CS10001: Programming & Data Structures

Dept. of Computer Science & Engineering

Course Materials

Books:

1. **Programming with C (Second Edition)**

   Byron Gottfried, Third Edition, Schaum's Outlines Series,

2. **The C Programming Language**

   Brian W Kernighan, Dennis M Ritchie

3. **Data structures**

   S. Lipschutz, Schaum's Outline Series

About the Course

- Section 9, 10
  - Teacher: Prof. Sandip Chakraborty (SC)
  - Mon (10:00-10:55) + Wed (8:00-9:55)
  - NR-122 (Nalanda Complex)

- Section 11, 12
  - Teacher: Prof. Bivas Mitra (BM)
  - Mon (10:00-10:55) + Wed (8:00-9:55),
  - NR-222 (Nalanda Complex)

About the Course

- Section 13,14
  - Teacher: Prof. Niloy Ganguly (NG)
  - Thurs (9:00-9:55) + Fri (11:00-12:55),
  - NR-122 (Nalanda Complex)

- Section 15,16
  - Teacher: Prof. K. S. Rao
  - Thurs (9:00-9:55) + Fri (11:00-12:55),
  - NR-222 (Nalanda Complex)

About the Course

- Course website: http://cse.iitkgp.ac.in/pds/current/

- Tutorial classes (one hour per week) will be conducted on a "per section" basis during Lab hours

- Evaluation in the theory course:
  - Mid-semester 30%
  - End-semester 50%
  - Two class tests and attendance 20%

Attendance REALLY matters

- Important for understanding the course
- Any student with low attendance may be deregistered from the course
- Leave due to medical reasons must be certified by the B.C. Roy Technology Hospital

Important Dates

- Class Test 1: Last week of August / first week of September
- Class Test 2: Last week of October / first week of November

(Class test dates are tentative and may change. The exact dates will be announced in the class)

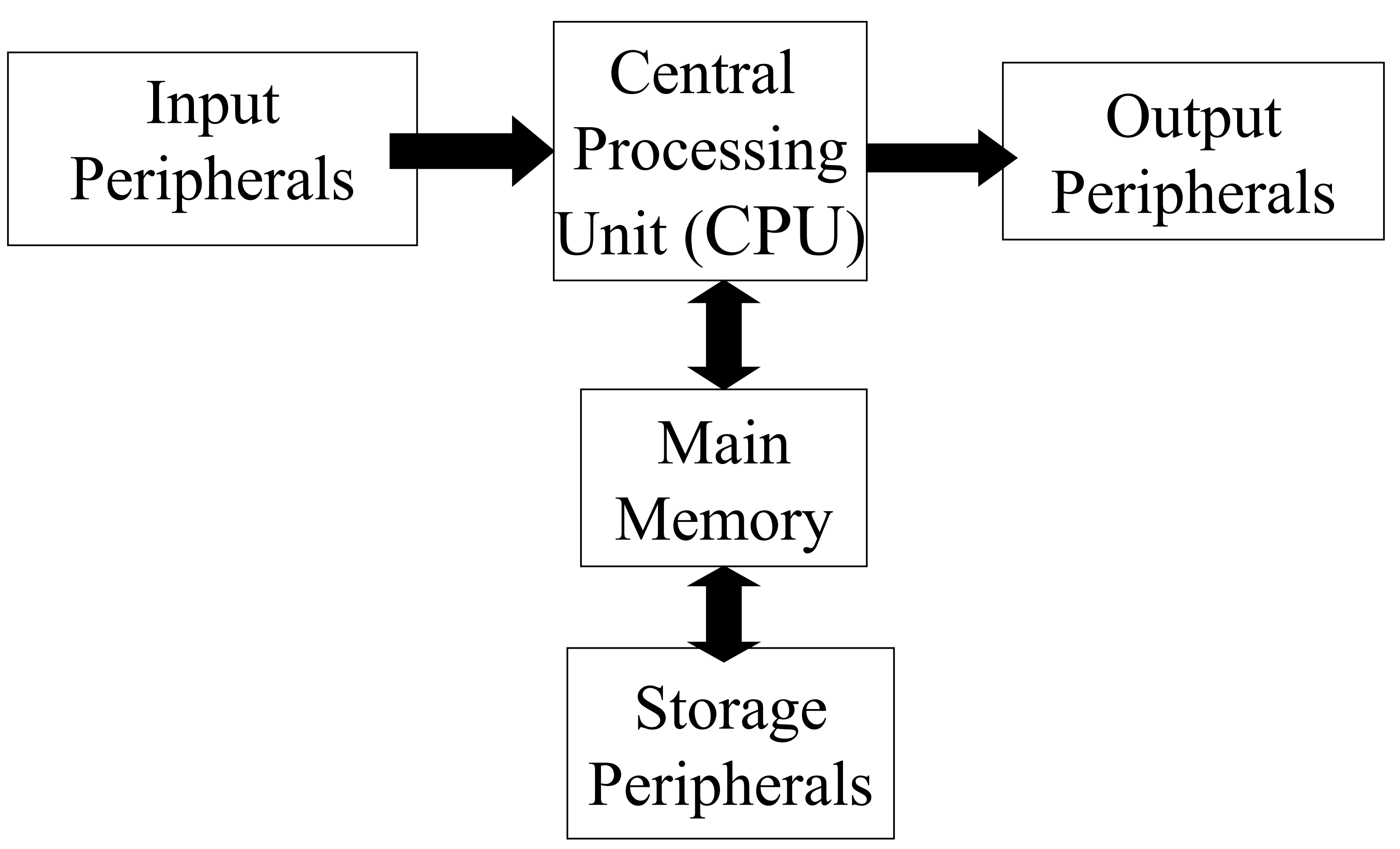
- Mid-semester: Sept 17 – Sep 26, 2018
- End-semester: Nov 16 – Nov 27, 2018

Introduction

Computer is a machine that can perform computation

1. Input : User gives a set of Input
2. Processing : Input data is processed by a well defined and finite sequence of steps
3. Output: Some data available from processing step and output to the user

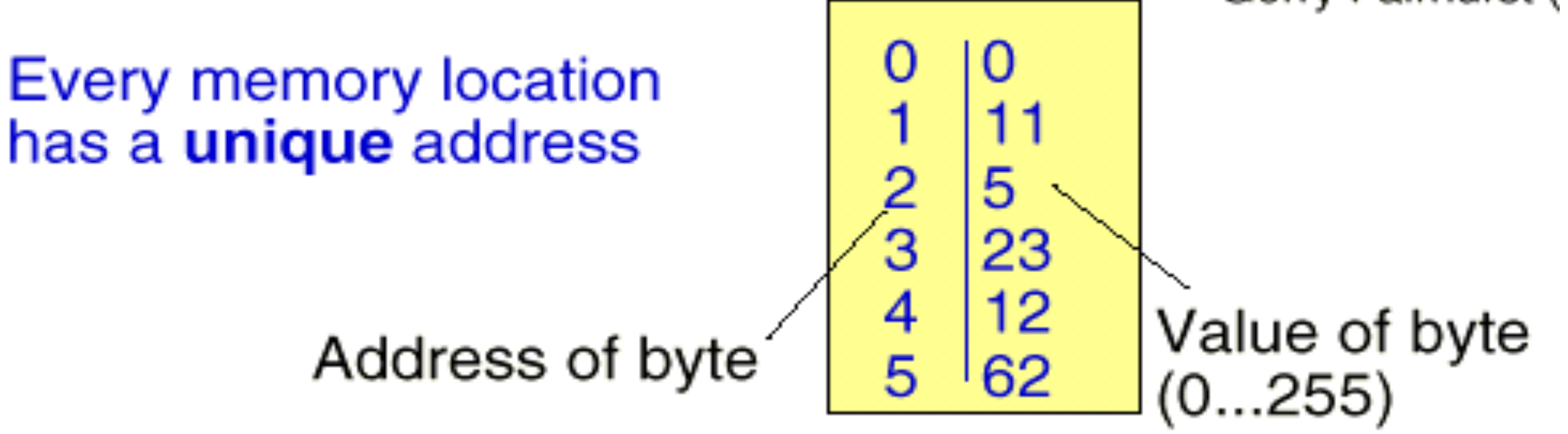
A Computer (Level 0 Version)

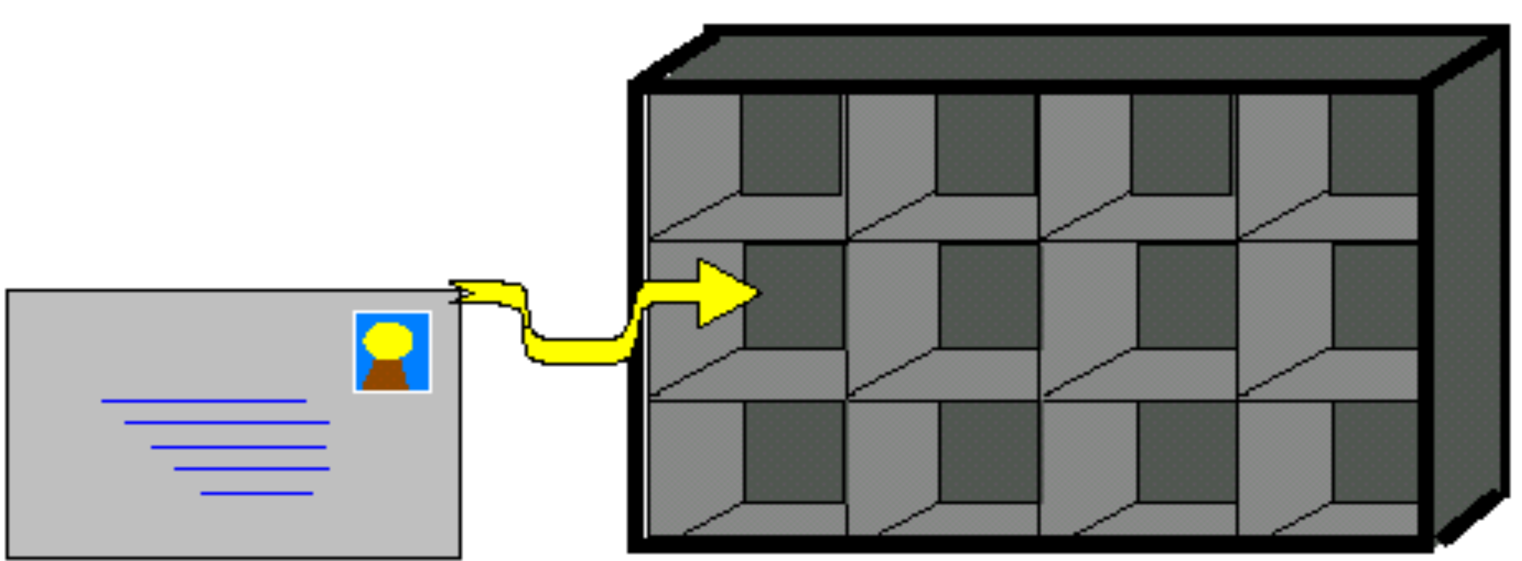


I/O and Peripherals: Examples

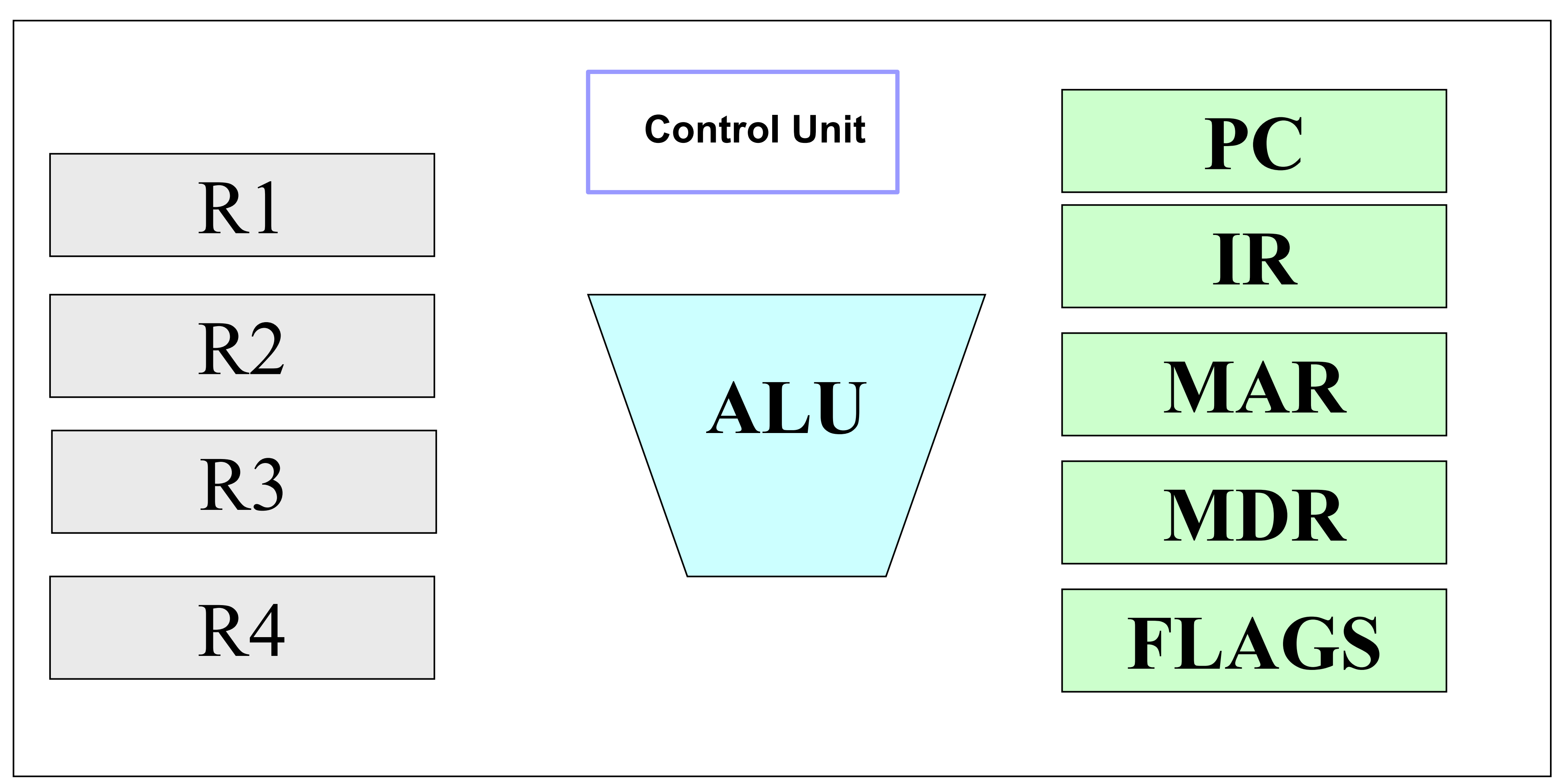
- Input Devices
  - Keyboard, Mouse, Digital Camera
- Output Devices
  - Monitor, Printer, Speaker
- Storage Peripherals
  - Magnetic Disks: hard disk
  - Optical Disks: CDROM, CD-RW, DVD
  - Flash Memory: pen drives

Memory: Address and Values





CPU: A first cut



Register

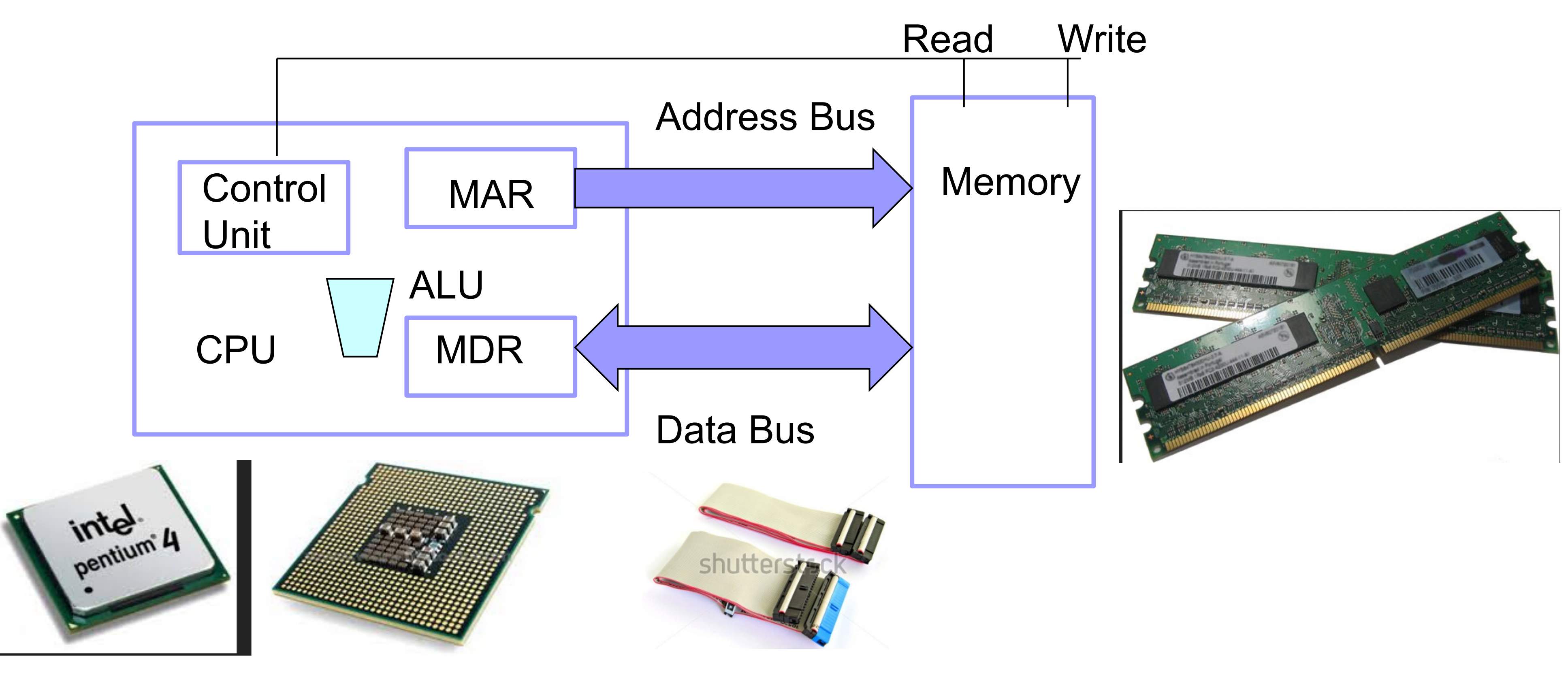
Temporary storage inside CPU

1. General purpose Register
2. Special purpose Register

PC: Program Counter
IR: Instruction Register
MDR: Memory Data Register
MAR: Memory Address Register

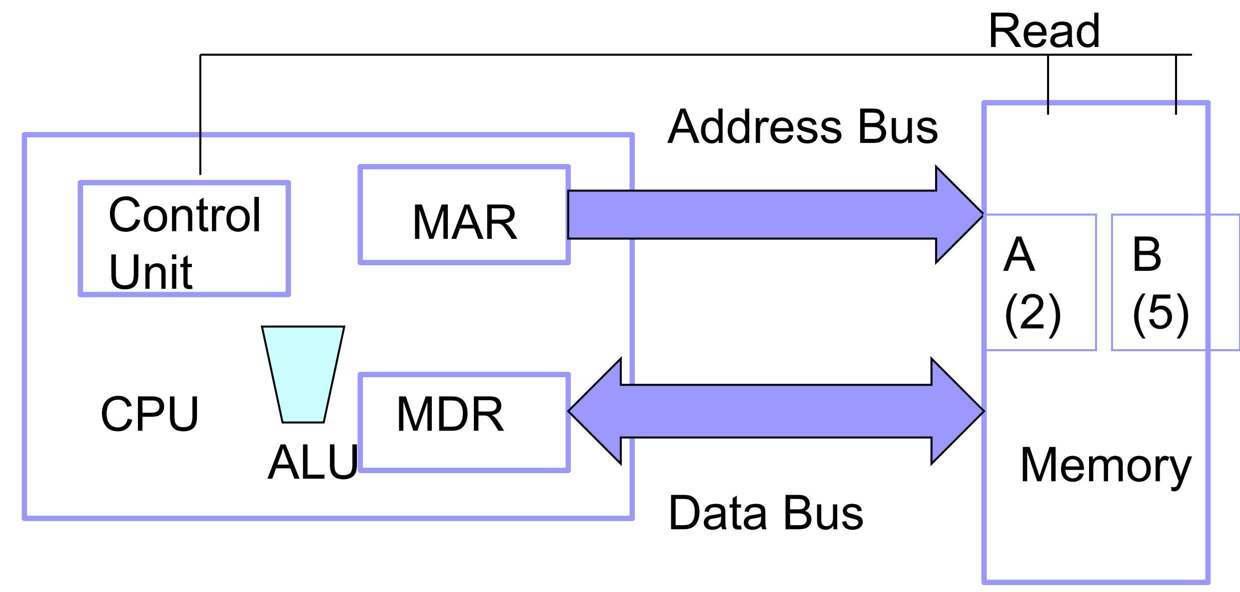
5

R1

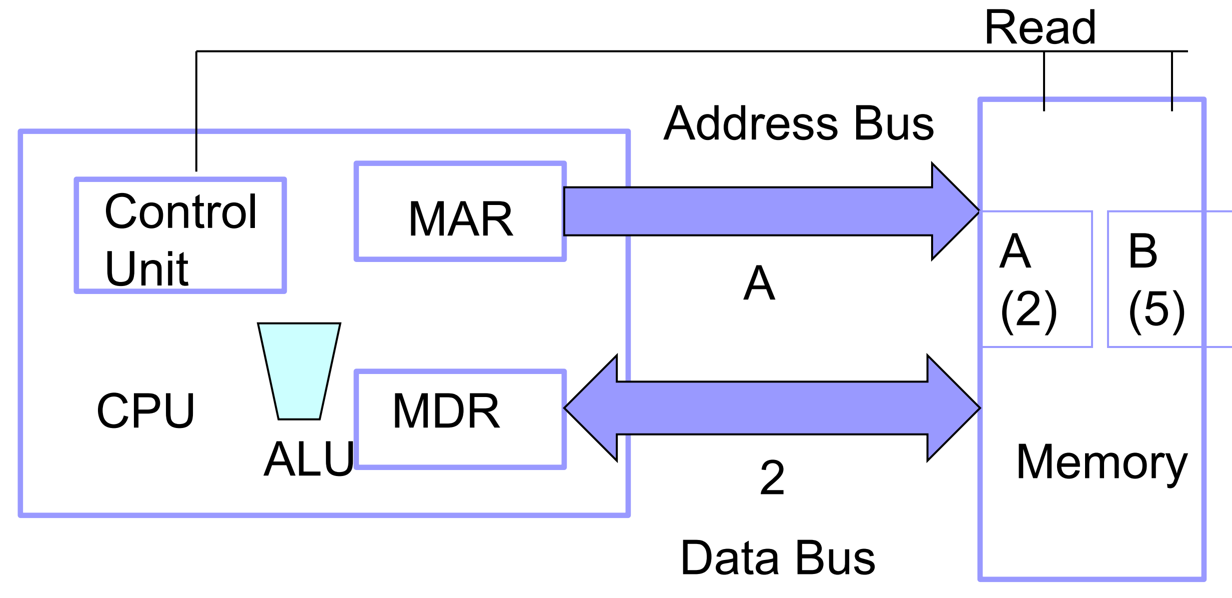


Von Newman Architecture

C=A+B



Step 1: Fetch Operand A from memory
Step 2: Store in Register R1
Step 3: Fetch Operand B from memory
Step 4: Store in Register R2
Step 5: Add content of R1 and R2
Step 6: Store the result in register R3
Step 7: Store the content of R3 in memory C



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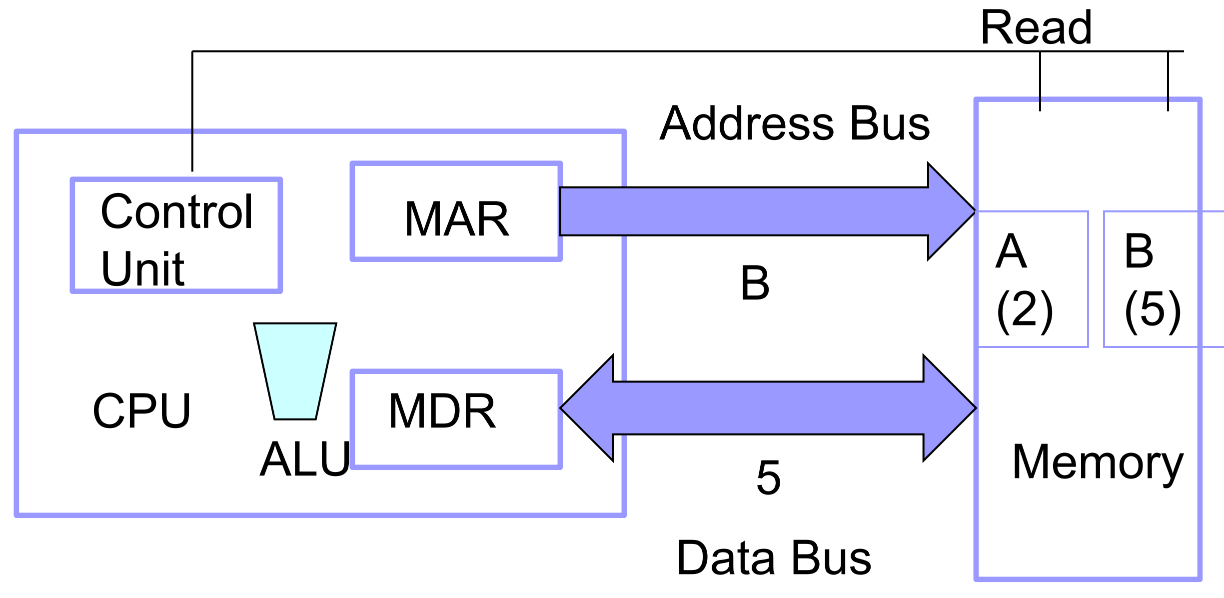
C=A+B



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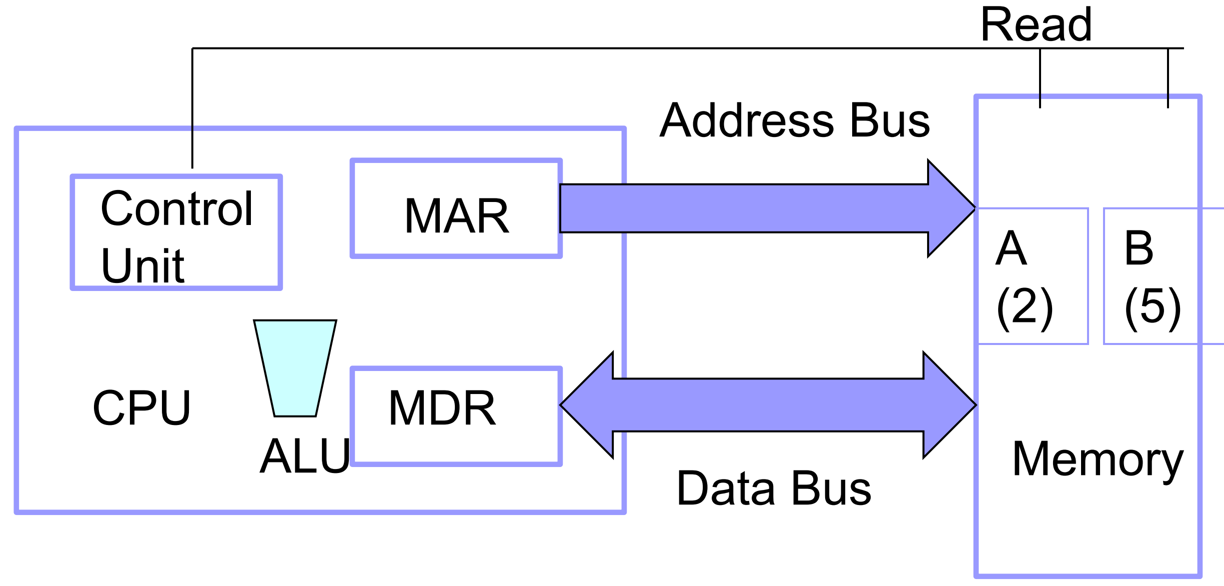

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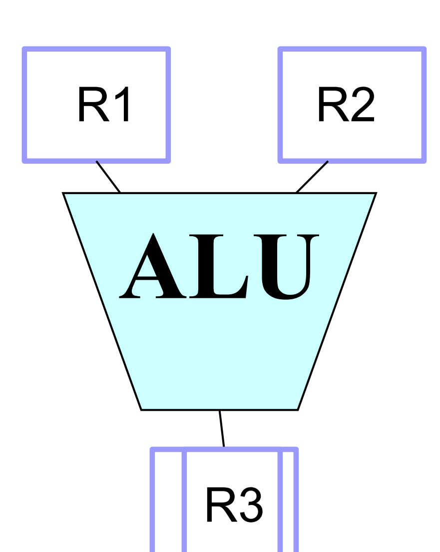
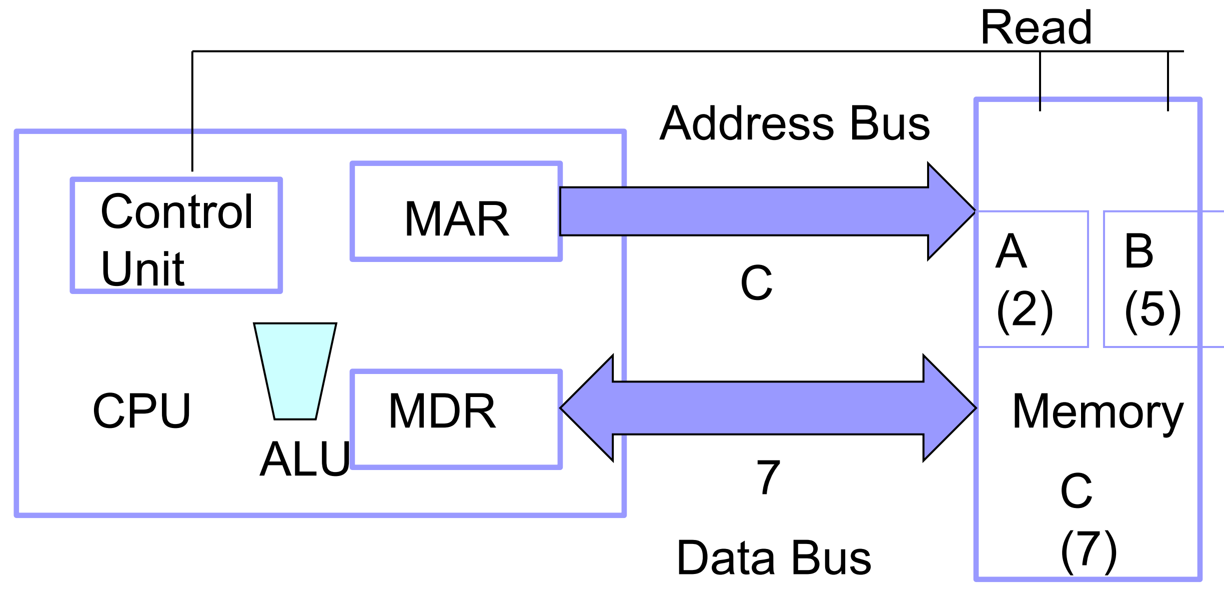


C=A+B



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What can a computer do

Solve Types of Problem

1. Functional Problem (Matrix Inverse)
2. Decision Problem (Primality test)
3. Search Problem
4. Optimization problem

What can a computer do

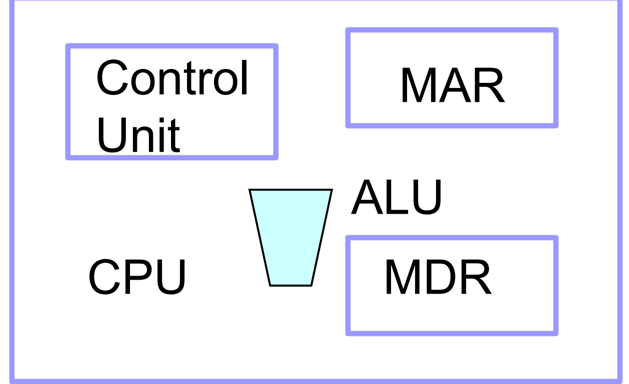
- Determining if a given integer is a prime number
- Root finding
- Read in airline route information as a matrix and determine the shortest time journey between two airports
- Telephone pole placement problem
- Matrix multiplication
- Finger-print recognition
- Chess Player
- Speech Recognition
- Language Recognition
- Discovering New Laws in Mathematics
- Automatic drug discovery
- …..

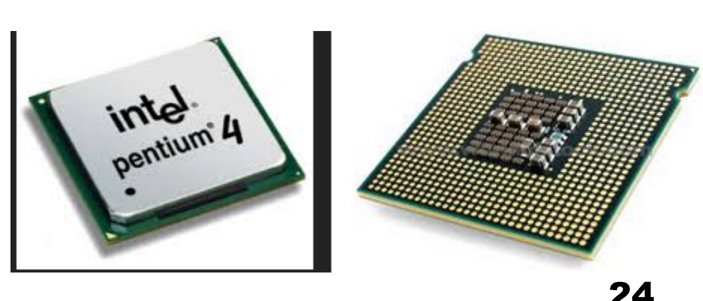
Programming and Software

- Computer needs to be programmed to do such tasks
- Programming is the process of writing instructions in a language that can be understood by the computer so that a desired task can be performed by it
- Program: sequence of instructions to do a task, computer processes the instructions sequentially one after the other
- Software: programs for doing tasks on computers

Challenges

- CPU understands machine language
  - Different strings of 0's and 1's only!!
  - Hard to remember and use
- Instruction set of a CPU
  - Mnemonic names for this strings





Instruction Set

- **Start**
- **Read M**
- **Write M**
- **Load Data, M**
- **Copy M1, M2**
- **Add M1, M2, M3**
- **Sub M1, M2, M3**
- **Compare M1, M2, M3**
- **Jump L**
- **J_Zero M, L**
- **Halt**

- **Start**
- **Read M**
- **Write M**
- **Load Data, M**
- **Copy M1, M2**
- **Add M1, M2, M3**
- **Sub M1, M2, M3**
- **Compare M1, M2, M3**
- **Jump L**
- **J_Zero M, L**
- **Halt**

Program

0: Start
1: Read 10
2: Read 11
3: Add 10, 11, 12
4: Write 12
5: Halt

Problems with programming using instruction sets directly

- Instruction sets of different types of CPUs different
  - Need to write different programs for computers with different types of CPUs even to do the same thing

- Solution: High level languages (C, C++, Java,…)
  - CPU neutral, one program for many
  - Compiler to convert from high-level program to low level program that CPU understands

High-Level Program

```
Variables x, y;
Begin
Read (x);
Read (y);
If (x >y) then Write (x)
               else  Write (y);
End.
```

High-Level Program

```
Variables x, y;
Begin
Read (x);
Read (y);
If (x >y) then Write (x)
           else  Write (y);
End.
```

Low-Level Program

```
0: Start
1: Read 20
2: Read 21
3: Compare 20, 21, 22
4: J_Zero 22, 7
5: Write 20
6: Jump 8
7: Write 21
8: Halt
```

Step 1: Write the program in a high-level language (in your case, C)

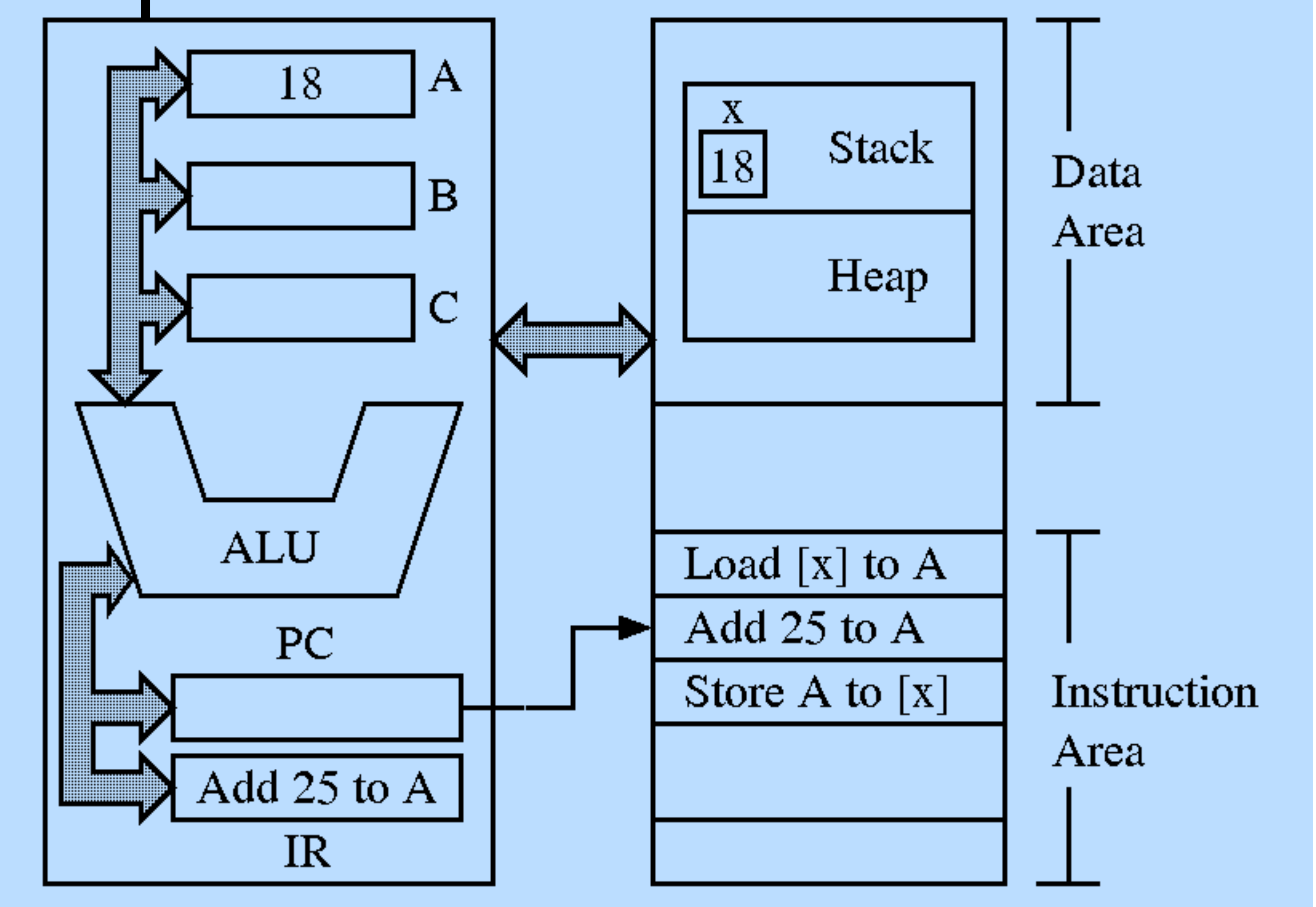
Step 2: Compile the program using a C compiler

Step 3: Run the program (as the computer to execute it)

Program and Algorithm

- Swap two elements
- Search an element from the list
- …

How does program run in a computer?



How does program run in a computer?

- Data area
- Instruction area

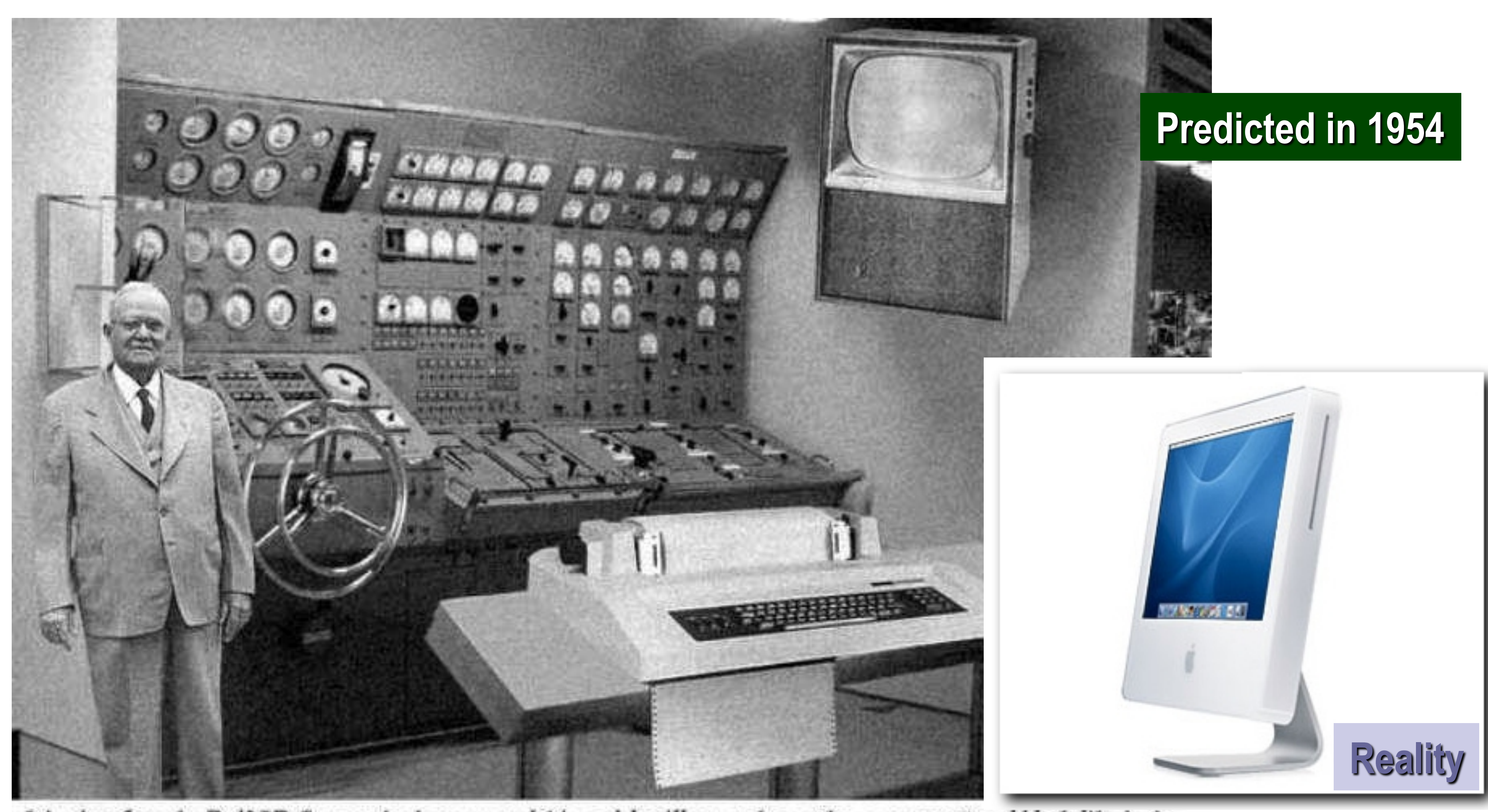
- Fetch-decode-execute

The fetch-decode-execute cycle

- Sequence of machine instructions is copied to the instruction area of the memory.
- A particular control register, called the **program counter** (**PC**), is loaded with the address of the first instruction of the program.
- The CPU fetches the instruction from that location in the memory that is currently stored in the PC register.
- The instruction (in IR) is decoded in the control unit of the CPU.
- The instruction may require one or more operands.
  - An operand may be either a **data or a memory address**. A data may be either a **constant** (also called an immediate operand) or **a value stored in the data area of the memory** or a value stored in **a register**. Similarly, an address may be either immediate or a resident of the main memory or available in a register.
- An immediate operand is available from the instruction itself. The content of a register is also available at the time of the execution of the instruction. Finally, a variable value is fetched from the data part of the main memory.

- If the instruction is a **data movement operation**, the corresponding movement is performed. For example, a **"load"** instruction copies the data fetched from memory to a register, whereas a **"store"** instruction sends a value from a register to the data area of the memory.
- If the instruction is an **arithmetic or logical instruction**, it is executed in the ALU after all the operands are available in the CPU (in its registers). The output from the ALU is stored back in a register.
- If the instruction is a **jump instruction**, the instruction must contain a memory address to jump to. The program counter (PC) is loaded with this address. A jump may be conditional, i.e., the PC is loaded with the new address if and only if some condition(s) is/are true.
- If the instruction is **not a jump instruction**, the address stored in the PC is incremented by one.
- If the end of the program is not reached, the CPU continues its fetch-decode-execute cycle.

Home Computer@2004: *Predicted versus Real*



Scientists from the RAND Corporation have created this model to illustrate how a "home computer" could look like in the year 2004. However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems. With teletype interface and the Fortran language, the computer will be easy to use.

Binary Representation

- Numbers are represented inside computers in the base-2 system (Binary Numbers)
  - Only two symbols/digits 0 and 1
  - Positional weights of digits: 2^0, 2^1, 2^2,…from right to left for integers
- Decimal number system we use is base-10
  - 10 digits, from 0 to 9, Positional weights 10^0, 10^1, 10^2,…from right to left for integers
  - Example: $723 = 3x10^0 + 2x10^1 + 7x10^2$

Binary Numbers

Dec	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000

Binary Numbers

Dec	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000

Binary to Decimal Conversion

101011 ➔ $1 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$ = 43

$(101011)_2 = (43)_{10}$

111001 ➔ $1 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$ = 57

$(111001)_2 = (57)_{10}$

10100 ➔ $1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$ = 20

$(10100)_2 = (20)_{10}$

Bits and Bytes

- Bit – a single 1 or 0
- Byte – 8 consecutive bits
  - 2 bytes = 16 bits
  - 4 bytes = 32 bits
- Max. integer that can represented
  - in 1 byte = 255 (=11111111)
  - In 4 bytes = 4294967295 (= 32 1’s)
- No. of integers that can be represented in 1 byte = 256 (the integers 0, 1, 2, 3,….255)

Fundamentals of C

First C program – print on screen

```
#include <stdio.h>
void main()
{
    printf ("Hello, World! \n") ;
}
```

More print

```
#include <stdio.h>
void main()
{
    printf ("Hello, World! ") ;
    printf ("Hello \n World! \n") ;
}
```

Some more print

```
#include <stdio.h>
void main()
{
    printf ("Hello, World! \n") ;
    printf ("Hello \n World! \n") ;
    printf ("Hell\no \t World! \n") ;
}
```

Reading values from keyboard

```
#include <stdio.h>
void main()
{
        int num ;
        scanf ("%d", &num) ;
        printf (“No. of students is %d\n”, num) ;
}
```

Centigrade to Fahrenheit

```
#include <stdio.h>
void main()
{
    float cent, fahr;
    scanf(“%f”,&cent);
    fahr = cent*(9.0/5.0) + 32;
    printf( “%f C equals %f F\n”, cent, fahr);
}
```

Largest of two numbers

```
#include <stdio.h>
void main()
{
    int x, y;
    scanf("%d%d",&x,&y);
    if (x>y) printf("Largest is %d\n",x);
    else printf("Largest is %d\n",y);
}
```

largest-1.c

What does this do?

```
#include <stdio.h>
void main()
{
    int x, y;
    scanf("%d%d",&x,&y);
    if (x>y) printf("Largest is %d\n",x);
    printf("Largest is %d\n",y);
}
```

largest-2.c

The C Character Set

- The C language alphabet
  - Uppercase letters ‘A’ to ‘Z’
  - Lowercase letters ‘a’ to ‘z’
  - Digits ‘0’ to ‘9’
  - Certain special characters:

<table>
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</table>

A C program should not contain anything else

Structure of a C program

- A collection of functions (we will see what they are later)
- Exactly one special function named main must be present. Program always starts from there
- Each function has statements (instructions) for declaration, assignment, condition check, looping etc.
- Statements are executed one by one

Variables

- Very important concept for programming
- An entity that has a value and is known to the program by a name
- Can store any temporary result while executing a program
- Can have only one value assigned to it at any given time during the execution of the program
- The value of a variable can be changed during the execution of the program

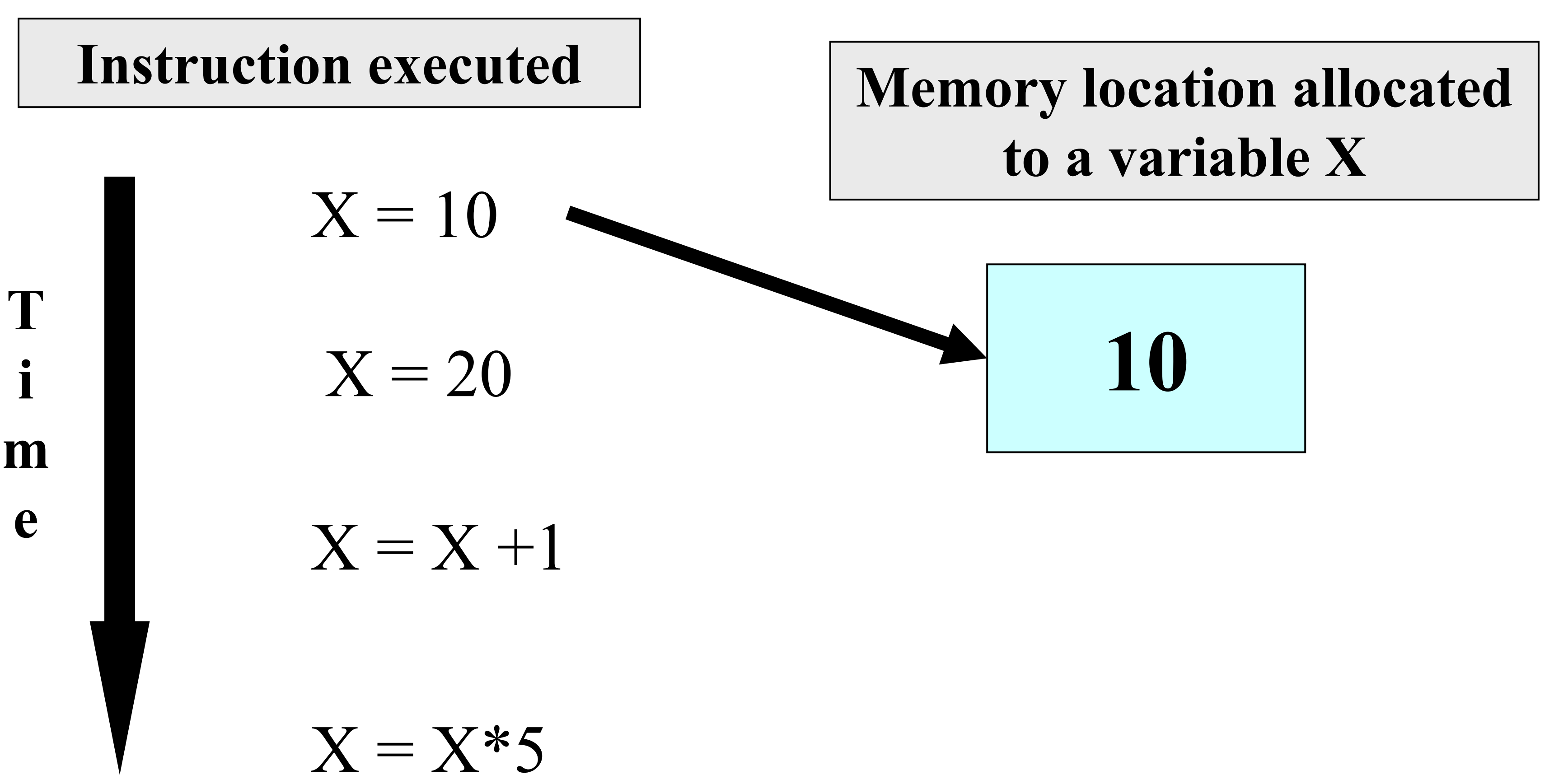
Contd.

- Variables stored in memory
- Remember that memory is a list of storage locations, each having a unique address
- A variable is like a bin
  - The contents of the bin is the value of the variable
  - The variable name is used to refer to the value of the variable
  - A variable is mapped to a location of the memory, called its address

Example

```
#include <stdio.h>
void main( )
{
    int x;
    int y;
    x=1;
    y=3;
    printf("x = %d, y= %d\n", x, y);
}
```

Variables in Memory



Variables in Memory

Instruction executed

Memory location allocated to a variable X

T
i
m
e

X = 10

X = 20

X = X +1

X = X*5

20

Variables in Memory

Instruction executed

Memory location allocated to a variable X

T
i
m
e

X = 10

X = 20

X = X +1

X = X*5

21

Variables in Memory

Instruction executed

Memory location allocated to a variable X

T i m e

X = 10

X = 20

X = X +1

X = X*5

105

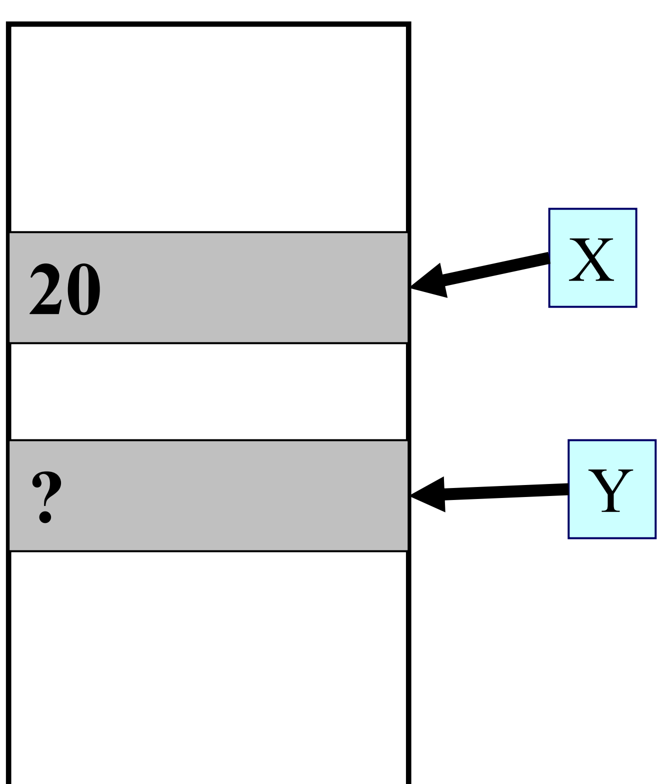
Variables (contd.)

X = 20

Y=15

X = Y+3

Y=X/6



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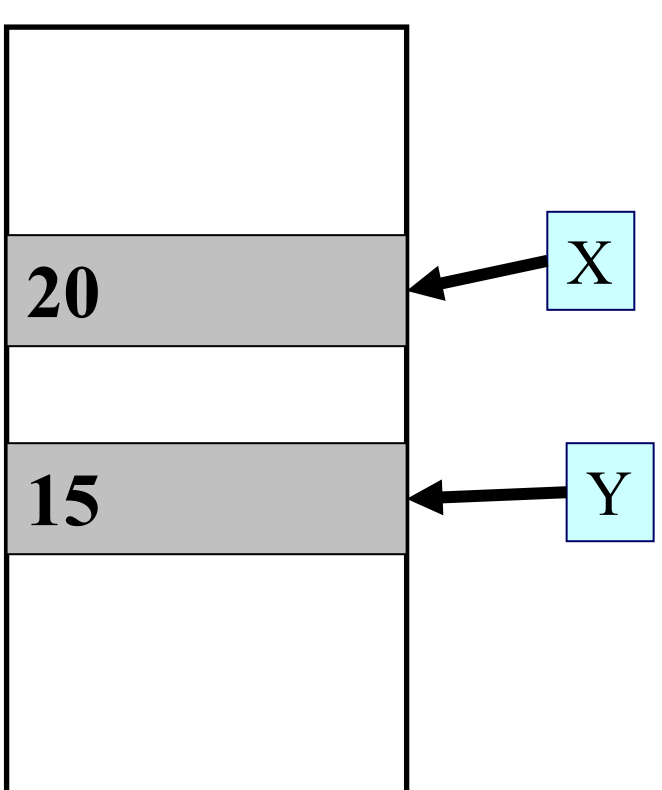

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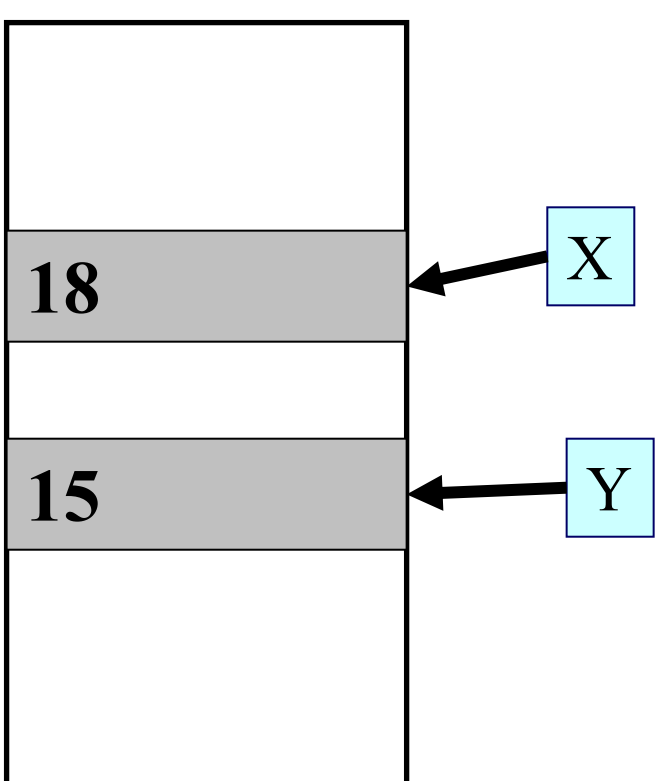

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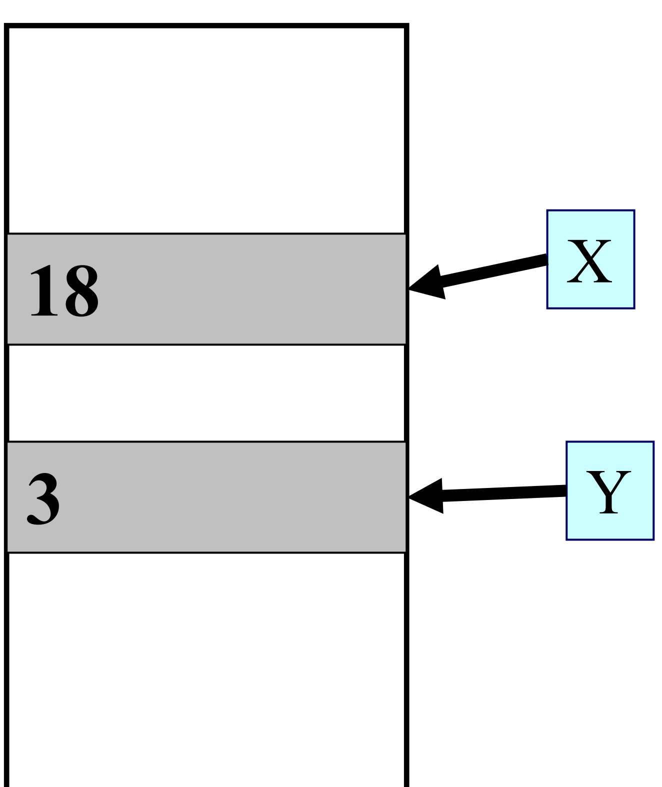

Data Types

- Each variable has a type, indicates what type of values the variable can hold
- Four common data types in C
  - int - can store integers (usually 4 bytes)
  - float - can store single-precision floating point numbers (usually 4 bytes)
  - double - can store double-precision floating point numbers (usually 8 bytes)
  - char - can store a character (1 byte)

Contd.

- Must declare a variable (specify its type and name) before using it anywhere in your program
- All variable declarations should be at the beginning of the main() or other functions
- A value can also be assigned to a variable at the time the variable is declared.

```
int   speed = 30;
char  flag = 'y';
```

Variable Names

- Sequence of letters and digits
- First character must be a letter or '_'
- No special characters other than '_'
- No blank in between
- Names are case-sensitive (max and Max are two different names)
- Examples of valid names:
  - i rank1 MAX max Min class_rank
- Examples of invalid names:
  - a's fact rec 2sqroot class,rank

More Valid and Invalid Identifiers

- Valid identifiers

  X

  abc

  simple_interest

  a123

  LIST

  stud_name

  Empl_1

  Empl_2

  avg_empl_salary

- Invalid identifiers

  10abc

  my-name

  “hello”

  simple interest

  (area)

  %rate

C Keywords

- Used by the C language, cannot be used as variable names
- Examples:
  - int, float, char, double, main, if else, for, while. do, struct, union, typedef, enum, void, return, signed, unsigned, case, break, sizeof,….
  - There are others, see textbook…

Example 1

```
#include <stdio.h>
void main()
{
      int x, y, sum;
      scanf(“%d%d”,&x,&y);
      sum = x + y;
      printf( “%d plus %d is %d\n”, x, y, sum );
}
```

Three int type variables declared

Values assigned

Example - 2

```
#include <stdio.h>
void main()
{
    float x, y;
    int d1, d2 = 10;
    scanf(“%f%f%d”,&x, &y, &d1);
    printf( “%f plus %f is %f\n”, x, y, x+y);
    printf( “%d minus %d is %d\n”, d1, d2, d1-d2);
}
```

Assigns an initial value to d2, can be changed later

Read-only variables

- Variables whose values can be initialized during declaration, but cannot be changed after that
- Declared by putting the const keyword in front of the declaration
- Storage allocated just like any variable
- Used for variables whose values need not be changed
    - Prevents accidental change of the value

Correct

```
void main() {
   const int LIMIT = 10;
   int n;
   scanf(“%d”, &n);
   if (n > LIMIT)
       printf(“Out of limit”);
}
```

Incorrect: Limit changed

```
void main() {
    const int Limit = 10;
    int n;
    scanf(“%d”, &n);
    Limit = Limit + n;
    printf(“New  limit is %d”, Limit);
}
```

Constants

- Integer constants
  - Consists of a sequence of digits, with possibly a plus or a minus sign before it
  - Embedded spaces, commas and non-digit characters are not permitted between digits
- Floating point constants
- Two different notations:
  - Decimal notation: 25.0, 0.0034, .84, -2.234
  - Exponential (scientific) notation

    3.45e23, 0.123e-12, 123e2

e means "10 to the power of"

Contd.

- Character constants
  - Contains a single character enclosed within a pair of single quote marks.
  - Examples :: ‘2’, ‘+’, ‘Z’
- Some special backslash characters

‘\n’	new line
‘\t’	horizontal tab
‘\’’	single quote
‘\”’	double quote
‘\\’	backslash
‘\0’	null

Input: scanf function

- Performs input from keyboard
- It requires a format string and a list of variables into which the value received from the keyboard will be stored
- format string = individual groups of characters (usually '%' sign, followed by a conversion character), with one character group for each variable in the list

```
int a, b;
float c;
scanf("%d %d %f", &a, &b, &c);
```

Variable list (note the & before a variable name)

Format string

- Commonly used conversion characters

  c   for char type variable

  d   for int type variable

  f   for float type variable

  lf   for double type variable

- Examples

```
scanf ("%d", &size) ;
scanf ("%c", &nextchar) ;
scanf ("%f", &length) ;
scanf (“%d%d”, &a, &b);
```

Reading a single character

- A single character can be read using scanf with %c
- It can also be read using the getchar() function

```
char c;
c = getchar();
```

- Program waits at the getchar() line until a character is typed, and then reads it and stores it in c

Output: printf function

- Performs output to the standard output device (typically defined to be the screen)
- It requires a format string in which we can specify:
  - The text to be printed out
  - Specifications on how to print the values

```
printf ("The number is %d\n", num);
```

  - The format specification %d causes the value listed after the format string to be embedded in the output as a decimal number in place of %d
  - Output will appear as: The number is 125

Contd.

- General syntax:

  printf (format string, arg1, arg2, …, argn);

  - format string refers to a string containing formatting information and data types of the arguments to be output
  - the arguments arg1, arg2, … represent list of variables/expressions whose values are to be printed
- The conversion characters are the same as in scanf

- Examples:

```
printf  (“Average of %d and %d is %f”, a, b, avg);
printf  (“Hello \nGood \nMorning \n”);
printf (“%3d %3d %5d”, a, b, a*b+2);
printf (“%7.2f  %5.1f”, x, y);
```

- Many more options are available for both printf and scanf
  - Read from the book
  - Practice them in the lab