Dr. Vishwanath Karad MIT WORLD PEACE UNIVERSITY | PUNE

TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

Fundamentals of Data Structures

S. Y. B. Tech CSE

Semester – III

SCHOOL OF COMPUTER ENGINEERING AND TECHNOLOGY

Introduction to Data Structures

- Data, Data objects, Data Types
- Abstract Data types (ADT) and Data Structure
- Types of data structure
- Introduction to Algorithms
- Algorithm Design Tools: Pseudo code and flowchart
- Analysis of Algorithms- Space complexity, Time complexity, Asymptotic notations

Data, Data Objects and Data Types

- Computer Science is study of data
  - Machines that hold data
  - Languages for describing data manipulations
  - Foundations which describe what kinds of refined data can be produced from raw data
  - Structures of refining data

Data, Data Objects and Data Types

Data is of two types

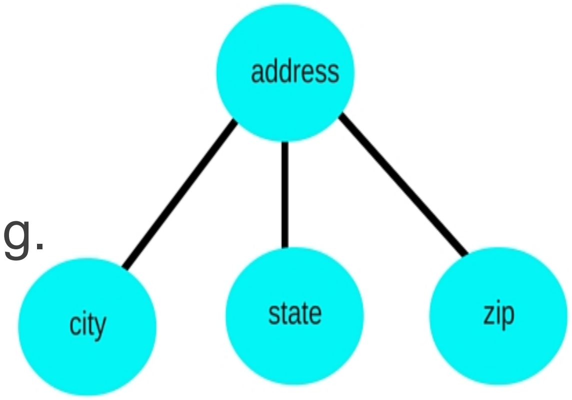
- **Atomic Data**

  It consist of single piece of information. It cannot be divided into other meaningful pieces of data. e.g Name of Person, Name of Book

- **Composite Data**

  It can be divided into subfields that have meaning.

  e.g. Address, Telephone number

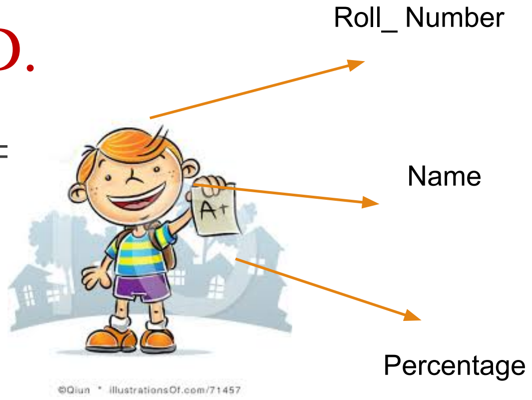


Data, Data Objects and Data Types

Data Objects

Data object is referring to set of elements say D.

For Example: Data Object integers refers to D= ±2,…………………}



Data Object represents an object having a data.

For Example:

If student is one object then it will consist of different data like roll no, name, percentage, address etc.

Data, Data Objects and Data Types

Data Types

- A Data type is a term which refers to the kinds of data that variables may hold in a programming languages.
- For Example: In C programming languages, the data types are integer, float, character etc.
- Data type is a way to classify various types of data such as integer, string, etc. which determines the values that can be used with the corresponding type of data, the type of operations that can be performed on the corresponding type of data.
- There are two data types –
  - Built-in Data Type
  - Derived Data Type

Data, Data Objects and Data Types

Built-in Data Type

Those data types for which a language has built-in support are known as Built-in Data types.

For example, most of the languages provide the following built-in data types.

- Integers
- Boolean (true, false)
- Floating (Decimal numbers)
- Character and Strings

Derived Data Type

These data types are normally built by the combination of primary or built-in data types and associated operations on them.

For example –

- List
- Array
- Stack
- Queue

Abstract Data Type(ADT) and Data Structure

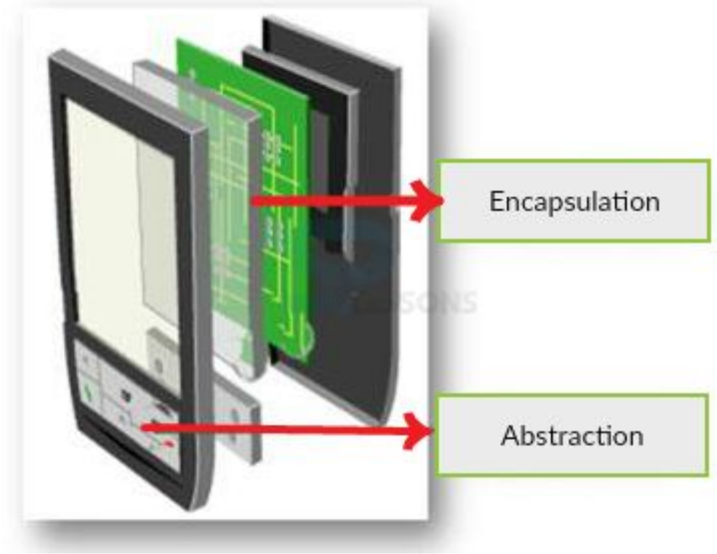
- **Abstract Data Type**
  - Concern about what can be done not how it can be done

Abstract Data Type consist of

- Declaration of Data
- Declaration of Operations
- Encapsulation of data and operations

Abstract data types

An abstract data type is a type with associated operations, but whose representation is hidden.



- The calculator explains it very well.
- One can use it different ways by giving various values and perform operations.
- But, mechanism how the operation is done is not shown.
- This process of hiding the information is called as *Abstraction*.

Abstract Data Types (ADT)

- An **ADT** is composed of
    - A collection of data
    - A set of operations on that data
- Specifications of an **ADT** indicate
    - What the ADT operations do, not how to implement them
- Implementation of an **ADT**
    - Includes choosing a particular data structure

Abstract Data Type(ADT) and Data Structure

Abstract Data Type Examples

- Array
- Tree
- Graph
- Linked List
- Matrix

structure ARRAY(value, index)
 declare CREATE()→array
  RETRIVE(array,index)→value
  STORE(array,index,value)→array;
 for all A ε array, i,j ε index ,x ε value **let**
  RETRIVE (CREATE,i) : : = **error**
  RETRIVE (STORE(A,i,x),j) : : =
   if EQUAL(i,j) **then x else**
 RETRIVE(A,j)
 end
end ARRAY

Data Structure

- A data structure is a set of domains D, a structured domain d ε D, a set of functions F and a set of axioms A.
- The triple(D,F,A) denotes the data structure d ε D and it will usually be abbreviated by writing d.
- The triple(D,F,A) is referred to as an abstract data type (ADT).
- It is called abstract precisely because the axioms do not imply a form of representations/implementation.

Data Structure

Example

Structure NATNO

Declare ZERO() → natno

ISZERO(NATNO) → Boolean

SUCC(natno) → natno

ADD(natno,natno) → natno

for all x,y ε natno let

ISZERO(ZERO) :: = true;

ADD(ZERO,y) :: =y;

ISZERO(SUCC(x))= false

D=NATNO

D ε D= {Boolean, natno}

F={ZERO,ISZERO,ADD,SUCC}

AXIOMS

Types of Data Structures

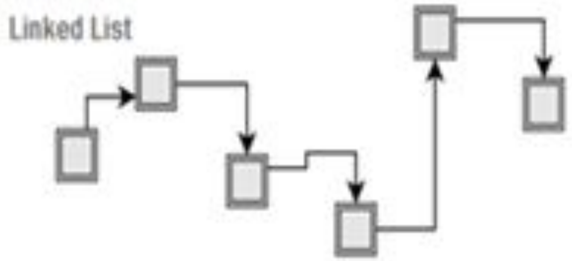
- **Linear data structure:**
  - The data structure where data items are organized sequentially or linearly where data elements attached one after another is called linear data structure. It has unique predecessor and Successor.
  - **Ex:** Arrays, Linked Lists

- **Non-Linear data structure:**
  - The data structure where data items are not organized sequentially is called non linear data structure. It don't have unique predecessor or Successor.
  - In other words, A data elements of the non linear data structure could be connected to more than one elements to reflect a special relationship among them.
  - **Ex:** Trees, Graphs

Types of Data Structures

Linear Data Structure

Non Linear Data Structure



Types of Data Structures

- **Static data structure:**
  - Static Data structure has fixed memory size. It is the memory size allocated to data, which is static.
  - **Ex:** Arrays
- **Dynamic data structure:**
  - In Dynamic Data Structure, the size can be randomly updated during run time which may be considered efficient with respect to memory complexity of the code.
  - **Ex:** Linked List
- In comparison to dynamic data structures, static data structures provide easier access to elements. Dynamic data structures, as opposed to static data structures, are flexible.

Introduction to Algorithms

Algorithm

- Solution to a problem that is independent of any programming language.
- Sequence of steps required to solve the problem
- Algorithm is a finite set of instructions that if followed, accomplishes a particular task
- All algorithms must satisfy the following criteria:
  - **Input:** Zero or more Quantities are externally supplied
  - **Output**: At least one quantity is produced
  - **Definiteness**: Each instruction is clear and unambiguous
  - **Finiteness**: if we trace out the instructions of an algorithm then for all cases the algorithm terminates after a finite number of steps.
  - **Effectiveness**: Every instruction must be very basic so that it can be carried out in principle by a person using pencil and paper.

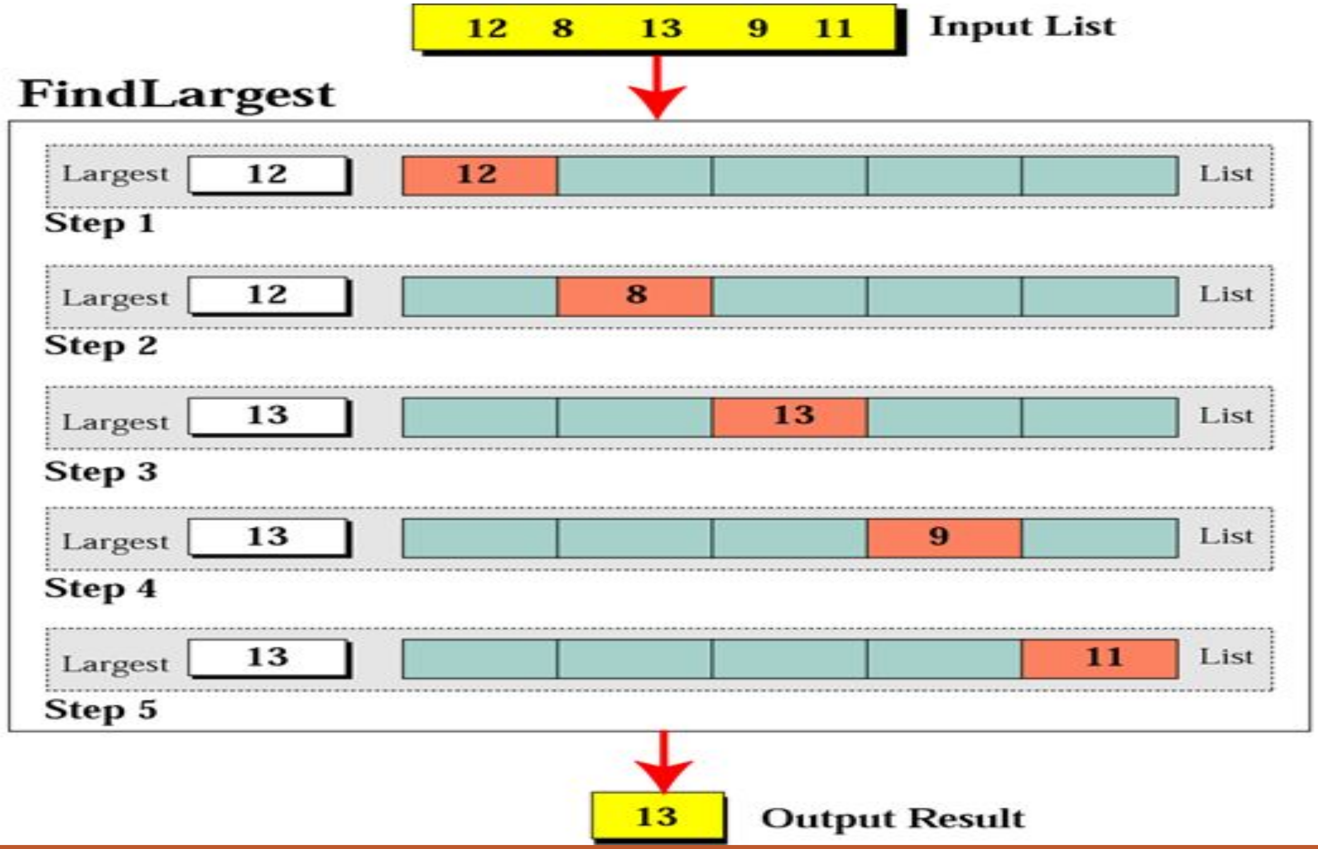
Introduction to Algorithms

Program vs Algorithm

- A program is a written out set of statements in a language that can be executed by the machine.
- An algorithm is simply an idea or a solution to a problem that is often procedurally written.

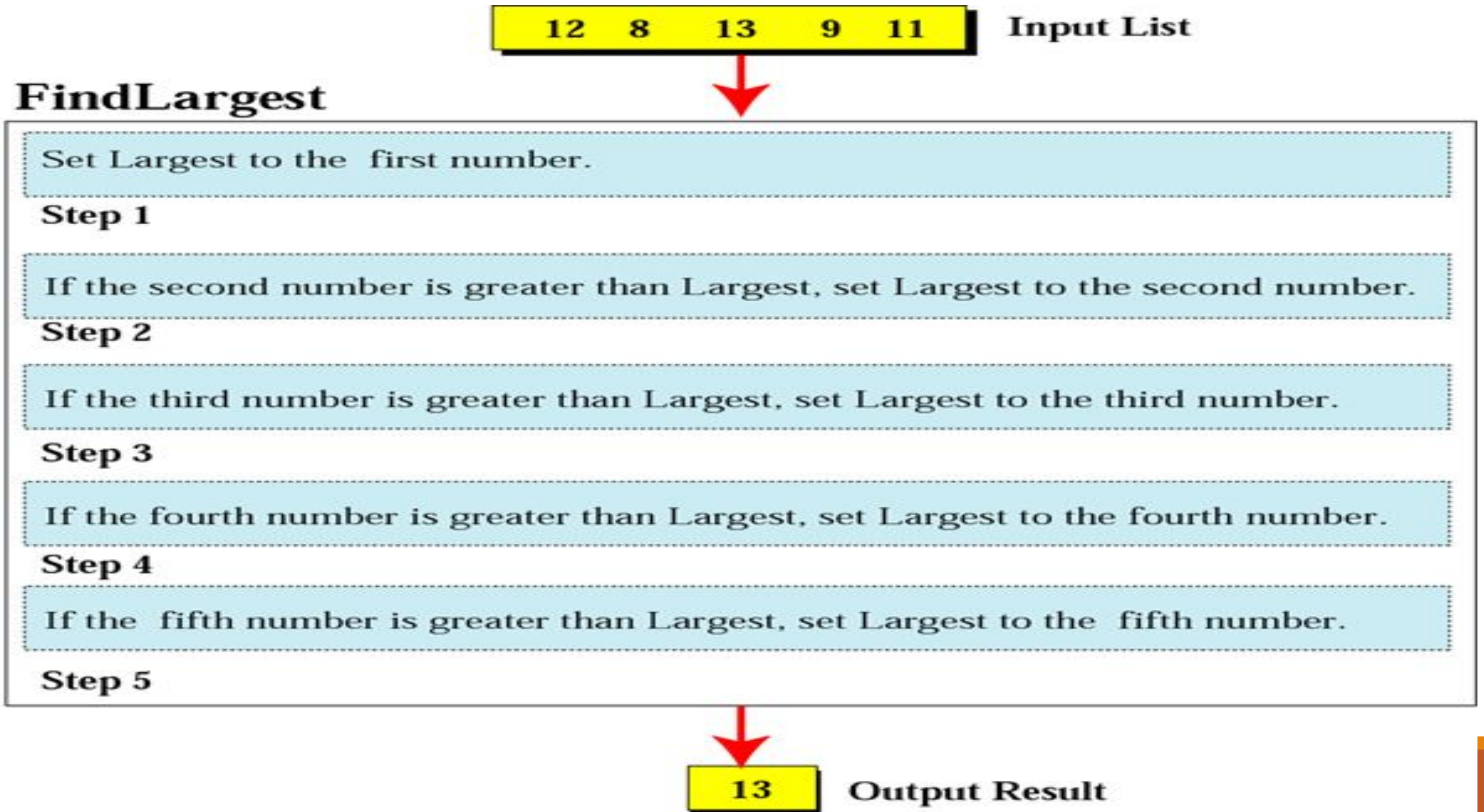
Introduction to Algorithms

Example : **Finding the largest integer among five integers**



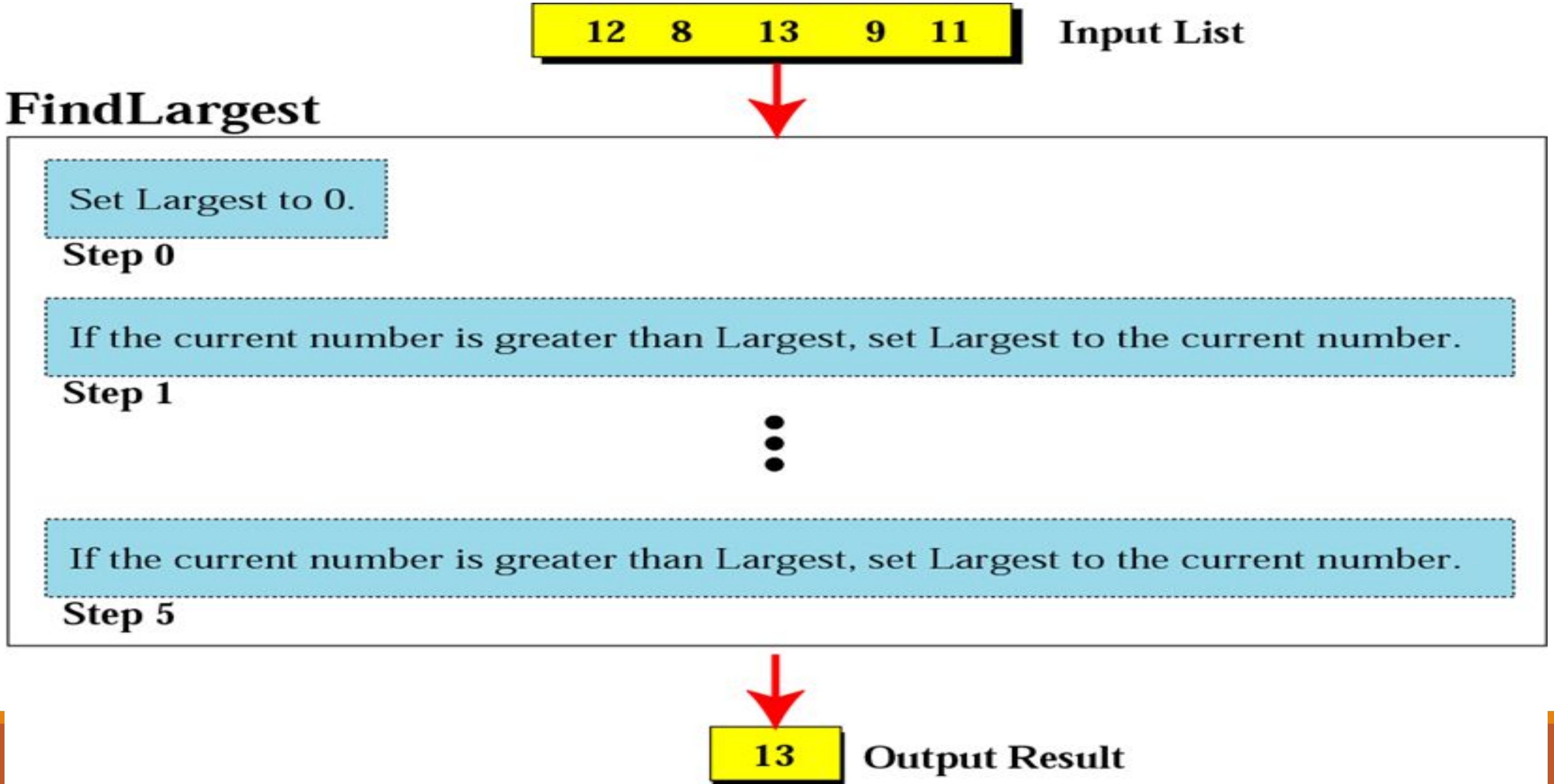
Introduction to Algorithms

Defining actions in Find Largest algorithm

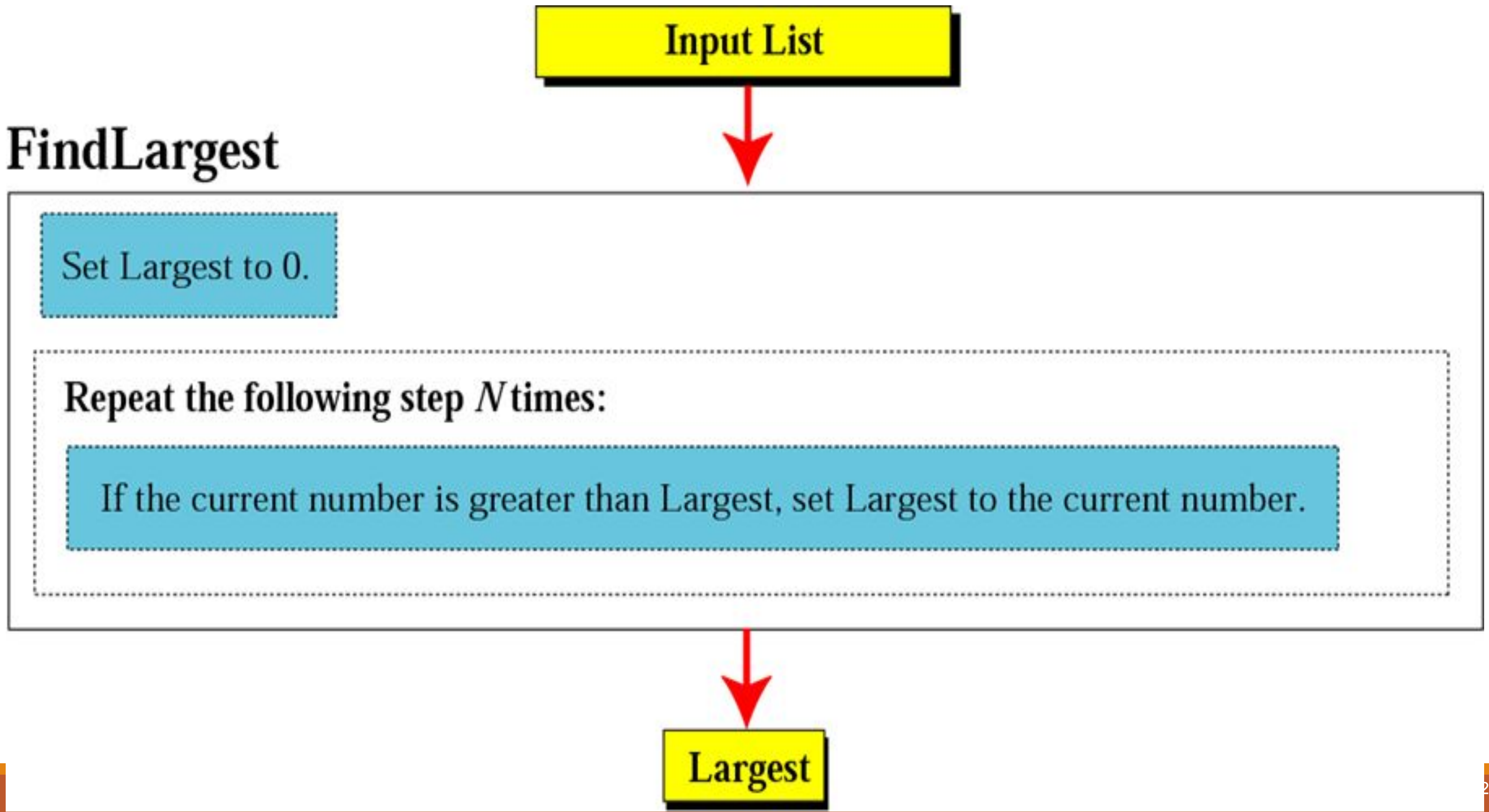


Introduction to Algorithms

Find Largest refined



Introduction to Algorithms



Introduction to Algorithms

Three constructs

```
do action 1
do action 2
. . .
. . .
do action n
```

a. Sequence

```
if a condition is true,
then
    do a  series of actions
else
    do another  series of actions
```

b. Decision

```
while a condition is true,
    do action 1
    do action 2
    . . .
    . . .
    do action n
```

c. Repetition

Algorithm Design Tools

- **Pseudo Code**
  - is an artificial and informal language that helps programmers develop algorithms.
  - Uses English-like phrases with some Visual Basic terms to outline the program
- **Flowchart**
  - Graphical representation of an algorithm.
  - Graphically depicts the logical steps to carry out a task and shows how the steps relate to each other.

Algorithm Design Tools

Flowchart

Example 1: Print 1 to 20:

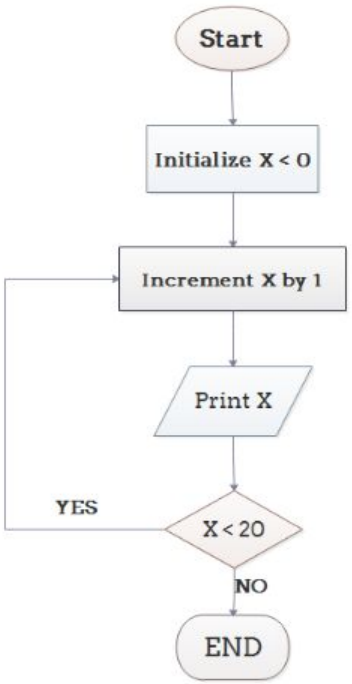
Algorithm

Step 1: Initialize X as 0,

Step 2: Increment X by 1,

Step 3: Print X,

Step 4: If X is less than 20 then go back to step 2.



Pseudo Code

- **Pseudocode** is an informal high-level description of the operating principle of a computer program or other algorithm.

- It uses the structural conventions of a normal programming language, but is intended for human reading rather than machine reading.

```
Algorithm SORT(A, n)
{
    for (i =1;i<n; i++)
      {
      j = i ;
      for (k = j+1;k<n; k++)
      {
        if A[k] <  A[j]
            j=k;
          }
          t = A[i];
       A[i]= A[j];
      A[j]=t
      }
}
```

Pseudo Code

Examples

Algorithm grade_assignment( )

```
{
    if (student_grade >= 60)
        print "passed"
    else
        print "failed"
}
```

Examples

Algorithm grade_count()

```
{
total=0
grade_counter =1

 while (grade_counter<10)
 {
   read next grade
   total=total + grade
   grade_counter=grade_counter + 1
 }
class_average=total/10
print class_average.
}
```

Pseudo Code

Some Keywords That Should be Used And Additional Points:

- Algorithm Keyword is used
- Curly brackets are used instead of begin-end
- Directly programming syntaxes are used
- Easy to convert into program
- Semicolons used

Pseudo Code

Some Keywords That Should be Used And Additional Points:

- Words such as set, reset, increment, compute, calculate, add, sum, multiply, ... print, display, input, output, edit, test , etc. with careful indentation tend to foster desirable pseudocode.

- Also, using words such as Set and Initialize, when assigning values to variables is also desirable.

Pseudo Code

Formatting and Conventions in Pseudo code

- INDENTATION in pseudocode should be identical to its implementation in a programming language.
- Use curly brackets for indentation
- No flower boxes (discussed ahead) in your pseudocode.
- Do not include data declarations in your pseudocode.
- But do cite variables that are initialized as part of their declarations. E.g. "initialize count to zero" is a good entry.

Pseudo Code

Calls to Functions should appear as:

Call FunctionName (arguments: field1, field2, etc.)

Returns in functions should appear as:

Return (field1)

Function headers should appear as:

FunctionName (parameters: field1, field2, etc.)

Functions called with addresses should be written as:

Call FunctionName (arguments: pointer to fieldn, pointer to field1, etc.)

Function headers containing pointers should be indicated as:

FunctionName (parameters: pointer to field1, pointer to field2, ...)

Returns in functions where a pointer is returned:

Return (pointer to fieldn)

Pseudo Code

1. Function Call

EVERY function should have a flowerbox PRECEDING IT.

This flower box is to include the functions name, the main purpose of the function, parameters it is expecting (number and type), and the type of the data it returns.

All of these listed items are to be on separate lines with spaces in between each explanatory item.

FORMAT of flowerbox should be

```
******************************************************
Function:   ( cryptic text describing single function
                  ....... (indented like this)
                  .......
        Calls:     Start listing functions "this" function calls
                  Show these functions:  one per line, indented

        Called by:  List of functions that calls "this" function
                  Show these functions:  one per line, indented.

        Input Parameters:  list, if appropriate; else None

        Returns:    List, if appropriate.
******************************************************
```

Pseudo Code

➢**Advantages and Disadvantages**

Pseudocode Disadvantages

- It's not visual
- There is no accepted standard, so it varies widely from company to company

Pseudocode Advantages

- Can be done easily on a word processor
- Easily modified
- Implements structured concepts well

Flow Charts

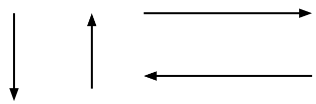
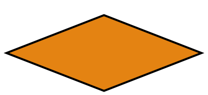
Flowchart Disadvantages

- Hard to modify
- Need special software

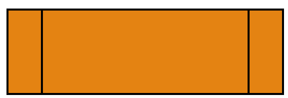
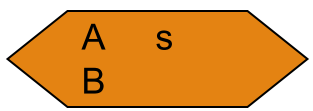
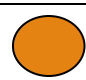
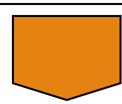
Flowchart Advantages

- Standardized: all pretty much agree on the symbols and their meaning
- Visual

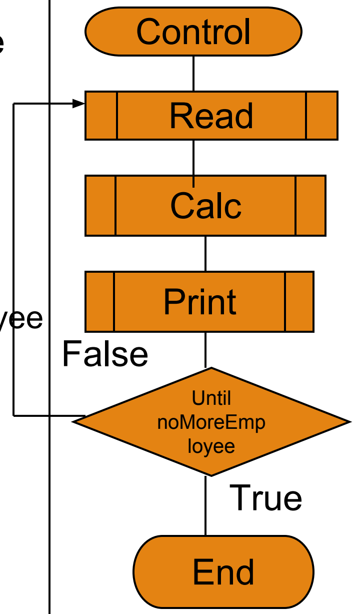
Flow Chart Symbols

Flowchart Symbol	Explanation
	Flow lines are indicated by straight lines with optional arrows to show direction of data flow.
 Start/Stop/End	An ellipse uses the name of the module at the start. The end is indicated by the word end or stop.
	Processing block such as calculations, opening and closing files
	Input to or output from the computer
	Decision symbol. one entrance and two and only two exits

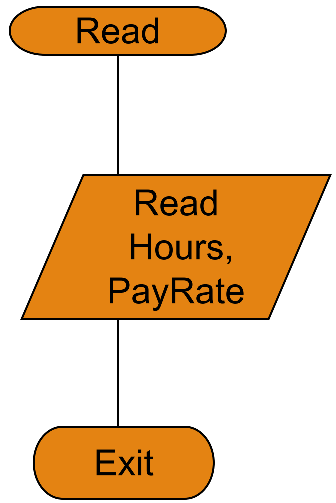
Drawing the Flowcharts

Flowchart Symbol	Explanation
	Process of module. Having one entrance and one exit
	Loop within counter. The counter starts with A and incremented by s until the counter is greater than B
	On-page connector. Connects sections on same page
	Off Page Connectors

Algorithms and Flowcharts

Algorithm	Flowcharts
Control Module 1.Repeat Process Read Process Calc Process Print Until NoMoreEmployee 2.End	

Algorithms and Flowcharts

Algorithm	Flowcharts
Read Module 1. Read Hours, 2. Read PayRate 3.Exit	

Algorithms and Flowcharts

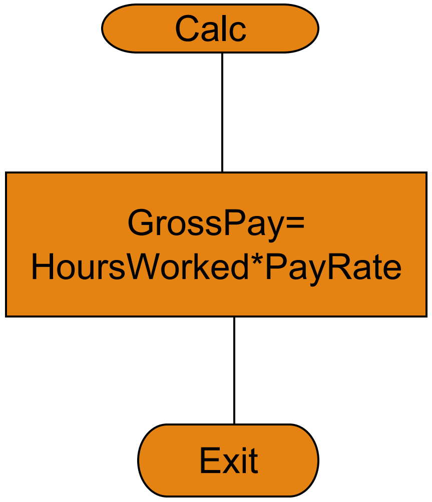
Algorithm

Calc Module

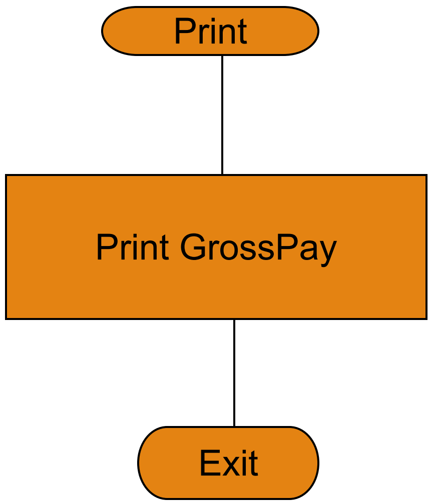
1. GrossPay= HoursWorked *PayRate

2.Exit

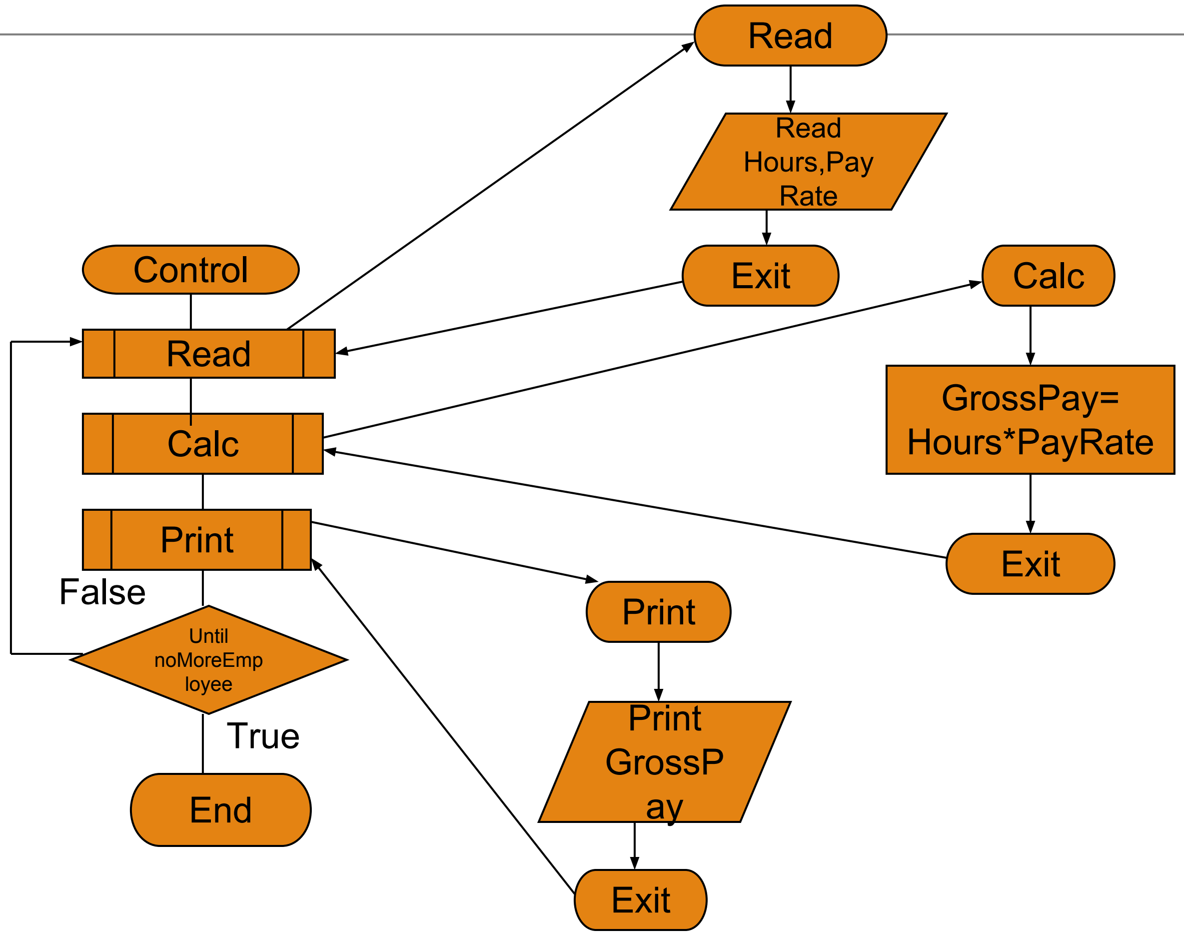
Flowcharts



Algorithms and Flowcharts

Algorithm	Flowcharts
Print Module 1. Print Pay 2.Exit	

Algorithms and Flowcharts



Analysis of Algorithms

- Finding Efficiency of an algorithm in terms of
  - Time Complexity
  - Space Complexity

Analysis of Algorithms

- **What is time complexity**
  - Finding amount of time required for executing set of instructions or functions
  - It is represented in terms of frequency count
  - Frequency count is number of time every instruction of a code is to be executed.

- **What is space complexity**
  - Finding amount of memory space the program is going to consume.
  - It is calculated in terms of variables used in program.

Common Rates of Growth

Let n be the size of input to an algorithm, and k some constant. The following are common rates of growth.

- Constant: O(k), for example O(1)
- Linear: O(n)
- Logarithmic: $O(\log_k n)$
- Linear : n O(n) or n log n: $O(n \log_k n)$
- Quadratic: $O(n^2)$
- Polynomial: $O(n^k)$
- Exponential: $O(k^n)$

Example

```
void fun()
{
  int a;
   a=5;
   printf("%d",a);
}
```

```
void fun()
{
  int a;
   a=0;
   for(i=0;i<n;i++)
    {
         a=a + i;
     }
   printf("%d",a);
}
```

Solving Problems

Find Frequency Count and Time Complexity

```
for(i=1;i<=n;i++)
{
        for(j=1;j<=n;j++)
        {
                C[j][j]=0;
            for(k=1;k<=n;k++)
                C[i][j]=c[i][j]+a[i][k]*b[k][j];
        }
}
```

```
i=1;
do
{
    a++;
    if(i==5)
      break;
    i++;
}
while(i<=n);
```

```
i=1;
while(i<=n)
{
   a++;
   if(i==5)
     break;
     i++;
}
```

Find Frequency Count and Time Complexity

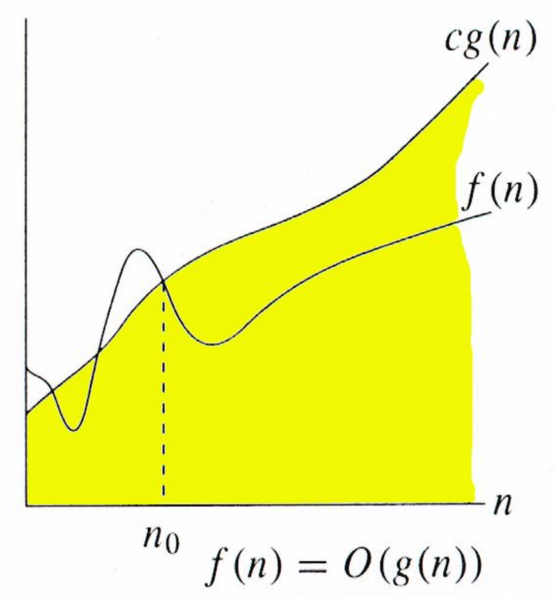
```
i=n;
while(i>=1){
        i--;
}
```

```
i=10;
for(i=10;i<=n;i++)
        for(j=1;j<i;j++)
                x=x+1;
```

```
i=0;

for(i=0;i<=n;i++)

for(j=1;j<i;j++)

x=x+1;
```

O-notation Example

For a given function g(n), we denote O(g(n)) as the set of
functions:
O(g(n)) = { f(n)| there exists positive constants c and n0 such that $0 \leq f(n) \leq c\, g(n)$ for all $n \geq n0$ }
It is used to represent the worst case growth of an algorithm in time or a data structure in space when they are dependent on n, where n is big enough.



Big Oh - Example

$f(n) = n^2 + 5n = O(n^2)$

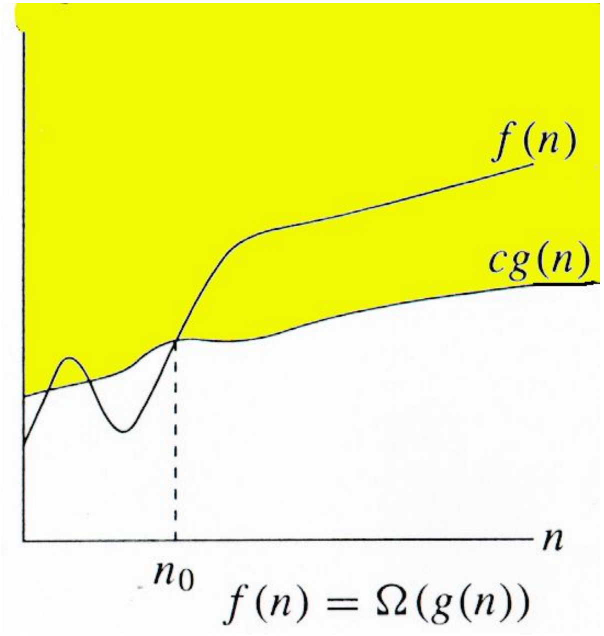
$g(n) = n^2$ .... $c = 2$

n	$n^2 + 5n$	$2n^2$
1	5	2
2	14	8
5	50	50

$f(n) <= c\, g(n)$ for all $n >= n_0$ where $c=2$ & $n_0 = 5$

Ω -notation

Ω (g(n)) represents a set of functions such that:
$\Omega(g(n)) = \{f(n)$: there exist positive constants c and n0 such that $0 \leq c\, g(n) \leq f(n)$ for all $n \geq n0\}$



Big Omega - Example

Example 1 :

$f(n) = n^2 + 5n$

$g(n) = n^2$ ……… c = 1

n	$n^2 + 5n$	$c*n^2$
1	5	1
2	14	4
5	50	25

$f(n) >= c\, g(n)$ for all $n >= n_0$ where $c=1$ & $n_0 = 1$

Example 1 :

Prove that if $T(n) = 15n^3 + n^2 + 4$, $T(n) = \Omega(n^3)$.

Proof.

Let $c = 15$ and $n_0 = 1$.

Must show that $0 \le cg(n)$ and $cg(n) \le f(n)$.

$0 \le 15n^3$ for all $n \ge n_0 = 1$.

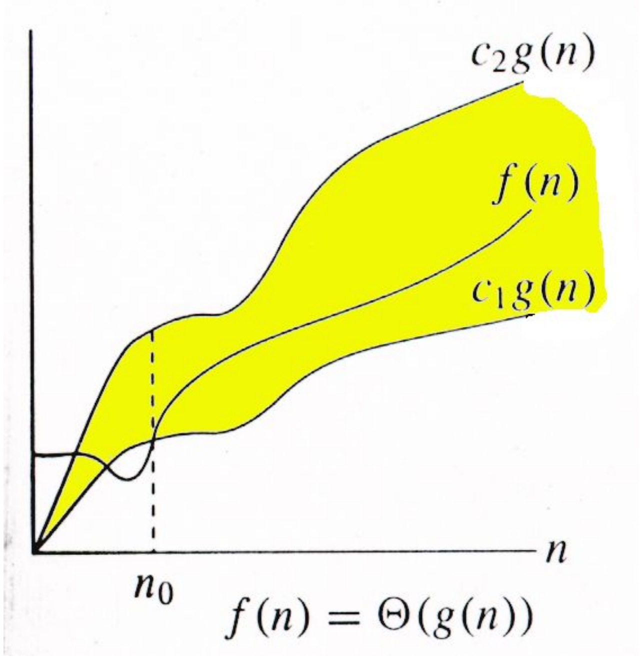
$cg(n) = 15n^3 \le 15n^3 + n^2 + 4 = f(n)$

Θ-notation

Asymptotic tight bound

Θ (g(n)) represents a set of functions such that:

Θ (g(n)) = {f(n): there exist positive constants c1, c2, and n0such that $0 \le c1g(n) \le f(n) \le c2g(n)$ for all $n \ge n0$ }



Theta Example

$f(N) = \Theta(g(N))$ iff $f(N) = O(g(N))$ and $f(N) = \Omega(g(N))$
It can be read as "f(N) has order exactly g(N)".

The growth rate of f(N) equals the growth rate of g(N). The growth rate of f(N) is the same as the growth rate of g(N) for large N.

Theta means the bound is the tightest possible.

If T(N) is a polynomial of degree k, $T(N) = \Theta(N^k)$.

For logarithmic functions, $T(\log_m N) = \Theta(\log N)$.

Analysis of Algorithms

- Algorithm analysis is done in following three cases

  – Best Case

  The amount of time a program might be expected to take on best possible input data

  – Worst Case

  The amount of time a program would take on worst possible input configuration.

  – Average case

  The amount of time a program might be expected to take on typical(or average) input data

Example: Sorting Algorithms

Practice Assignments

1. Write a pseudo code and draw flowchart to input any alphabet and check whether it is vowel or consonant.
2. Write a pseudo code to check whether a number is even or odd
3. Write a pseudo code to check whether a year is leap year or not.
4. Write a pseudo code to check whether a number is negative, positive or zero
5. Write a pseudo code to input basic salary of an employee and calculate its Gross salary according to following:

   Basic Salary <= 10000 : HRA = 20%, DA = 80%
   Basic Salary <= 20000 : HRA = 25%, DA = 90%
   Basic Salary > 20000 : HRA = 30%, DA = 95%

Practice Problems

Q.1 Determine frequency count of following statements? Analyze time complexity of the following code:

```
i) for (i=1;i<=n;i++)
      for (j=1;j<=m;j++)
      sum=sum+i;

ii) i=n;
while(i>=1)
{
i--;
}
```

Practice Problems

Problems on frequency count & time complexity

```
for(i=1;i<=n;i++)
{
For(j=1;j<=n;j++)
{
C[j][j]=0;
For(k=1;k<=n;k++)
C[i][j]=c[i][j]+a[i][k]*b[k][j];
}
}
```

```
double IterPow(double X,int N)
{
double Result=1;
while(N>0)
{
Result=Result* X
N--;
}
return result;
```

Practice Problems

Q.3 What is the frequency count of a statement? Analyze time complexity of following code?

```
for(i=1;i<=n;i++)
    for(j=1;j<=m;j++)
        for(k=1;k<=p;k++)
{
              Sum=sum+i
}
```

Takeaway

- Data Structures plays major role in problem solving.
- Pseudo code and flowcharts are the tools used to represent the solution of a problem in effective way.
- Analysis of algorithms is done in terms of time complexity and space complexity.