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TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

Fundamentals of Data Structures

S. Y. B. Tech CSE **Semester – III**

SCHOOL OF COMPUTER ENGINEERING AND TECHNOLOGY

Assessment Scheme:

Marks-60 [Class Continuous Assessment]

Marks-50 [lab Continuous Assessment] **Marks-40 [Term End Exam]**

Class Continuous Assessment (CCA)- 60 Marks

Assignments	Mid-term	Any Other (Active Learning)
33.33% (20)	33.33% (20)	33.33% (20)

Laboratory Continuous Assessment (LCA)-50 Marks

Practical Assessment	Practical Examination	Any other (Problem solving through coding platform)
50% (25)	30% (15)	20% (10)

Fundamentals of Data Structures

Assessment Scheme:

Marks-60 [Class Continuous Assessment]

Marks-50 [Lab Continuous Assessment] **Marks-40[Term End Exam]**

Course Objectives:

1. Knowledge

i. Learn the linear data structure and its fundamental concept.

2. Skills

i. Understand the different linear data structure such as Array, Stack, Queue and Linked list.

ii. Study the different searching and sorting techniques.

3. Attitude

i. Learn to apply advanced concepts of linear data structure to solve real world problems.

Course Outcomes: ***(After Completion of course Student should be able to:-)***

1. To develop skills for writing and analyzing algorithms to solve domain problems.
2. To compare and contrast different linear data structures and identify appropriate usage.
3. To demonstrate the use of sequential data structures.
4. To analyze different searching and sorting algorithms so as to understand their applications.

Syllabus

Introduction to Data Structures: Data, Data Objects, Abstract Data types (ADT) and Data Structures, Types of data structures (Linear and Non-linear, Static and dynamic) Introduction to algorithms Analysis of Algorithms- Space complexity, Time complexity, Asymptotic notations-Big-O, Theta and Omega, finding complexity using step count method, Analysis of programming constructs-Linear, Quadratic, Cubic, Logarithmic.

Linear Data Structures: Array as an Abstract Data Type, Sequential Organization, Storage Representation and their Address Calculation: Row major and Column Major, Multidimensional Arrays: Concept of Ordered List, Single Variable Polynomial: Representation using arrays, Polynomial as array of structure, Polynomial addition, Polynomial evaluation and Polynomial multiplication. Sparse Matrix: Sparse matrix representation using array, Sparse matrix addition, Transpose of sparse matrix- Simple and Fast Transpose, Time and Space tradeoff.

Syllabus

Searching and Sorting:

Searching: Search Techniques-Sequential Search/Linear Search, Variant of Sequential Search- Sentinel Search, Binary Search, and Fibonacci Search.

Sorting: Types of Sorting-Internal and External Sorting, General Sort Concepts-Sort Order, Stability, Efficiency, and Number of Passes, Comparison Based Sorting Methods-Bubble Sort, Insertion Sort, Selection Sort, Quick Sort, Merge sort and Shell Sort, Non-comparison Based Sorting Methods-Radix Sort, and Bucket Sort, Comparison of All Sorting Methods and their complexities.

Linked List: Linked List as an Abstract Data Type, Representation of Linked List Using Sequential Organization, Representation of Linked List Using Dynamic Organization, Types of Linked List: singly linked, Circular Linked Lists, Doubly Linked List, Doubly Circular Linked List, Primitive Operations on Linked List, Polynomial Manipulations-Polynomial addition. Generalized Linked List (GLL) concept, Representation of Polynomial using GLL.

Case Study : Garbage Collection

Syllabus

Stacks: Stack as an Abstract Data Type, Representation of Stack Using Sequential Organization, stack operations, Multiple Stacks Applications of Stack- Expression Conversion and Evaluation, Linked Stack and Operations, Recursion.

Queues: Queue as Abstract Data Type, Representation of Queue Using Sequential Organization, Queue Operations Circular Queue, Advantages of Circular queues, Linked Queue and Operations Deque-Basic concept, types (Input restricted and Output restricted), Application of Queue: Job scheduling.

Syllabus

Laboratory work:

Assignment No.	Assignment Title
1	Write a C program to compute following computation on matrix: a) Addition of two matrices b) Subtraction of two matrices c) Multiplication of two matrices d) Transpose of a matrix
2	Write a C program for sparse matrix realization and operations on it- Transpose, Fast Transpose.
3	Write a C program to create student database using array of structures. Apply searching (Linear and Binary Search) and sorting techniques (Insertion Sort, Selection Sort, Shell sort).
4	Write a C program to store first year percentage of students in array. Write function for sorting array of floating-point numbers in ascending order using bucket sort and display top five scores.
5	Department of Computer Engineering has student's club named 'Pinnacle Club'. Students of second, third and final year of department can be granted membership on request. Similarly, one may cancel the membership of club. First node is reserved for president of club and last node is reserved for the secretary of the club. Write C program to maintain club member ‘s information using singly linked list. Store student PRN and Name. Write functions to: a) Add and delete the members as well as president or even secretary. b) Compute total number of members of club c) Display members d) sorting of two linked list e) merging of two linked list f) Reversing using three pointers

Syllabus

6	Implement following polynomial operations using Circular Linked List: i) Create ii) Display iii) Addition.
7	Implement stack as an ADT and apply it for different expression conversions (infix to postfix or infix to prefix (Any one), prefix to postfix or prefix to infix, postfix to infix or postfix to prefix (Any one)).
8	Write a C program to evaluate postfix expression using stack.
9	Queues are frequently used in computer programming, and a typical example is the creation of a job queue by an operating system. If the operating system does not use priorities, then the jobs are processed in the order they enter the system. Write a program for simulating job queue. Write functions to add job and delete job from queue

Syllabus

Text Books:

1. Fundamentals of Data Structures, E. Horowitz, S. Sahni, S. A-Freed, Universities Press.

2. Data Structures and Algorithms, A. V. Aho, J. E. Hopperoft, J. D. UIlman, Pearson.

Reference Books:

1. The Art of Computer Programming: Volume 1: Fundamental Algorithms, Donald E. Knuth.

2. Introduction to Algorithms, Thomas, H. Cormen, Charles E. Leiserson, Ronald L. Rivest, Clifford Stein, The MIT Press.

3. Open Data Structures: An Introduction (Open Paths to Enriched Learning), (Thirty First Edition), Pat Morin, UBC Press.

Supplementary Readings:

1. Aaron Tanenbaum, “Data Structures using C”, Pearson Education.

2. R. Gilberg, B. Forouzan, "Data Structures: A pseudo code approach with C", Cenage Learning, ISBN 9788131503140.

```
Void multiply(int x[10][10],int y[10][10],int r,int c,int c1)
{
for(i=0;i<r;i++)
   for(j=0;j<c1;j++)
   {
     m[i][j]=0;
     for(k=0;k<c;k++)
     {
       m[i][j]= m[i][j]+ x[i][k]*y[k][j];
     }
   }
}
```

Transpose

```
for(i=0;i<r;i++)
 for(j=0;j<c;j++)
 {
   m[i][j]=x[j][i];
 }
```

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

1) Machines that hold data

2) Languages for describing data manipulations

3) Foundations which describe what kinds of refined data can be produced from raw data

4) Structures of refining data

Data, Data Objects and Data Types

Data is of two types

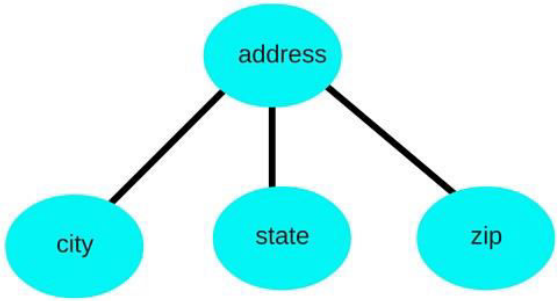
- **Atomic Data**

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

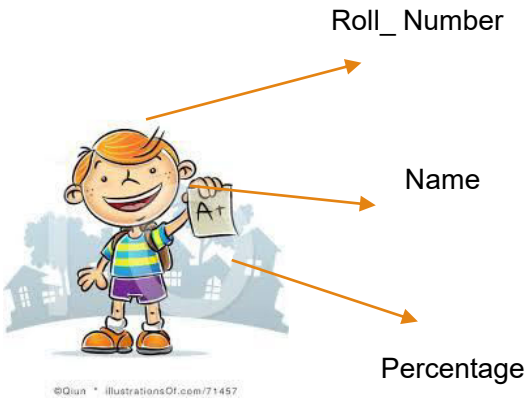


Data, Data Objects and Data Types

Data Objects

Data object is referring to set of elements say D.

For Example: Data Object integers refers to
D={0,±1,±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

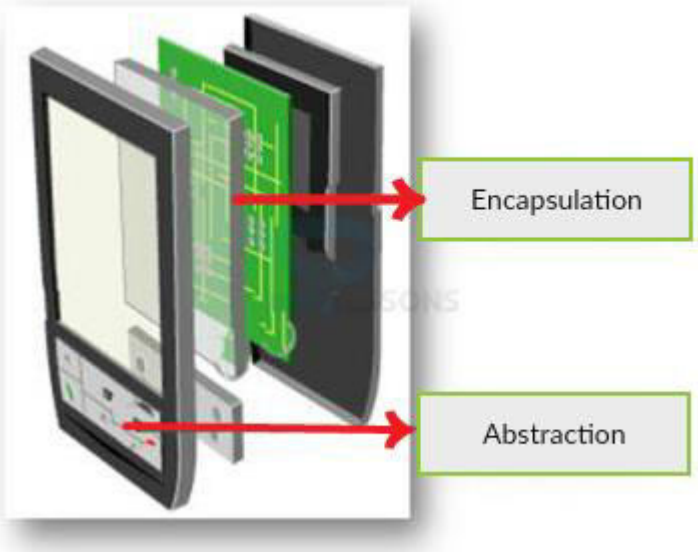
- **Abstract Data Type**
  - Concern about what can be done not how it can be done

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:

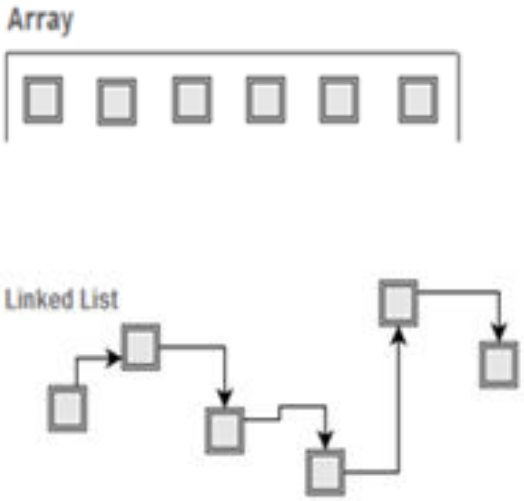
The data structure where data items are not organized sequentially is called non linear data structure. It don't have unique predecessor or Successor.

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.

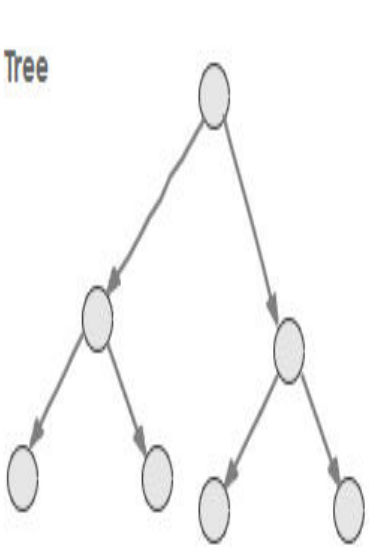
Ex: Trees, Graphs

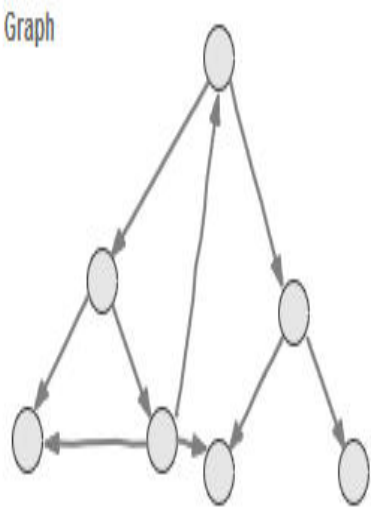
Types of Data Structures

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.

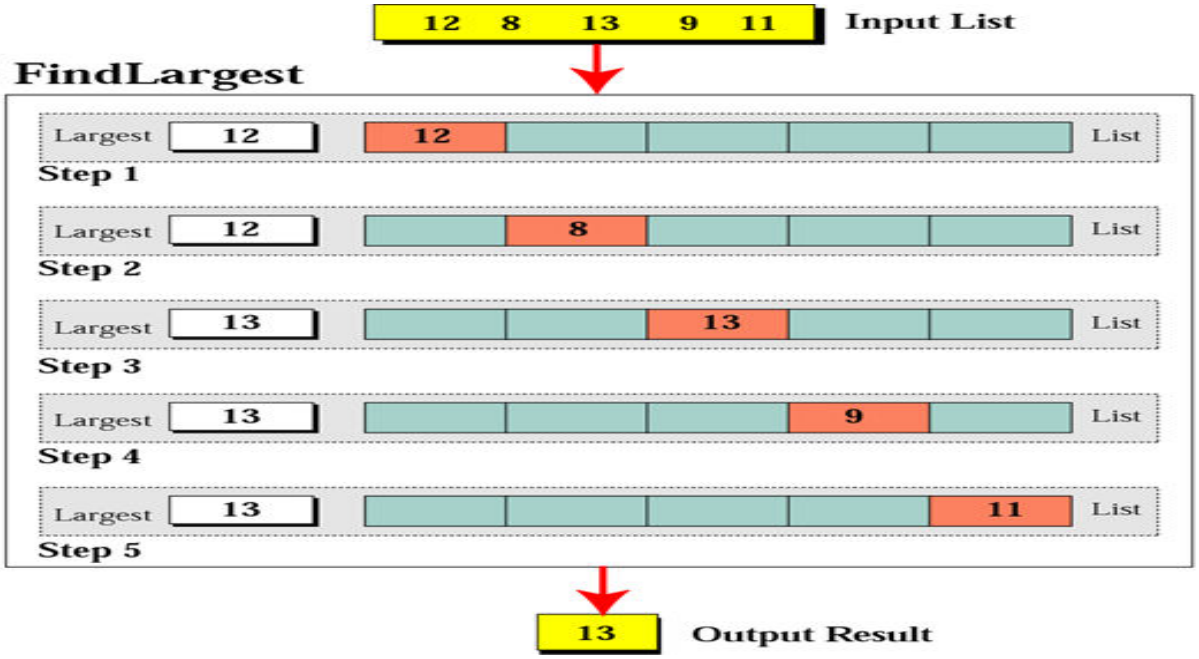
Introduction to Algorithms

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.

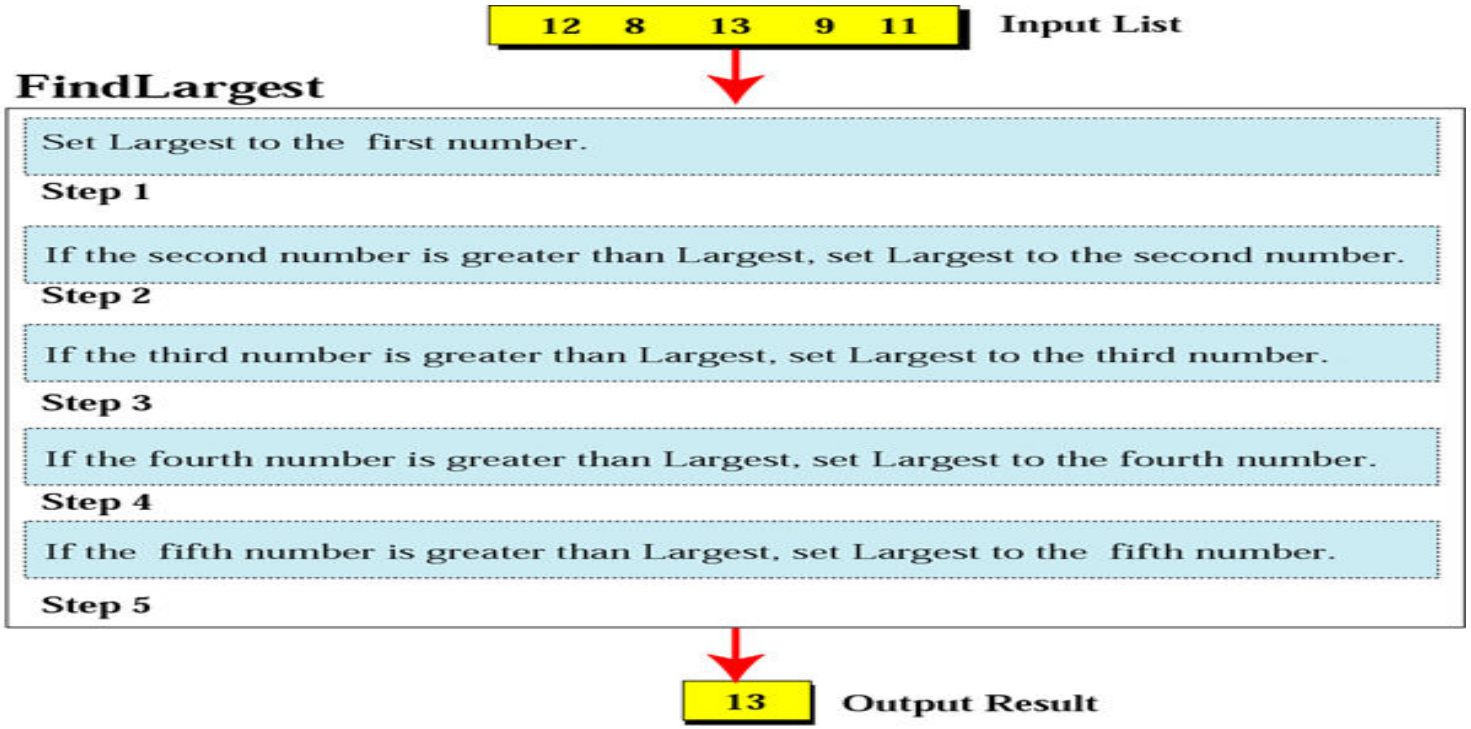
Introduction to Algorithms

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



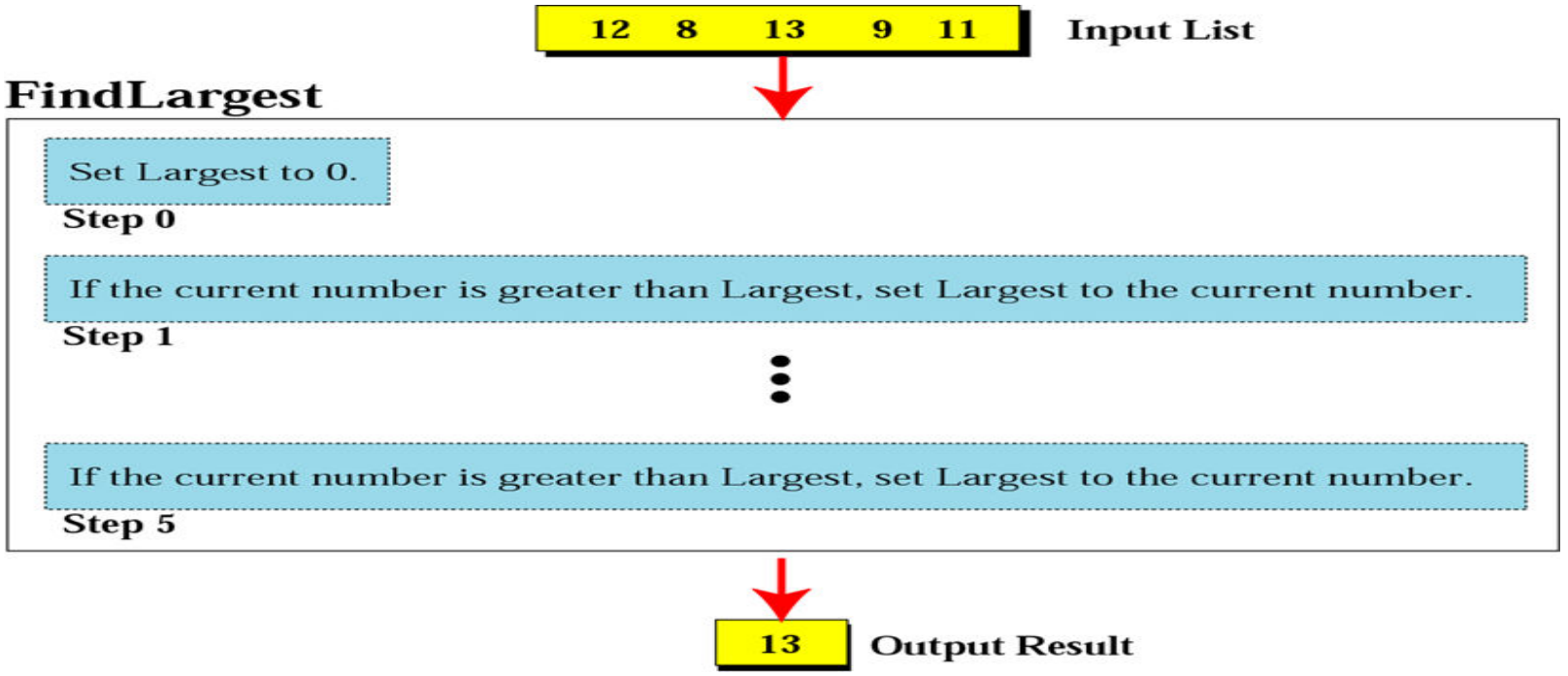
Introduction to Algorithms

Defining actions in Find Largest algorithm

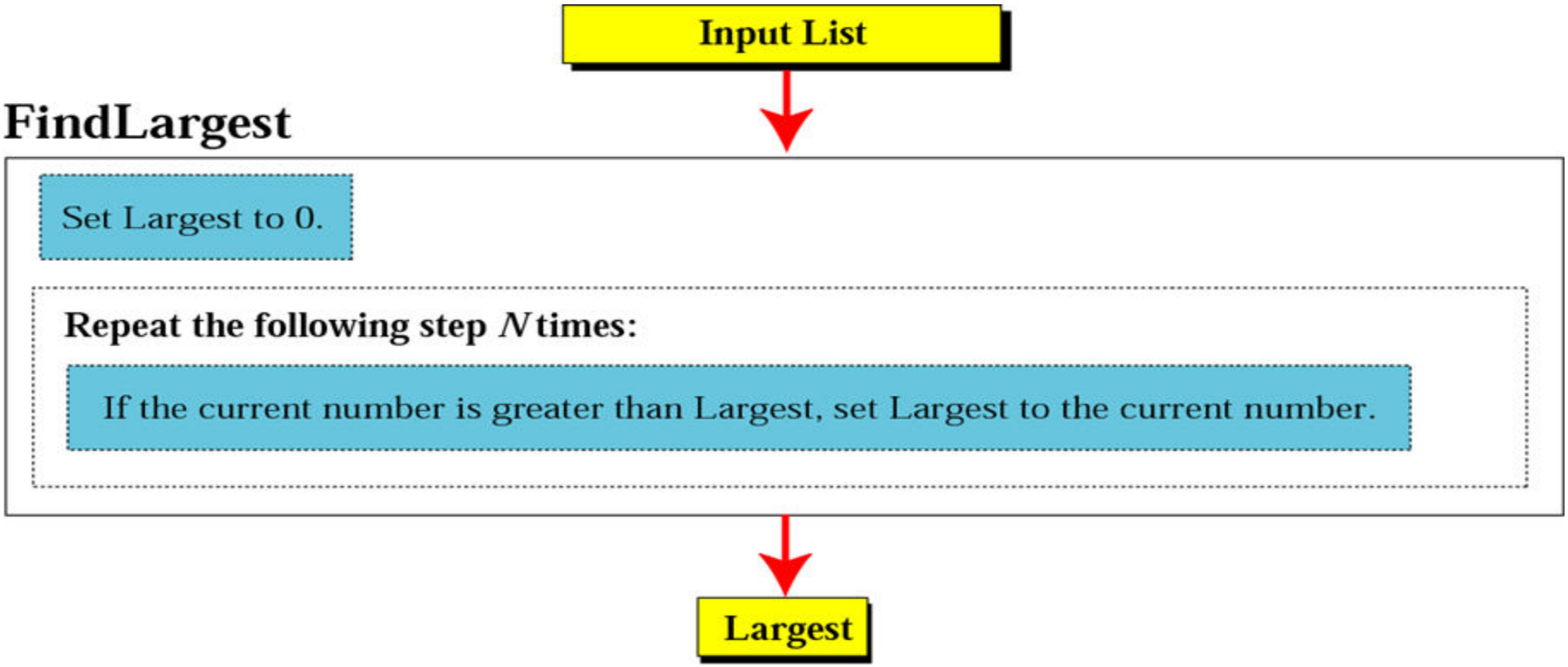


Introduction to Algorithms

Find Largest refined

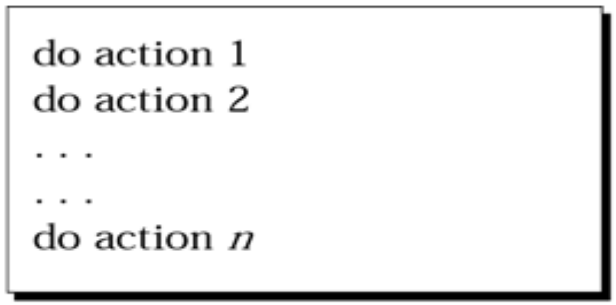


Introduction to Algorithms

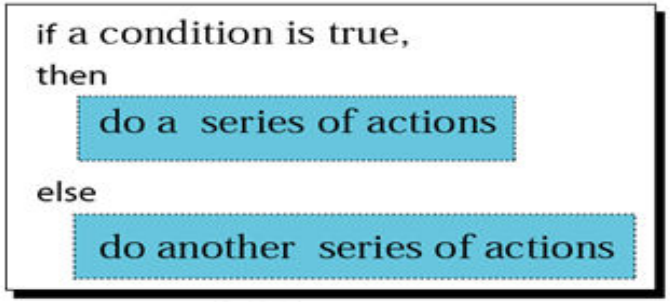


Introduction to Algorithms

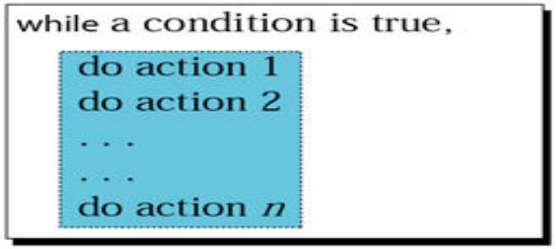
Three constructs



a. Sequence



b. Decision



c. Repetition

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
- 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

➢ **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

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: $O(k^n)$

Space Complexity

Definition

- The ***space complexity*** of a program is the amount of memory that it needs to run to completion

The space needed is the sum of

- ***Fixed*** space and ***Variable*** space

Fixed space

- Includes the instructions, variables, and constants
- Independent of the number and size of I/O

Variable space

- Includes dynamic allocation, functions recursion

Total space of any program

- $S(P) = c + S_p(Instance)$

Examples of Evaluating Space Complexity

```
float abc(float a, float b, float c)
{
  return a+b+b*c+(a+b-c)/(a+b)+4.00;
}
```

$S_{abc}(I) = 0$

```
float sum(float list[], int n)
{
 float fTmpSum= 0;
 int i;
 for (i= 0; i< n; i++)
   fTmpSum+= list[i];
 return fTmpSum;
}
```

$S_{sum}(I) = S_{sum}(n) = 0$

```
float rsum(float list[], int n)
{
  if (n) return rsum(list, n-1)+ list[n-1];
  return 0;
}
```

$S_{rsum}(n) = 4*n$

parameter:float(list[])	1		
parameter:integer(n)	1		
return address		1	
return value			1

Time Complexity

- Definition
  - The time complexity, T(p), taken by a program P is the sum of the compile time and the run time

---

- Total time
  - T(P)= compile time + run (or execution) time
    = c + tp(instance characteristics)
    Compile time does not depend on the instance characteristics
- How to evaluate?
  - Use the system clock
  - Number of steps performed
    machine-independent
- Definition of a program step
  - A program step is a syntactically or semantically meaningful program segment whose execution time is independent of the instance characteristics

(10 additions can be one step, 100 multiplications can also be one step)

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

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=10;

for(i=10;i<=n;i++)

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

x=x+1;
```

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

Asymptotic Notation(O, Ω, Θ)

- Target: Compare the time complexity of two programs that computing the same function and predict the growth in run time as instance characteristics change
- Determining the exact step count is difficult task
- Not very useful for comparative purpose

  ex: C1n2+C2n <= C3n for n <= 98, (C1=1, C2=2, C3=100)

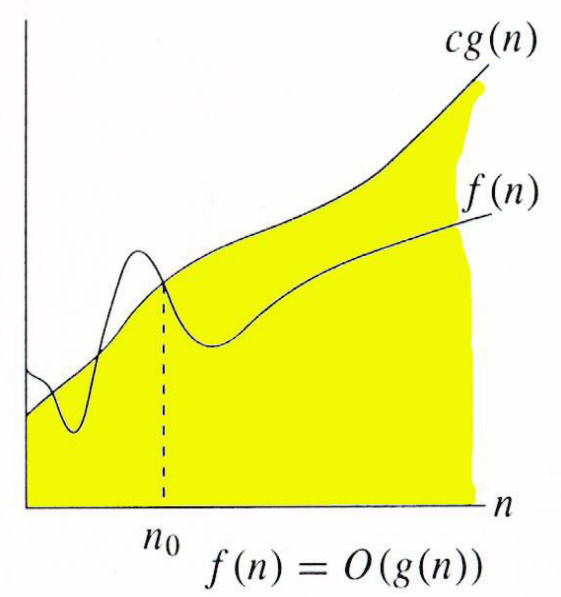
  C1n2+C2n > C3n for n > 98,
- Determining the exact step count usually not worth(can not get exact run time)

Asymptotic notation

- Big "oh“ O
  - upper bound(current trend)
- Omega Ω
  - lower bound
- Theta Θ
  - upper and lower bound

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

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

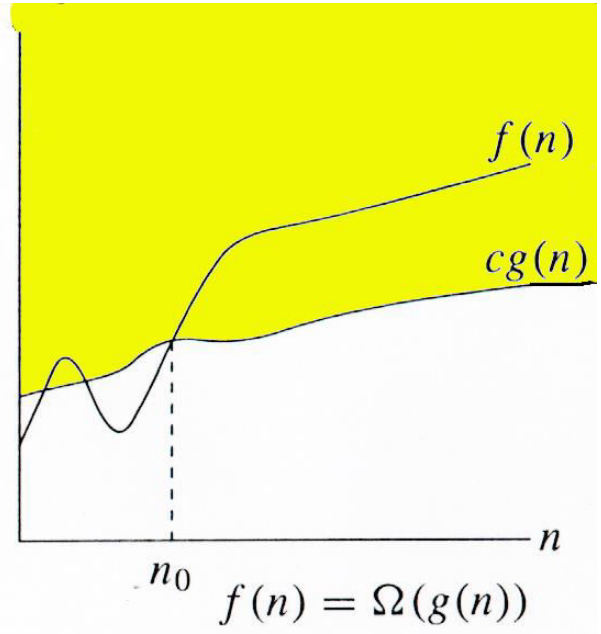
$g(n) = n^2$ ..... $c = 2$

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:
Ω(g(n)) = {f(n): there exist positive constants c and n0 such that 0 ≤ c g(n) ≤ f(n) for all n≥ 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 $0 \leq cg(n)$ and $cg(n) \leq f\ (n)$.

$0 \leq 15n^3$ for all $n \geq n_0 = 1$.

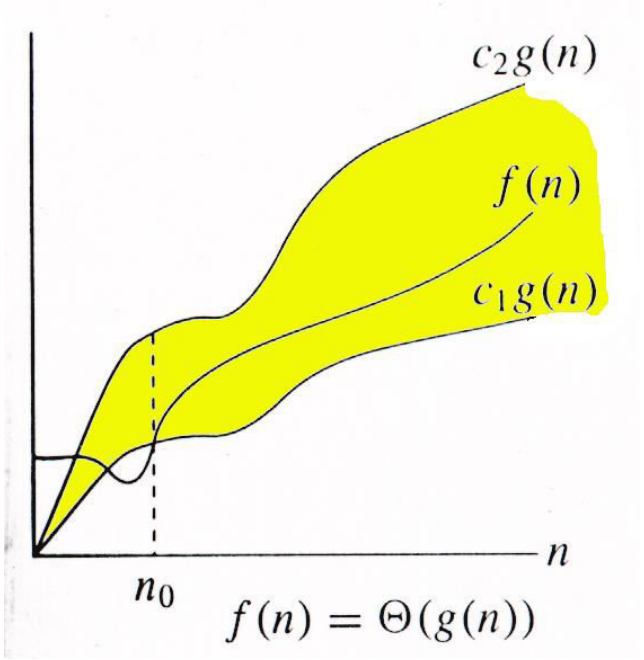
$cg(n) = 15n^3 \leq 15n^3 + n^2 + 4 = f\ (n)$

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 $0 \leq c1g(n) \leq f(n) \leq c2g(n)$ for all $n \geq n0$ }



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, $T(N) = \Theta(N^{\mathbf{k}})$.

For logarithmic functions, $T(\log_{\mathbf{m}} N) = \Theta(\log N)$.

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.