Add the operand at memory location LOCA to the operand in a register R0 in the processor.
- Place the sum into register R0.
- The original contents of LOCA are preserved.
- The original contents of R0 is overwritten.
- Instruction is fetched from the memory into the processor – the operand at LOCA is fetched and added to the contents of R0 – the resulting sum is stored in register R0.

Instruction with memory access operation with an ALU operation.

Load LOCA, R1

Add R1, R0

- Whose contents will be overwritten?

Connection Between the Processor and the Memory

Registers

- Instruction register (IR)
- Program counter (PC)
- General-purpose register ($R_0 – R_{n-1}$)
- Memory address register (MAR)
- Memory data register (MDR)

Typical Operating Steps

- Programs reside in the memory through input devices
- PC is set to point to the first instruction
- The contents of PC are transferred to MAR
- A Read signal is sent to the memory
- The first instruction is read out and loaded into MDR
- The contents of MDR are transferred to IR
- Decode and execute the instruction

Typical Operating Steps (Cont')

- Get operands for ALU
  - General-purpose register
  - Memory (address to MAR – Read – MDR to ALU)
- Perform operation in ALU
- Store the result back
  - To general-purpose register
  - To memory (address to MAR, result to MDR – Write)
- During the execution, PC is incremented to the next instruction

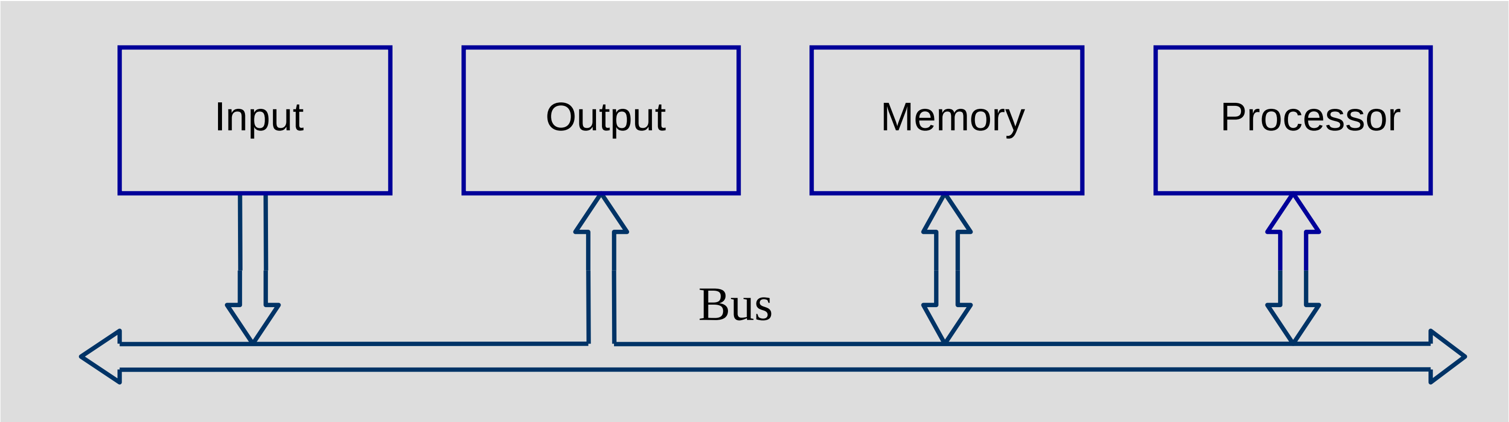
Interrupt

- Normal execution of programs may be preempted if some device requires urgent servicing.
- The normal execution of the current program must be interrupted – the device raises an *interrupt* signal.
- Interrupt-service routine
- Current system information backup and restore (PC, general-purpose registers, control information, specific information)

How are the functional units connected?

Bus Structures

- For a computer to achieve its operation, the functional units need to communicate with each other.
- In order to communicate, they need to be connected.



- Functional units may be connected by a group of parallel wires.
- The group of parallel wires is called a ***bus***.
- Each wire in a bus can transfer one bit of information.
- The number of parallel wires in a bus is equal to the word length of a computer

Bus Structures

- Single bus
  - Low cost
  - Flexibility
- Multiple bus
  - More transfers to be carried out same time
  - Better performance but at an increased cost

Speed Issue

- The devices connected to bus vary widely in their speed of operation.
- To smooth out the differences in timing among processor, memories and external devices, buffer registers are used.

Software

- Translating programs from source form prepared by the user into object form consisting of machine instructions

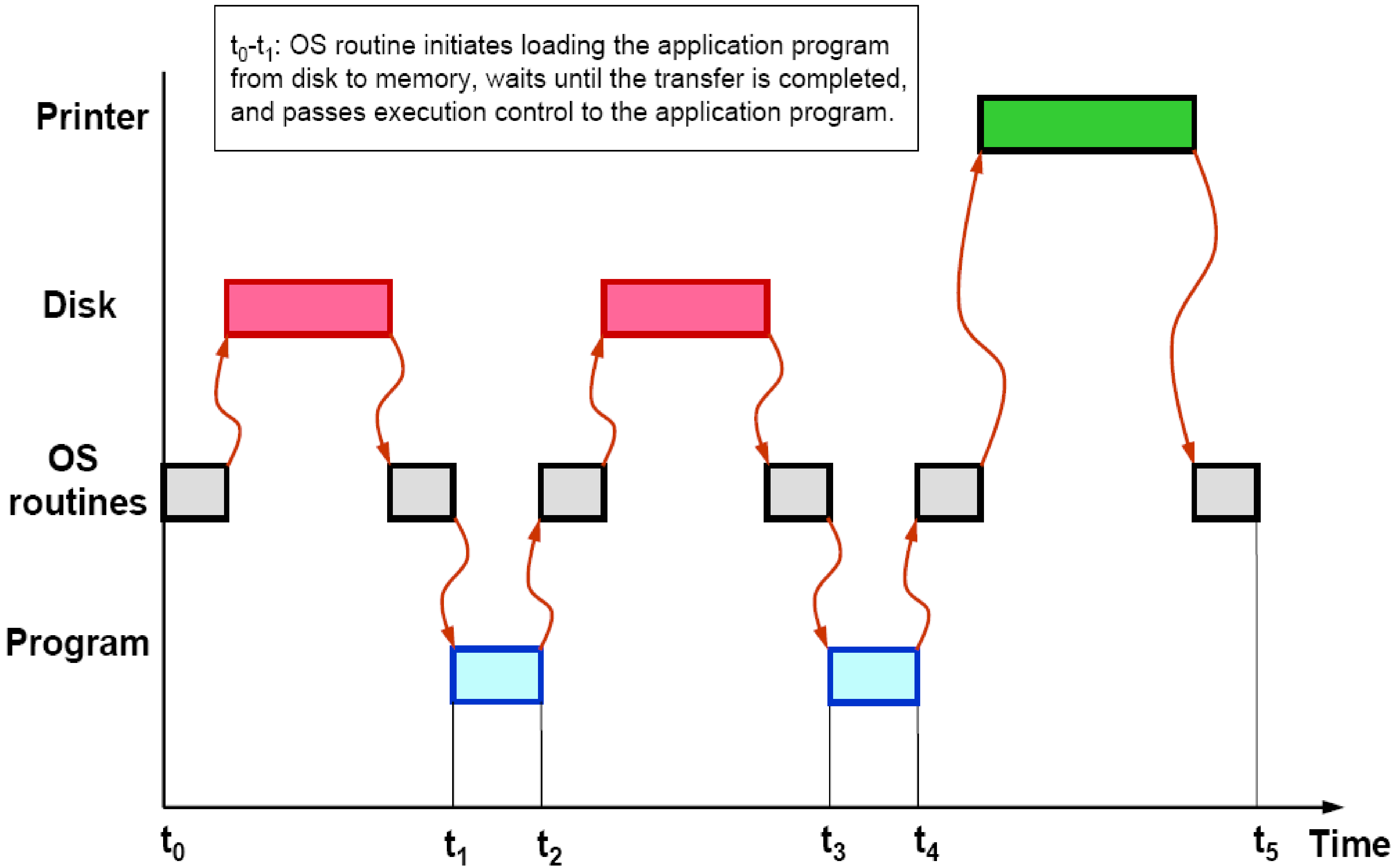
- Linking and running user-written application programs with existing standard library routines, such as numerical computation packages

- System software is thus responsible for the coordination of all activities in a computing system

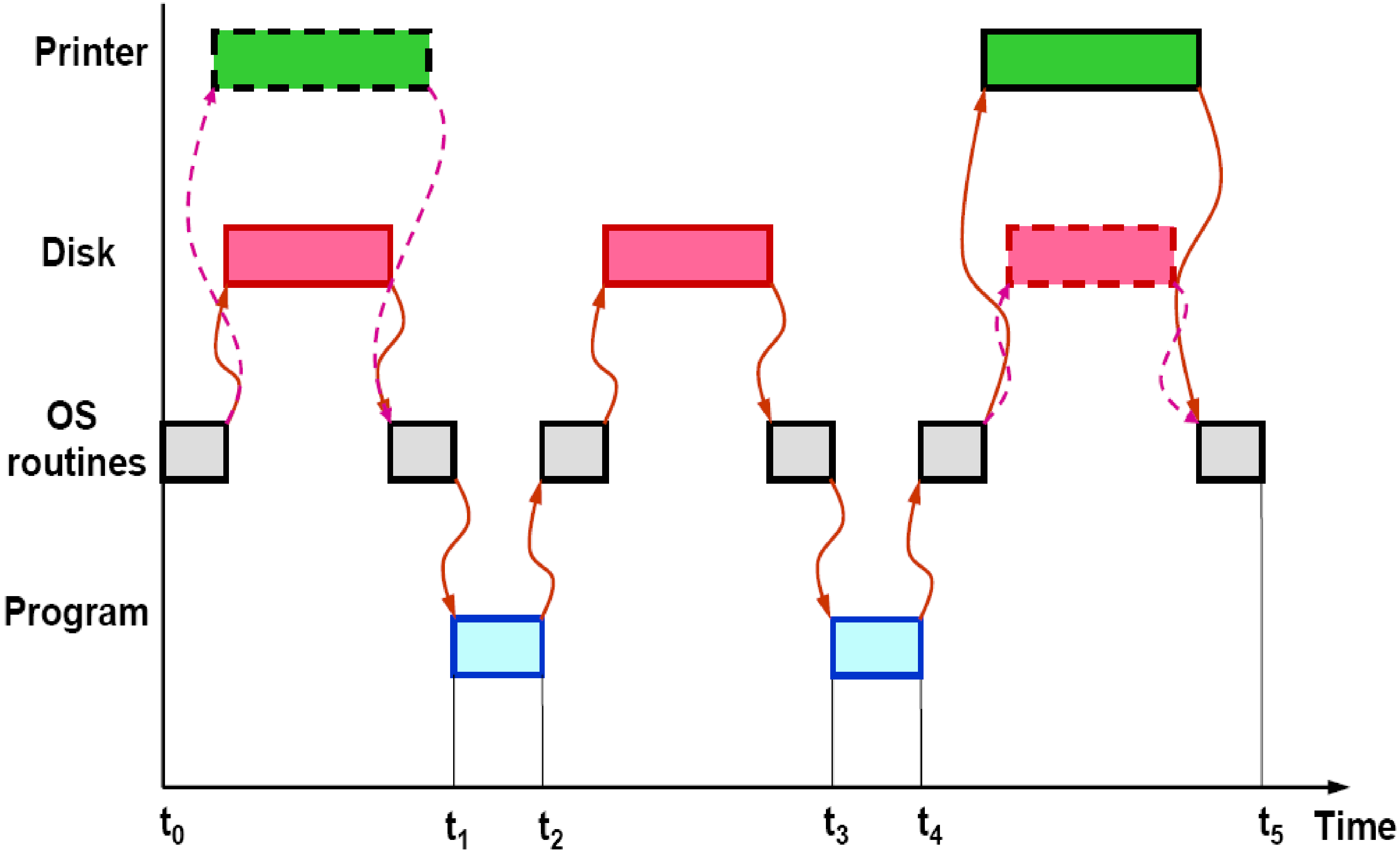
Operating System

- Operating system (OS)
  - This is a large program, or actually a collection of routines, that is used to control the sharing of and interaction among various computer units as they perform application programs
- The OS routines perform the tasks required to assign computer resource to individual application programs
  - These tasks include assigning memory and magnetic disk space to program and data files, moving data between memory and disk units, and handling I/O operations
- In the following, a system with one processor, one disk, and one printer is given to explain the basics of OS
  - Assume that part of the program's task involves reading a data file from the disk into the memory, performing some computation on the data, and printing the results

User Program and OS Routine Sharing



Multiprogramming or Multitasking



Performance

- The speed with which a computer executes programs is affected by the design of its hardware and its machine language instructions
- Because programs are usually written in a high-level language, performance is also affected by the compiler that translates programs into machine languages
- For best performance, the following factors must be considered
  - Compiler
  - Instruction set
  - Hardware design

Performance

- Processor circuits are controlled by a timing signal called a clock
  - The clock defines regular time intervals, called clock cycles
- To execute a machine instruction, the processor divides the action to be performed into a sequence of basic steps, such that each step can be completed in one clock cycle
- Let the length P of one clock cycle, its inverse is the clock rate, $R=1/P$
- Basic performance equation
  - $T=(N \times S)/R$, where T is the processor time required to execute a program, N is the number of instruction executions, and S is the average number of basic steps needed to execute one machine instruction

Performance Improvement

- Pipelining and superscalar operation
  - Pipelining: by overlapping the execution of successive instructions
  - Superscalar: different instructions are concurrently executed with multiple instruction pipelines. This means that multiple functional units are needed
- Clock rate improvement
- Improving the integrated-circuit technology makes logic circuits faster, which reduces the time needed to complete a basic step

Performance Improvement

- Reducing amount of processing done in one basic step also makes it possible to reduce the clock period, P.
- However, if the actions that have to be performed by an instruction remain the same, the number of basic steps needed may increase
- Reduce the number of basic steps to execute
  - Reduced instruction set computers (RISC) and complex instruction set computers (CISC)

Performance Measurement

- T is difficult to compute.
- Measure computer performance using benchmark programs.
- System Performance Evaluation Corporation (SPEC) selects and publishes representative application programs for different application domains, together with test results for many commercially available computers.
- Compile and run (no simulation)
- Reference computer

$$SPEC\ rating = \frac{\text{Running time on the reference computer}}{\text{Running time on the computer under test}}$$

$$SPEC\ rating = \left(\prod_{i=1}^{n} SPEC_i\right)^{\frac{1}{n}}$$