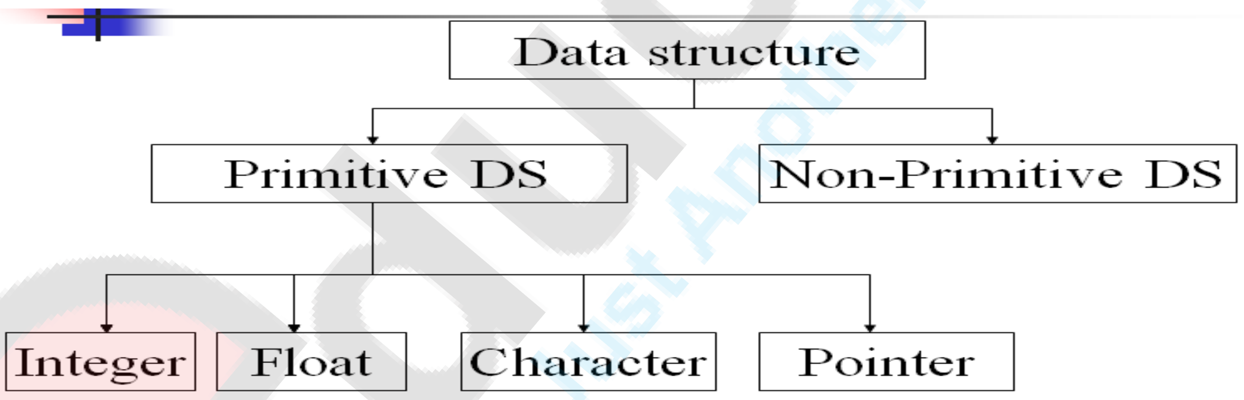
Introduction to Data Structures

- Data structure is representation of the logical relationship existing between individual elements of data.
- In other words, a data structure is a way of organizing all data items that considers not only the elements stored but also their relationship to each other.
- Data structure affects the design of both structural & functional aspects of a program. Program=algorithm + Data Structure
- You know that a algorithm is a step by step procedure to solve a particular function.
- That means, algorithm is a set of instruction written to carry out certain tasks & the data structure is the way of organizing the data with their logical relationship retained.
- To develop a program of an algorithm, we should select an appropriate data structure for that algorithm. Therefore algorithm and its associated data structures from a program.

Classification of Data Structures :

- Data structure are normally divided into two broad categories:

1. Primitive Data Structure
2. Non-Primitive Data Structure



Primitive Data Structure

- There are basic structures and directly operated upon by the machine instructions.
- In general, there are different representation on different computers.
- Integer, Floating-point number, Character constants, string constants, pointers etc, fall in this category.

Non-Primitive Data Structure

- There are more sophisticated data structures.

- These are derived from the primitive data structures.
- The non-primitive data structures emphasize on structuring of a group of homogeneous (same type) or heterogeneous (different type) data items.
- Lists, Stack, Queue, Tree, Graph are example of non-primitive data structures.
- The design of an efficient data structure must take operations to be performed on the data structure.
- The most commonly used operation on data structure are broadly categorized into following types:

1. Create
2. Selection
3. Updating
4. Searching
5. Sorting
6. Merging
7. Destroy or Delete

Different between them

- A primitive data structure is generally a basic structure that is usually built into the language, such as an integer, a float.
- A non-primitive data structure is built out of primitive data structures linked together in meaningful ways, such as a or a linked-list, binary search tree, AVL Tree, graph etc.

Description of various
Data Structures : Arrays

- An array is defined as a set of finite number of homogeneous elements or same data items.
- It means an array can contain one type of data only, either all integer, all float-point number or all character.

Arrays

- Simply, declaration of array is as follows:

```
int arr[10]
```

- Where int specifies the data type or type of elements arrays stores.
- “arr” is the name of array & the number specified inside the square brackets is the number of elements an array can store, this is also called sized or length of array.
- Following are some of the concepts to be remembered about arrays:
    1. The individual element of an array can be accessed by specifying name of the array, following by index or subscript inside square brackets.
    2. The first element of the array has index zero[0]. It means the first element

and last element will be specified as:arr[0] & arr[9].Respectively.

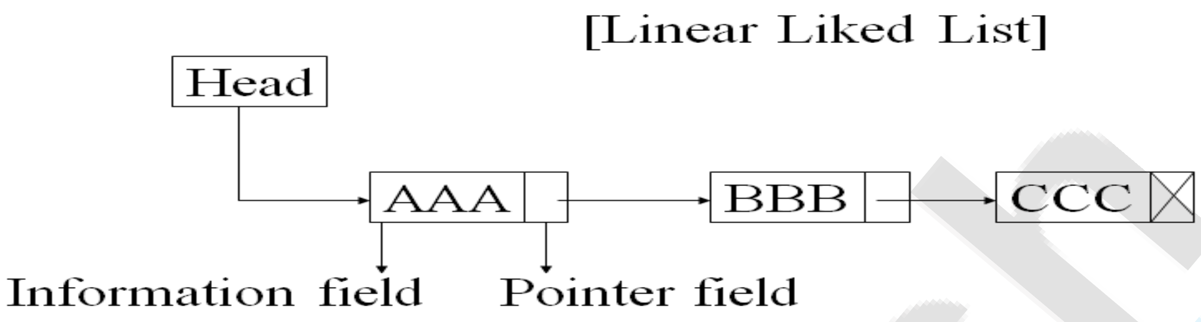
3. The elements of array will always be stored in the consecutive (continues) memory location.
4. The number of elements that can be stored in an array, that is the size of array or its length is given by the following equation:
5. (Upperbound-lowerbound)+1
6. For the above array it would be (9-0)+1=10,where 0 is the lower bound of array and 9 is the upper bound of array.
7. Array can always be read or written through loop. If we read a one-dimensional array it require one loop for reading and other for writing the array.
8. For example: Reading an array
```
For(i=0;i<=9;i++)
 scanf("%d",&arr[i]);
```
9. For example: Writing an array
```
For(i=0;i<=9;i++)

printf("%d",arr[i]);
```
10. If we are reading or writing two-dimensional array it would require two loops. And similarly the array of a N dimension would required N loops.
11. Some common operation performed on array are:
    - Creation of an array
    - Traversing an array
    - Insertion of new element
    - Deletion of required element
    - Modification of an element
    - Merging of arrays

Lists

- A lists (Linear linked list) can be defined as a collection of variable number of data items.
- Lists are the most commonly used non-primitive data structures.
- An element of list must contain at least two fields, one for storing data or information and other for storing address of next element.
- As you know for storing address we have a special data structure of list the address must be pointer type.

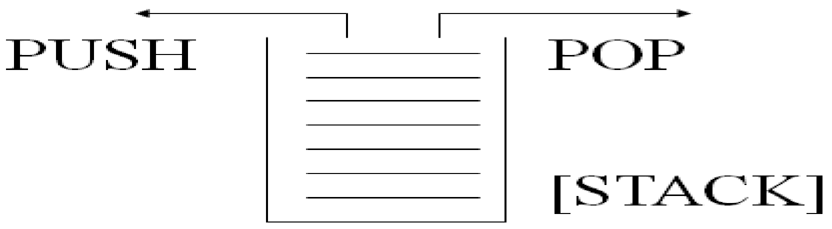
- Technically each such element is referred to as a node, therefore a list can be defined as a collection of nodes as show bellow:



- Types of linked lists:
    1. Single linked list
    2. Doubly linked list
    3. Single circular linked list
    4. Doubly circular linked list

Stack

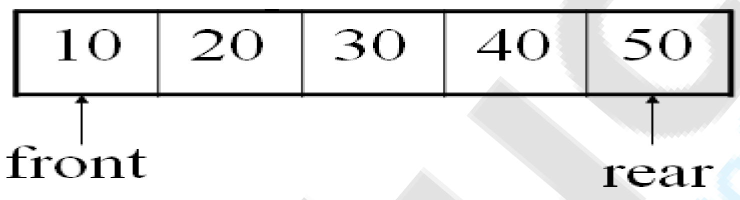
- A stack is also an ordered collection of elements like arrays, but it has a special feature that deletion and insertion of elements can be done only from one end called the top of the stack (TOP)
- Due to this property it is also called as last in first out type of data structure (LIFO).
- It could be through of just like a stack of plates placed on table in a party, a guest always takes off a fresh plate from the top and the new plates are placed on to the stack at the top.
- It is a non-primitive data structure.
- When an element is inserted into a stack or removed from the stack, its base remains fixed where the top of stack changes.
- Insertion of element into stack is called PUSH and deletion of element from stack is called POP.
- The bellow show figure how the operations take place on a stack:



- The stack can be implemented into two ways:
  - Using arrays (Static implementation)
  - Using pointer (Dynamic implementation)

Queue

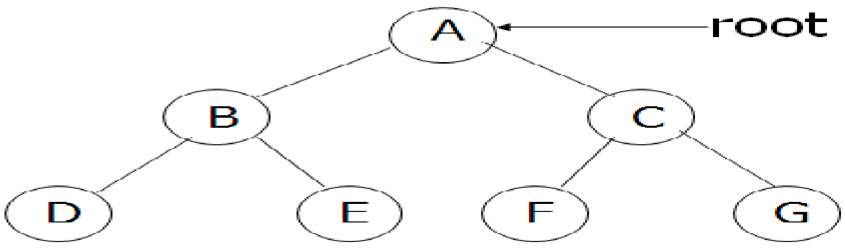
- Queue are first in first out type of data structure (i.e. FIFO)
- In a queue new elements are added to the queue from one end called REAR end and the element are always removed from other end called the FRONT end.
- The people standing in a railway reservation row are an example of queue.
- Each new person comes and stands at the end of the row and person getting their reservation confirmed get out of the row from the front end.
- The bellow show figure how the operations take place on a stack:



- The queue can be implemented into two ways:
  1. Using arrays (Static implementation)
  2. Using pointer (Dynamic implementation)

Trees

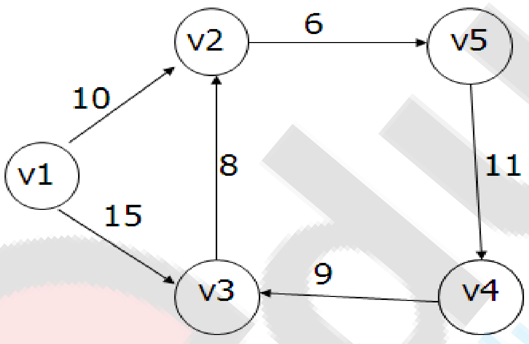
- A tree can be defined as finite set of data items (nodes).
- Tree is non-linear type of data structure in which data items are arranged or stored in a sorted sequence.
- Tree represent the hierarchical relationship between various elements.
- In trees:
- There is a special data item at the top of hierarchy called the Root of the tree.
- The remaining data items are partitioned into number of mutually exclusive subset, each of which is itself, a tree which is called the sub tree.
- The tree always grows in length towards bottom in data structures, unlike natural trees which grows upwards.
- The tree structure organizes the data into branches, which related the information.



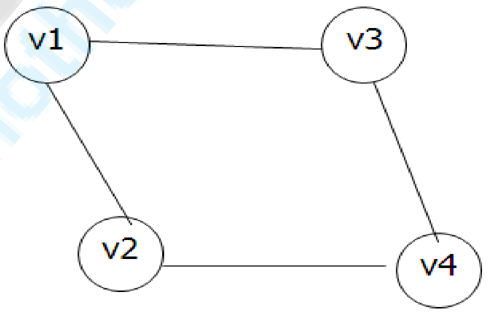
Graph

- Graph is a mathematical non-linear data structure capable of representing many kind of physical structures.
- It has found application in Geography, Chemistry and Engineering sciences.
- Definition: A graph G(V,E) is a set of vertices V and a set of edges E.
- An edge connects a pair of vertices and many have weight such as length, cost and another measuring instrument for according the graph.
- Vertices on the graph are shown as point or circles and edges are drawn as arcs or line segment.

- Example of graph:



[a] Directed & Weighted Graph



[b] Undirected Graph

- Types of Graphs:
    1. Directed graph, Undirected graph, Simple graph, Weighted graph, Connected graph, Non-connected graph

ABSTRACT DATA TYPES

- One of the basic rules concerning programming is that no routine should ever exceed a page. This is accomplished by breaking the program down into *modules*. Each module is a logical unit and does a specific job. Its size is kept small by calling other modules. Modularity has several advantages.

1. it is much easier to debug small routines than large routines.
2. it is easier for several people to work on a modular program simultaneously.
3. a well-written modular program places certain dependencies in only one routine, making changes easier.

- For instance, if output needs to be written in a certain format, it is certainly important to have one routine to do this. If printing statements are scattered throughout the program, it will take considerably longer to make modifications.
- The idea that global variables and side effects are bad is directly attributable to the idea that modularity is good.
- An *abstract data type* (ADT) is a set of operations. Abstract data types are mathematical abstractions; nowhere in an ADT's definition is there any mention of *how* the set of operations is implemented. This can be viewed as an extension of modular design.
- Objects such as lists, sets, and graphs, along with their operations, can be viewed as abstract data types, just as integers, reals, and Boolean s are data types. Integers, reals, and Boolean s have operations associated with them, and so do abstract data types. For the set ADT, we might have such operations as *union, intersection, size*, and *complement*. Alternately, we might only want the two operations *union* and *find,* which would define a different ADT on the set.

- The basic idea is that the implementation of these operations is written once in the program, and any other part of the program that needs to perform an operation on the ADT can do so by calling the appropriate function. If for some reason implementation details need to change, it should be easy to do so by merely changing the routines that perform the ADT operations. This change, in a perfect world, would be completely transparent to the rest of the program.
- There is no rule telling us which operations must be supported for each ADT; this is a design decision. Error handling and tie breaking (where appropriate) are also generally up to the program designer. The three data structures that we will study in this chapter are primary examples of ADTs. We will see how each can be implemented in several ways, but if they are done correctly, the programs that use them will not need to know which implementation was used.

Performance Analysis :

Space Complexity

- Space complexity of an algorithm represents the amount of memory space required by the algorithm in its life cycle. The space required by an algorithm is equal to the sum of the following two components –
    1. A fixed part that is a space required to store certain data and variables, that are independent of the size of the problem. For example, simple variables and constants used, program size, etc.
    2. A variable part is a space required by variables, whose size depends on the

size of the problem. For example, dynamic memory allocation, recursion stack space, etc. Space complexity S(P) of any algorithm P is S(P) = C + SP(I), where C is the fixed part and S(I) is the variable part of the algorithm, which depends on instance characteristic I.

- Following is a simple example that tries to explain the concept −

```
Algorithm: SUM(A, B)
Step 1 -  START
Step 2 -  C ← A + B + 10
Step 3 -  Stop
```

- Here we have three variables A, B, and C and one constant. Hence S(P) = 1+3. Now, space depends on data types of given variables and constant types and it will be multiplied accordingly.

Time Complexity

Time complexity of an algorithm represents the amount of time required by the algorithm to run to completion. Time requirements can be defined as a numerical function T(n), where T(n) can be measured as the number of steps, provided each step consumes constant time.

For example, addition of two n-bit integers takes n steps. Consequently, the total computational time is T(n) = c*n, where c is the time taken for the addition of two bits. Here, we observe that T(n) grows linearly as the input size increases.

Time complexity of an algorithm signifies the total time required by the program to run to completion. The time complexity of algorithms is most commonly expressed using the **big O notation**.

Time Complexity is most commonly estimated by counting the number of elementary functions performed by the algorithm. And since the algorithm's performance may vary with different types of input data, hence for an algorithm we usually use the **worst-case Time complexity** of an algorithm because that is the maximum time taken for any input size.

Types of Notations for Time Complexity

Now we will discuss and understand the various notations used for Time Complexity.

1. **Big Oh** denotes "*fewer than or the same as*" <expression> iterations.
2. **Big Omega** denotes "*more than or the same as*" <expression> iterations.
3. **Big Theta** denotes "*the same as*" <expression> iterations.
4. **Little Oh** denotes "*fewer than*" <expression> iterations.

5. **Little Omega** denotes "*more than*" <expression> iterations.

Asymptotic Notations

- Asymptotic analysis of an algorithm refers to defining the mathematical boundation/framing of its run-time performance. Using asymptotic analysis, we can very well conclude the best case, average case, and worst case scenario of an algorithm.
- Asymptotic analysis is input bound i.e., if there's no input to the algorithm, it is concluded to work in a constant time. Other than the "input" all other factors are considered constant.
- Asymptotic analysis refers to computing the running time of any operation in mathematical units of computation. For example, the running time of one operation is computed as f(n) and may be for another operation it is computed as g(n2). This means the first operation running time will increase linearly with the increase in n and the running time of the second operation will increase exponentially when n increases. Similarly, the running time of both operations will be nearly the same if n is significantly small.
- Usually, the time required by an algorithm falls under three types –
  1. Best Case − Minimum time required for program execution.
  2. Average Case − Average time required for program execution.
  3. Worst Case − Maximum time required for program execution.

Asymptotic Notations

Following are the commonly used asymptotic notations to calculate the running time complexity of an algorithm.

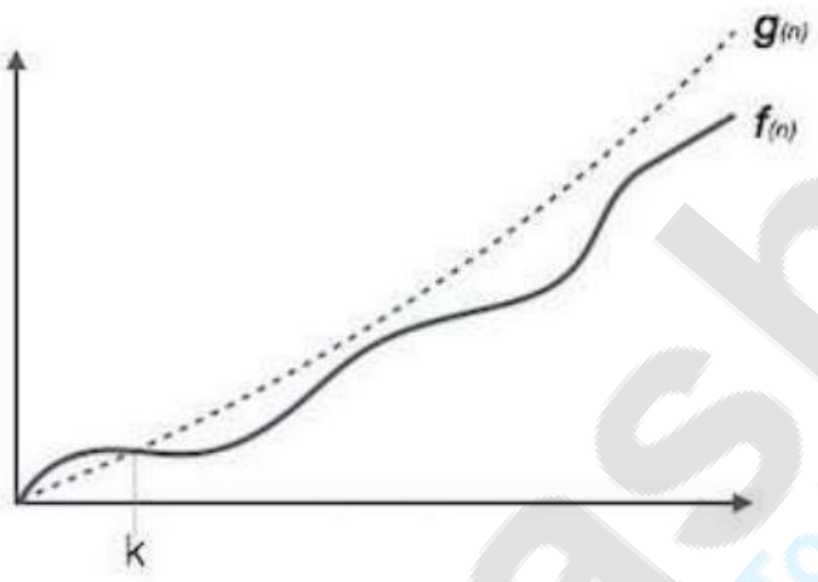
• O Notation

• Ω Notation

• θ Notation

Big Oh Notation, O

- The notation O(n) is the formal way to express the upper bound of an algorithm's running time. It measures the worst case time complexity or the longest amount of time an algorithm can possibly take to complete.



For example, for a function ***f*(n)**

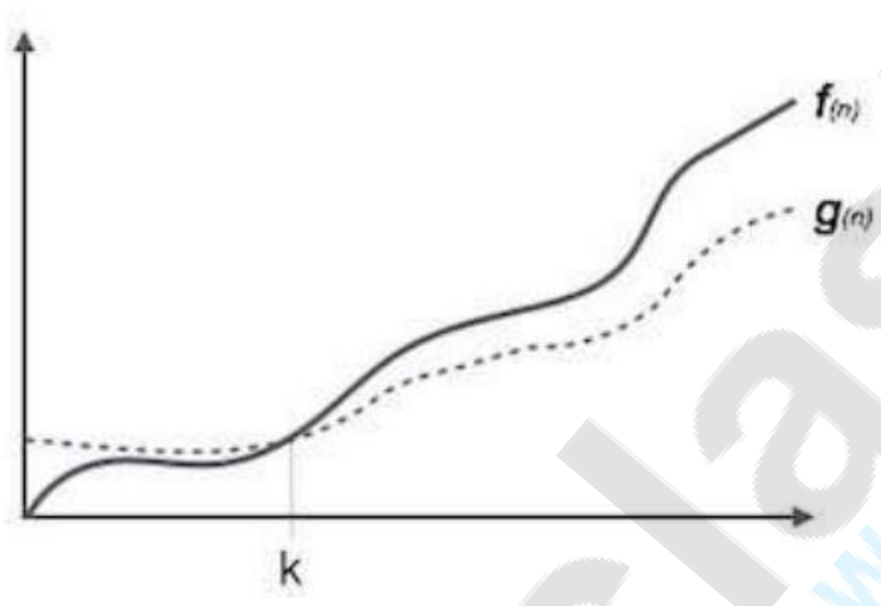
```
O(f(n)) = { g(n) : there exists c > 0 and n0 such that g(n) ≤ c.f(n) for all n
> n0. }
```

Omega Notation, Ω

The notation Ω(n) is the formal way to express the lower bound of an algorithm's running time. It measures the best case time complexity or the best amount of time an algorithm can possibly take to complete.

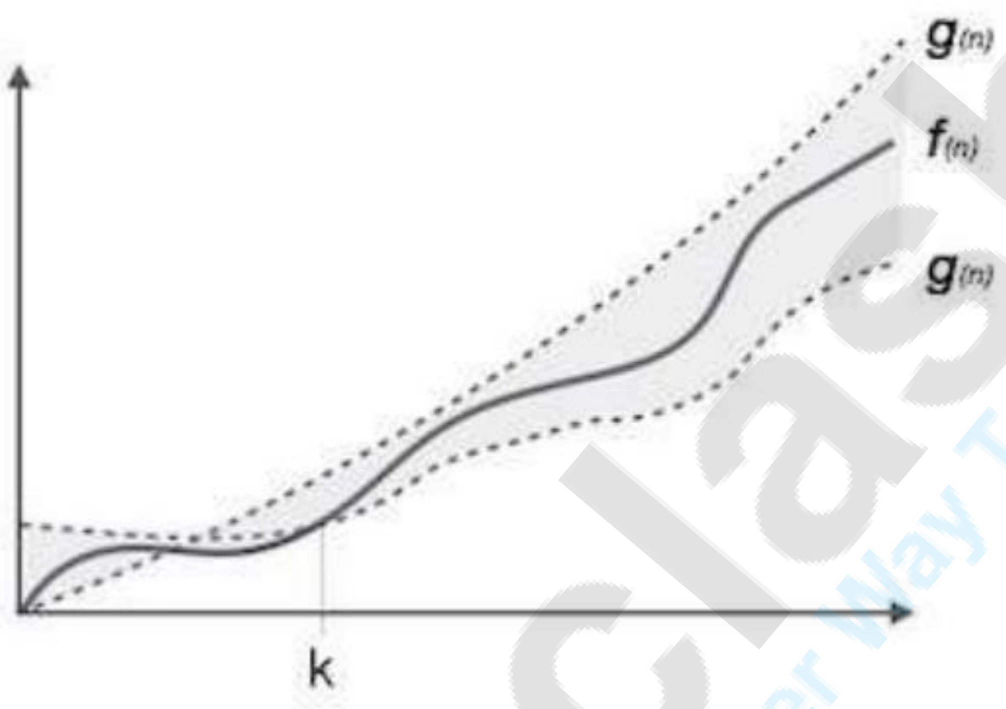
For example, for a function ***f*(n)**

```
Ω(f(n)) ≥ { g(n) : there exists c > 0 and n0 such that g(n) ≤ c.f(n) for all n
> n0. }
```



Theta Notation, θ

The notation θ(n) is the formal way to express both the lower bound and the upper bound of an algorithm's running time. It is represented as follows –



```
θ(f(n)) = { g(n) if and only if g(n) =  Ο(f(n)) and g(n) = Ω(f(n)) for all n >
n0. }
```

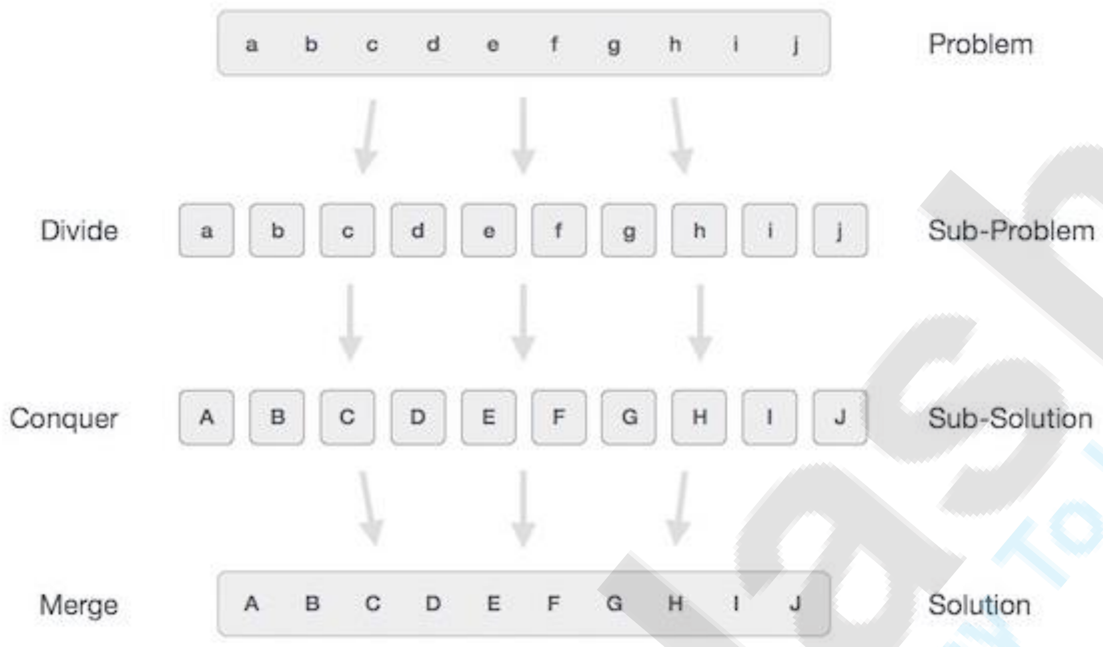
Common Asymptotic Notations

Following is a list of some common asymptotic notations:

constant	–	O(1)
logarithmic	–	O(log n)
linear	–	O(n)
n log n	–	O(n log n)
quadratic	–	$O(n^2)$
cubic	–	$O(n^3)$
polynomial	–	$n^{O(1)}$
exponential	–	$2^{O(n)}$

Divide and Conquer

- In divide and conquer approach, the problem in hand, is divided into smaller sub-problems and then each problem is solved independently. When we keep on dividing the sub problems into even smaller sub-problems, we may eventually reach a stage where no more division is possible. Those "atomic" smallest possible sub-problem (fractions) are solved. The solution of all sub-problems is finally merged in order to obtain the solution of an original problem.



Broadly, we can understand **divide-and-conquer** approach in a three-step process.

Divide/Break

This step involves breaking the problem into smaller sub-problems. Sub-problems should represent a part of the original problem. This step generally takes a recursive approach to divide the problem until no sub-problem is further divisible. At this stage, sub-problems become atomic in nature but still represent some part of the actual problem.

Conquer/Solve

This step receives a lot of smaller sub-problems to be solved. Generally, at this level, the problems are considered 'solved' on their own.

Merge/Combine

When the smaller sub-problems are solved, this stage recursively combines them until they formulate a solution of the original problem. This algorithmic approach works recursively and conquer & merge steps works so close that they appear as one.

Examples

The following computer algorithms are based on **divide-and-conquer** programming approach −

- Merge Sort
- Quick Sort
- Binary Search
- Strassen's Matrix Multiplication
- Closest pair (points)

There are various ways available to solve any computer problem, but the mentioned are a good example of divide and conquer approach.

Dynamic programming

- Dynamic programming approach is similar to divide and conquer in breaking down the problem into smaller and yet smaller possible sub-problems. But unlike, divide and conquer, these sub-problems are not solved independently. Rather, results of these smaller sub-problems are remembered and used for similar or overlapping sub-problems.
- Dynamic programming is used where we have problems, which can be divided into similar sub-problems, so that their results can be re-used. Mostly, these algorithms are used for optimization. Before solving the in-hand sub-problem, dynamic algorithm will try to examine the results of the previously solved sub-problems. The solutions of sub-problems are combined in order to achieve the best solution.
- So we can say that −
    1. The problem should be able to be divided into smaller overlapping sub-problem.
    2. An optimum solution can be achieved by using an optimum solution of smaller sub-problems.
    3. Dynamic algorithms use memorization.

Comparison

- In contrast to greedy algorithms, where local optimization is addressed, dynamic algorithms are motivated for an overall optimization of the problem.
- In contrast to divide and conquer algorithms, where solutions are combined to achieve an overall solution, dynamic algorithms use the output of a smaller sub-problem and then try to optimize a bigger sub-problem. Dynamic algorithms use memorization to remember the output of already solved sub-problems.

Example

- The following computer problems can be solved using dynamic programming approach –

  1. Fibonacci number series
  2. Knapsack problem
  3. Tower of Hanoi
  4. All pair shortest path by Floyd-Warshall
  5. Shortest path by Dijkstra
  6. Project scheduling

- Dynamic programming can be used in both top-down and bottom-up manner. And of course, most of the times, referring to the previous solution output is cheaper than recomputing in terms of CPU cycles.

Back Tracking Method

Pending

Performance measurement

Pending