Computer Organization

&

Architecture

For

Computer Science

&

Information Technology

By

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Syllabus for Computer Organization & Architecture

Machine Instructions and Addressing Modes, ALU, Data-Path and Control Unit, Instruction Pipelining, Memory Hierarchy, Cache, Main Memory and Secondary Storage, I/O Interface (Interrupt and DMA Mode).

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Contents

"The best way to predict your future is to create it."
.....Abraham Lincoln

CHAPTER 1

Introduction

Learning Objectives

After reading this chapter, you will know:

1. Computer Architecture
2. Computer Organization
3. Computer Design
4. Positional Numbering Systems
5. Binary Data Representation
6. Hamming Codes
7. Booth's Algorithm
8. CPU Design
9. Binary Adder
10. Arithmetic Logic Unit (ALU)

Computer Architecture

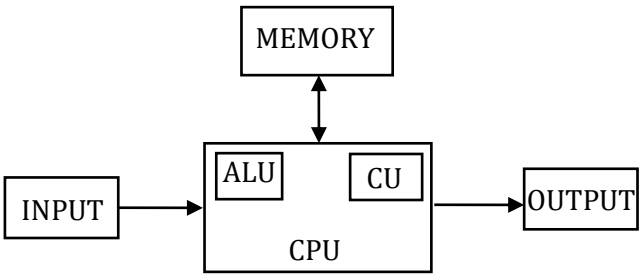
Computer architecture deals with the structure and behavior of the computer system. It includes the information formats, the instruction set and the hardware units that implement the instructions along with the techniques for addressing memory.

Computer Organization

Computer organization deals with the way the various hardware components operate and the way they are connected together to form the computer system. It also deals with the units of the computer that receive information from external sources and send computed results to external destinations.

Computer Design

Computer design is concerned with the hardware design of the computer. This aspect of computer hardware is sometimes referred to as computer implementation. Figure. Shows in the below basic building blocks of a typical computer system.



Basic Functional Units of a Computer

- The basic blocks available in any digital computer are, Arithmetic Logic Unit (ALU), Control Unit, Memory and Input/Output Unit.

- **Input Unit**
  It is a medium of communication between the user and the computer. With the help of input units only, it is possible to enter programs and data to the computer.

  E.g.: Keyboard, floppy disk drive, hard disk drive, mouse, Magnetic Ink Character Recognition (MICR), Optical Character Recognition (OCR), paper tape reader, Magnetic tape reader, Scanner etc. Joy stick,

- **Output Unit**
  It is a medium of communication between the computer and the user. With the help of output units only, it is possible to get results from the computer.
  Example: Printers, Video Display Unit (VDU), Floppy disk drive, Hard disk drive, Magnetic tape drive, punched cards, paper tape, plotter, digitizer etc.

Memory: The memory unit is responsible for storing the user programs and data. The digital computer memory unit mainly consists of two types of memories: Read Only Memory (ROM) and Read Write Memory (R/WM) or Random Access Memory (RAM).

- **ROM**
  ROM is used to store permanent programs or system programs. It does not have write capability.
  Types: PROM, EPROM, EEPROM

- **RAM**
  It is also called user memory because the user programs or application programs are stored in this memory. The CPU is able to write or read information into or from this type of memory.
  Types: static, dynamic, scratch pad etc.

Central Processing Unit (CPU)

The ALU and Control Unit together are called CPU. It is the heart of any digital computer.

ALU (Arithmetic Logic Unit)

The data processing part of CPU is responsible for executing arithmetic and logical instructions on various operand types including fixed point and floating point numbers.
Various circuits used to execute data processing instructions are usually combined in a single circuit called an arithmetic logic unit (ALU). The complexity of an ALU is determined by the way in which its arithmetic instructions are realized. Simple ALU's those perform fixed point addition and subtraction as well as word based logical operations, can be realized by combinational circuits. Much more extensive data processing and control logic are necessary to implement is floating point arithmetic in hardware.

Example: For finding the sum of a series $x = y \times 2 + y \times 4 + y \times 8 + \ldots\ldots\ldots + y \times 128$, how will you use an ALU without a multiplier unit but with an adder and barrel shifter? Barrel shifter is a shifter that does n − bit shift in one clock cycle.

Solution: Left shift by 7 means multiplication by 128,6 means multiplication by 64,5 means multiplication by 32, ……. and 1 means multiplication by2. Hence the shift operations will be faster for computing. Using the barrel shifter seven times for shifting by 1,2,3,4 ….., we find and store left shifted values of *y* in a register and add these values.

Two Types of ALUs

1. **Combinational ALUs**
   The simple ALU combine the functions of 2's complement adder-subtracter with those of a circuit that generates word based logic functions of the form f(x, y).
   For example AND, XOR and NOT. They can thus implement most of a CPU's fixed point data processing instructions.

2. **Sequential ALU's**
   Both multiplication and division can be implemented by combinational logic. It is generally impractical to merge these operations with addition and subtraction into a single, combinational ALU.
   The combinational multipliers and dividers are costly in terms of hardware. They are also much slower than addition and subtraction.

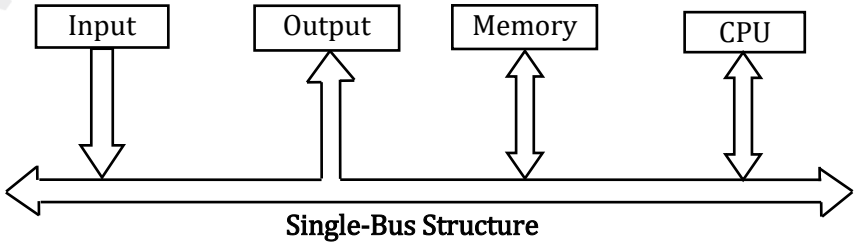
An n-bit combinational multiplier or divider is typically composed of n or more levels of add-subtract logic, making multiplication and division at least 'n' times slower than addition (or) subtraction, where addition and subtraction each takes one clock cycle, while multiplication and division are multicycle operations.

Example: How many 16-bit ALU slices can be used for designing a 64-bit ALU?

Solution: Four slices will be needed in parallel if ALU 64-bits operations are to take nearly the same time as 16-bit slice, and four slices will be needed in series if ALU 64- bits operations are to take nearly four times of 16-bit slice.

Interconnection of Basic of Blocks

In order to form an operational system individual components or parts of computer that we have discussed need to be connected in some organized way, for this purpose, '***bus***' is introduced which is defined as a group of lines that serves as a connecting path for several devices. These lines carry data, address and control signals. Figure. Shows in the below exemplanary interconnection using single bus structure



Single-Bus Structure

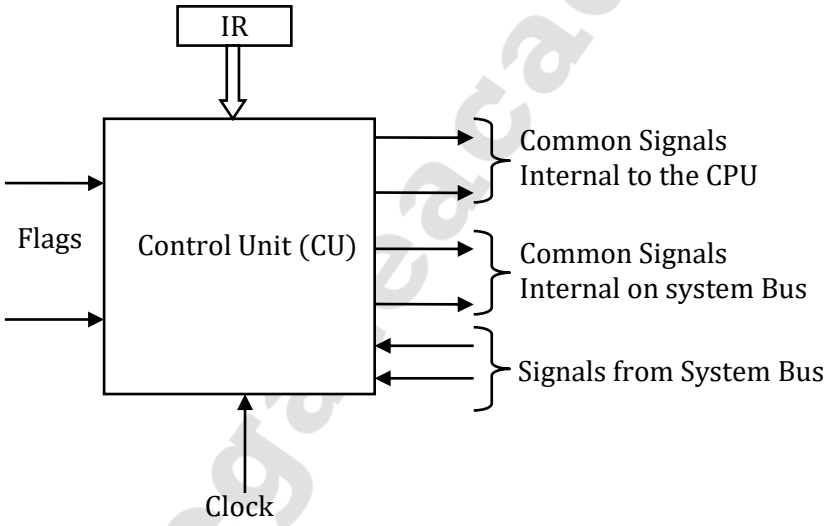
Since, this bus can be used only for single transfer at a time multiple buses are introduced so as to achieve more concurrency in operations so that two or more transfers can be carried out at the same time. Hereby, increasing performance but at an increased cost.

Control Unit

The control unit (CU) is the heart of the CPU. Every instruction CPU supports has to be decided by the CU and executed appropriately. Every instruction consists of a sequence of micro instructions that carries out that instruction The CU controls the elements inside the CPU and the interfaces to the external data rate.

Following are the Basic Tasks of the Control Unit

1. For each instruction the CU causes the CPU to go through a sequence of control steps:
2. In each control step the CU issues a set of signal which caused the corresponding operation to be executed.
3. The signals to be generated by CU depends upon the actual step to be executed, the condition and states of flag register of the processor, the actual instruction to be executed and any external signals received on the system bus (i.e., interrupt signals)



Basic Task of CU

Positional Numbering Systems

The general idea behind positional numbering systems is that a numeric value is represented through increasing powers of a radix (or base). This is often referred to as a weighted numbering system because each position is weighted by a power of the radix.

The set of valid numerals for a positional numbering system is equal in size to the radix of that system. For example, there are 10 digits in the decimal system, 0 through 9, and 3 digits for the ternary (base 3) system, 0, 1, and 2. The largest valid number in a radix system in one smaller than the radix, so 8 is not a valid numeral in any radix system smaller than 9. To distinguish among numbers in different radices, we use radix as a subscript, such as in 33_{10} to represent the decimal number 33. (In this text, numbers written without a subscript should be assumed to be decimal.) Any decimal integer can be expressed exactly in any other integral base system.

Example: Three numbers represented as powers of a radix.

$243.51_{10} = 2 \times 10^2 + 4 \times 10^1 + 3 \times 10^0 + 5 \times 10^{-1} + 1 \times 10^{-2}$

$212_3 = 2 \times 3^2 + 1 \times 3^1 + 2 \times 3^0 = 23_{10}$

$10110_2 = 1 \times 2^4 + 0 \times 2^3 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 22_{10}$

The two most important radices in computer science are binary (base two), and hexadecimal (base 16). Another radix of interest is octal (base 8). The binary system uses only the digits 0 and 1; the octal system, 0 through 7. The hexadecimal system allows the digits 0 thought 9 with A, B, C, D, E, and F being used to represent the numbers 10 through 15.

Powers of 2
$2^{-2} = \frac{1}{4} = 0.25$
$2^{-1} = \frac{1}{2} = 0.5$
$2^0 = 1$
$2^1 = 2$
$2^2 = 4$
$2^3 = 8$
$2^4 = 16$
$2^5 = 32$
$2^6 = 64$
$2^7 = 128$
$2^8 = 256$
$2^9 = 512$
$2^{10} = 1024$
$2^{15} = 32{,}768$
$2^{16} = 65{,}536$

Decimal	4-Bit Binary	Hexadecimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

Some Numbers to Remember

Converting Unsigned Whole Numbers

We begin with the base conversion of unsigned numbers. Conversion of signed numbers (numbers that can be positive or negative) is more complex, and it is important that you first understand the basic technique for conversion before continuing with signed numbers.

Conversion between base systems can be done by using either repeated subtraction or a division-remainder method. The subtraction method is cumbersome and requires a familiarity with the powers of the radix being used, because it the more intuitive of the two methods, however, we will explain it first.

As an example, let's say we want to convert 104_{10} to base 3. We know that $3^4 = 81$ is the highest power of 3 that is less than 104, so our base 3 number will be 5 digits wide (one for each power of the radix: 0 through 4). We make note that 81 goes once into 104 and subtract, leaving a difference of 23. We know that the next power of 3, $3^3 = 27$, is too large to subtract, so we note the zero.

"Placeholder" and look for how many times $3^2 = 9$ divides 23. We see that it goes twice and subtract 18. We are left with 5, from which we subtract $3^1 = 3$, leaving 2, which is 2×3^0.

Example:

Convert 104_{10} to base 3 using subtraction.

$$\begin{array}{l} 104 \\ \underline{-81} = 3^4 \times 1 \\ 23 \\ \underline{-0} = 3^3 \times 0 \\ 23 \\ \underline{-18} = 3^2 \times 2 \\ 5 \\ \underline{-3} = 3^1 \times 1 \\ 2 \\ \underline{-2} = 3^0 \times 2 \\ 0 \end{array}$$

$104_{10} = 10212_3$

The division-remainder method is faster and easier than the repeated subtraction method. It employs the idea that successive division by the base are in fact successive subtractions by powers of the base. The remainders that we get when we sequentially divide by the base end up being the digits of the result, which are read from bottom to top.

Example:

Convert 147_{10} to binary.

$2 \div 147$ 1 2 Divides 147 73 times with a remainder of 1
$2 \div 73$ 1 2 Divides 73 76 times with a remainder of 1
$2 \div 36$ 0 2 Divides 36 18 times with a remainder of 0
$2 \div 18$ 0 2 Divides 18 9 times with a remainder of 0
$2 \div 9$ 1 2 Divides 9 4 times with a remainder of 1
$2 \div 4$ 1 2 Divides 4 2 times with a remainder of 0
$2 \div 2$ 1 2 Divides 2 1 times with a remainder of 0
$2 \div 1$ 1 2 Divides 1 0 times with a remainder of 1
0

Reading the remainders from bottom to top, we have: $147_{10} = 10010011_2$.

A binary number with N bits can represent unsigned integers from 0 to$2^N - 1$. For example, 4 bits can represent the decimal values 0 through 15, whereas 8 bits can represent the values 0 through 255. The range of values that can be represented by a given number of bits is extremely important when doing arithmetic operations on binary numbers. Consider a situation in which binary numbers are 4 bits in length, and we wish to add1111_2. (15_{10}) to1111_2. We know that 15 plus 15 is 30, but 30 cannot be represented using only 4 bits. This is an example of a condition known as overflow, which occurs in unsigned binary representation when the result of an arithmetic operation is outside the range of allowable precision for the given number of bits..