Contents

Data structures and Algorithms

A data structure is a data organization, management, and storage format that enables efficient access and modification. More precisely, a data structure is a collection of data values, the relationships among them, and the functions or operations that can be applied to the data.

BigO Notation

Data Structure	Time Complexity								Space Complexity
	Average				Worst				Worst
	Access	Search	Insertion	Deletion	Access	Search	Insertion	Deletion	
Array	O(1)	O(n)	O(n)	O(n)	O(1)	O(n)	O(n)	O(n)	O(n)
Stack	O(n)	O(n)	O(1)	O(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Queue	O(n)	O(n)	O(1)	O(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Singly-Linked List	O(n)	O(n)	O(1)	O(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Doubly-Linked List	O(n)	O(n)	O(1)	O(1)	O(n)	O(n)	O(1)	O(1)	O(n)
Skip List	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)	O(n)	O(n)	O(n)	O(n log(n))
Hash Table	N/A	O(1)	O(1)	O(1)	N/A	O(n)	O(n)	O(n)	O(n)
Binary Search Tree	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)	O(n)	O(n)	O(n)	O(n)
Cartesian Tree	N/A	O(log(n))	O(log(n))	O(log(n))	N/A	O(n)	O(n)	O(n)	O(n)
B-Tree	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)
Red-Black Tree	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)
Splay Tree	N/A	O(log(n))	O(log(n))	O(log(n))	N/A	O(log(n))	O(log(n))	O(log(n))	O(n)

AVL Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(log(n))	O(log(n))	O(log(n))	O(log(n))	O(n)
KD Tree	Θ(log(n))	Θ(log(n))	Θ(log(n))	Θ(log(n))	O(n)	O(n)	O(n)	O(n)	O(n)

Array Sorting Algorithms

Algorithm	Time Complexity			Space Complexity
	Best	Average	Worst	Worst
Quicksort	Ω(n log(n))	Θ(n log(n))	O(n^2)	O(log(n))
Mergesort	Ω(n log(n))	Θ(n log(n))	O(n log(n))	O(n)
Timsort	Ω(n)	Θ(n log(n))	O(n log(n))	O(n)
Heapsort	Ω(n log(n))	Θ(n log(n))	O(n log(n))	

Data Structures		**Average Case**			**Worst Case**	
	Search	Insert	Delete	Search	Insert	Delete
Array	O(n)	N/A	N/A	O(n)	N/A	N/A
AVL Tree	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)
B-Tree	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)
Binary SearchTree	O(log n)	O(log n)	O(log n)	O(n)	O(n)	O(n)
Doubly Linked List	O(n)	O(1)	O(1)	O(n)	O(1)	O(1)
Hash table	O(1)	O(1)	O(1)	O(n)	O(n)	O(n)
Linked List	O(n)	O(1)	O(1)	O(n)	O(1)	O(1)
Red-Black tree	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)
Sorted Array	O(log n)	O(n)	O(n)	O(log n)	O(n)	O(n)
Stack	O(n)	O(1)	O(1)	O(n)	O(1)	O(1)

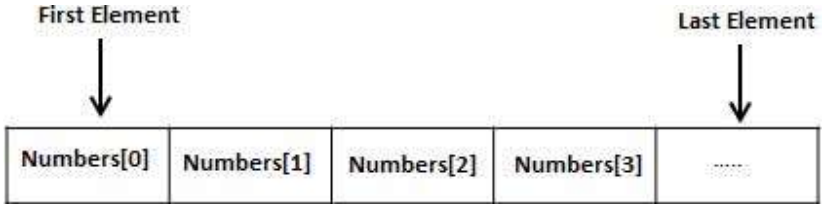
Sorting Algorithms	Space Complexity		Time Complexity	
	Worst case	Best case	Average case	Worst case
Bubble Sort	O(1)	O(n)	$O(n^2)$	$O(n^2)$
Heapsort	O(1)	O(n log n)	O(n log n)	O(n log n)
Insertion Sort	O(1)	O(n)	$O(n^2)$	$O(n^2)$
Mergesort	O(n)	O(n log n)	O(n log n)	O(n log n)
Quicksort	O(log n)	O(n log n)	O(n log n)	O(n log n)
Selection Sort	O(1)	$O(n^2)$	$O(n^2)$	$O(n^2)$
ShellSort	O(1)	O(n)	$O(n \log n^2)$	$O(n \log n^2)$
Smooth Sort	O(1)	O(n)	O(n log n)	O(n log n)
Tree Sort	O(n)	O(n log n)	O(n log n)	$O(n^2)$
Counting Sort	O(k)	O(n + k)	O(n + k)	O(n + k)
Cubesort	O(n)	O(n)	O(n log n)	O(n log n)

Arrays

An array is used to store a collection of data, but it is often more useful to think of an array as a collection of variables of the same type.

Instead of declaring individual variables, such as number0, number1, ..., and number99, you declare one array variable such as numbers and use numbers[0], numbers[1], and ..., numbers[99] to represent individual variables. A specific element in an array is accessed by an index.

All arrays consist of contiguous memory locations. The lowest address corresponds to the first element and the highest address to the last element.



Declaration and array:

```
type arrayName [ arraySize ];
double balance[10];
```

Initializing an array:

```
double balance[5] = {1000.0, 2.0, 3.4, 7.0, 50.0};
```

Accessing an array element:

```
double salary = balance[9];
```

Iterations and Recursion

Iteration. This is a loop, in C that is done with a for, while or do-while loop.

Recursion is processing an element of a data structure and then calling the same function with the remaining elements or multiple times with different subsets of the remaining elements.

Linked list

https://www.hackerearth.com/practice/data-structures/linked-list/singly-linked-list/tutorial/

A linked list is formed when many such nodes are linked together to form a chain. Each node points to the next node present in the order. The first node is always used as a reference to traverse the list and is called **HEAD**. The last node points to **NULL**.

A **linked list** is a way to store a collection of elements. Like an array these can be character or integers. Each element in a linked list is stored in the form of a **node**.

Declaring a Linked list:

In C language, a linked list can be implemented using structure and pointers

```
struct LinkedList{
    int data;
    struct LinkedList *next;
 };
```

Creating a Node:

Let's define a data type of `struct LinkedList` to make code cleaner.

```
typedef struct LinkedList *node; //Define node as pointer of data type struct
LinkedList

node createNode(){
    node temp; // declare a node
    temp = (node)malloc(sizeof(struct LinkedList)); // allocate memory using
malloc()
    temp->next = NULL;// make next point to NULL
    return temp;//return the new node
}
```

typedef is used to define a data type in C.

malloc() is used to dynamically allocate a single block of memory in C, it is available in the header file `stdlib.h`.

sizeof() is used to determine size in bytes of an element in C. Here it is used to determine size of each node and sent as a parameter to `malloc`.

Let's see how to **add a node to the linked list:**

```
node addNode(node head, int value){
    node temp,p;// declare two nodes temp and p
    temp = createNode();//createNode will return a new node with data = value
and next pointing to NULL.
    temp->data = value; // add element's value to data part of node
    if(head == NULL){
        head = temp;     //when linked list is empty
    }
    else{
        p  = head;//assign head to p
        while(p->next != NULL){
            p = p->next;//traverse the list until p is the last node.The last
node always points to NULL.
        }
        p->next = temp;//Point the previous last node to the new node
created.
    }
    return head;
}
```

This type of linked list is known as **simple or singly linked list**. A simple linked list can be traversed in only one direction from **head** to the last node.

The last node is checked by the condition:

```
p->next = NULL;
```

Here -> is used to access **next** sub element of node p. **NULL** denotes no node exists after the current node , i.e. its the end of the list.

Traversing the list:

The linked list can be traversed in a while loop by using the **head** node as a starting reference:

```
node p;
p = head;
while(p != NULL){
    p = p->next;
}
```

Stack

https://www.programiz.com/dsa/stack

https://www.cs.cmu.edu/~adamchik/15-121/lectures/Stacks%20and%20Queues/Stacks%20and%20Queues.html

An array is a random access data structure, where each element can be accessed directly and in constant time. A typical illustration of random access is a book - each page of the book can be open independently of others. Random access is critical to many algorithms, for example binary search.

A linked list is a sequential access data structure, where each element can be accessed only in particular order. A typical illustration of sequential access is a roll of paper or tape - all prior material must be unrolled in order to get to data you want.

In this note we consider a subcase of sequential data structures, so-called limited access data structures.

A stack is a container of objects that are inserted and removed according to the last-in first-out (LIFO) principle. In the pushdown stacks only two operations are allowed: push the item into the stack, and pop the item out of the stack. A stack is a limited access data structure - elements can be added and removed from the stack only at the top. push adds an item to the top of the stack, pop removes the item from the top. A helpful analogy is to think of a stack of books; you can remove only the top book, also you can add a new book on the top.

A stack is a recursive data structure. Here is a structural definition of a Stack:

a stack is either empty or
it consists of a top and the rest which is a stack;

Stack is a linear data structure which follows a particular order in which the operations are performed. The order may be LIFO(Last In First Out) or FILO(First In Last Out).

Mainly the following three basic operations are performed in the stack:

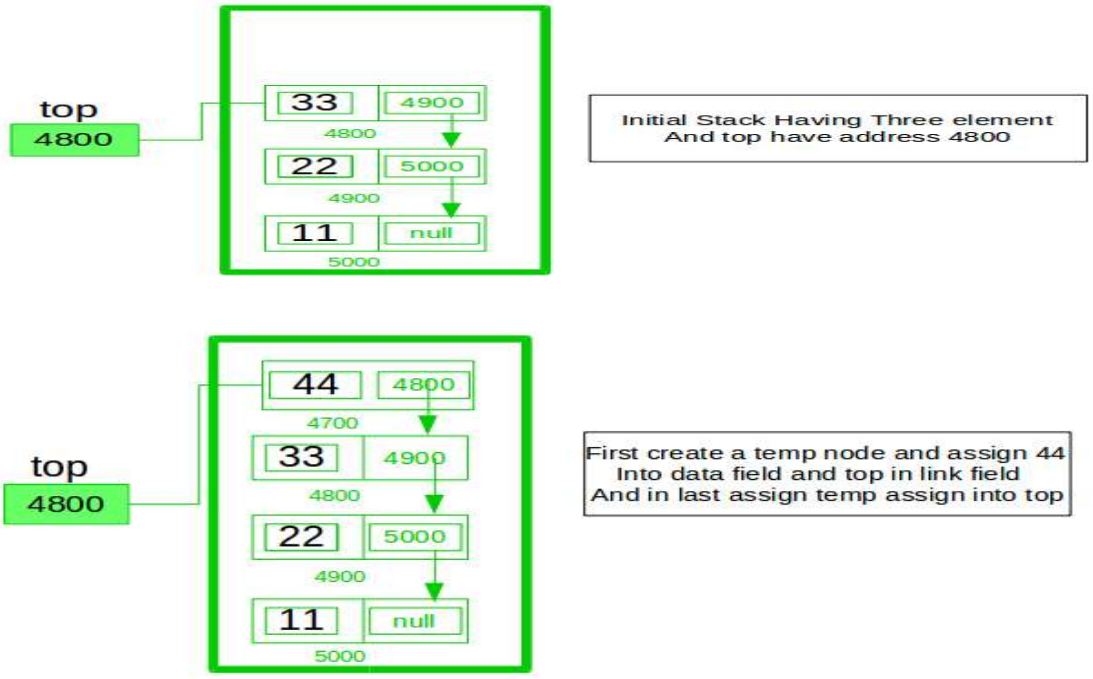
- **Push:** Adds an item in the stack. If the stack is full, then it is said to be an Overflow condition.
- **Pop:** Removes an item from the stack. The items are popped in the reversed order in which they are pushed. If the stack is empty, then it is said to be an Underflow condition.
- **Peek or Top:** Returns top element of stack.
- **isEmpty:** Returns true if stack is empty, else false.

Implementation:
There are two ways to implement a stack:

- Using array
- Using linked list

Stack Operations:

1. push() : Insert the element into linked list nothing but which is the top node of Stack.
2. pop() : Return top element from the Stack and move the top pointer to the second node of linked list or Stack.
3. peek(): Return the top element.
4. display(): Print all element of Stack.



Depth-First Search with a Stack

In depth-first search we go down a path until we get to a dead end; then we backtrack or back up (by popping a stack) to get an alternative path.

- Create a stack
- Create a new choice point
- Push the choice point onto the stack
- while (not found and stack is not empty)
    - Pop the stack
    - Find all possible choices after the last one tried
    - Push these choices onto the stack
- Return

Queue

A queue is a container of objects (a linear collection) that are inserted and removed according to the first-in first-out (FIFO) principle. An excellent example of a queue is a line of students in the food court of the UC. New additions to a line made to the back of the queue, while removal (or serving) happens in the front. In the queue only two operations are allowed enqueue and dequeue. Enqueue means to insert an item into the back of the queue, dequeue means removing the front item. The picture demonstrates the FIFO access.

The difference between stacks and queues is in removing. In a stack we remove the item the most recently added; in a queue, we remove the item the least recently added.

Breadth-First Search with a Queue

In breadth-first search we explore all the nearest possibilities by finding all possible successors and enqueue them to a queue.

- Create a queue
- Create a new choice point
- Enqueue the choice point onto the queue
- while (not found and queue is not empty)
    - Dequeue the queue
    - Find all possible choices after the last one tried
    - Enqueue these choices onto the queue
- Return

Evaluating a Postfix Expression. We describe how to parse and evaluate a postfix expression.

1. We read the tokens in one at a time.
2. If it is an integer, push it on the stack
3. If it is a binary operator, pop the top two elements from the stack, apply the operator, and push the result back on the stack.

Consider the following postfix expression

```
5 9 3 + 4 2 * * 7 + *
```

Here is a chain of operations

```
Stack Operations              Output
---------------------------------------
push(5);                        5
push(9);                        5 9
push(3);                        5 9 3
push(pop() + pop())             5 12
push(4);                        5 12 4
push(2);                        5 12 4 2
push(pop() * pop())             5 12 8
push(pop() * pop())             5 96
push(7)                         5 96 7
push(pop() + pop())             5 103
push(pop() * pop())             515
```

Trees

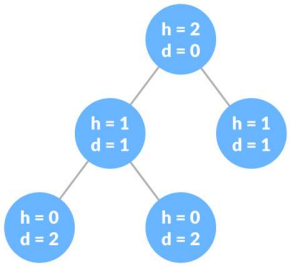
https://data-flair.training/blogs/binary-tree-in-c/

https://www.programiz.com/dsa/avl-tree

A tree is a nonlinear hierarchical data structure that consists of nodes connected by edges.

Following are the important terms with respect to tree.

- Path − Path refers to the sequence of nodes along the edges of a tree.
- Root − The node at the top of the tree is called root. There is only one root per tree and one path from the root node to any node.
- Parent − Any node except the root node has one edge upward to a node called parent.
- Child − The node below a given node connected by its edge downward is called its child node.
- Leaf − The node which does not have any child node is called the leaf node.
- Subtree − Subtree represents the descendants of a node.
- Visiting − Visiting refers to checking the value of a node when control is on the node.
- Traversing − Traversing means passing through nodes in a specific order.
- Levels − Level of a node represents the generation of a node. If the root node is at level 0, then its next child node is at level 1, its grandchild is at level 2, and so on.
- keys − Key represents a value of a node based on which a search operation is to be carried out for a node.



Height and depth of each node in a tree

Degree of a Node

The degree of a node is the total number of branches of that node.

Types of Tree

1. Binary Tree
2. Binary Search Tree
3. AVL Tree
4. B-Tree

Tree Node

The code to write a tree node would be similar to what is given below. It has a data part and references to its left and right child nodes.

```
struct node {
   int data;
   struct node *leftChild;
   struct node *rightChild;
};
```

BST Basic Operations

The basic operations that can be performed on a binary search tree data structure, are the following −

- Insert − Inserts an element in a tree/create a tree.
- Search − Searches an element in a tree.
- Preorder Traversal − Traverses a tree in a pre-order manner.
- Inorder Traversal − Traverses a tree in an in-order manner.
- Postorder Traversal − Traverses a tree in a post-order manner.

Tree Applications

Binary Search Trees(BSTs) are used to quickly check whether an element is present in a set or not.

Heap is a kind of tree that is used for heap sort.

A modified version of a tree called Tries is used in modern routers to store routing information.

Most popular databases use B-Trees and T-Trees, which are variants of the tree structure we learned above to store their data

Compilers use a syntax tree to validate the syntax of every program you write.

Working program

It is noted that above code snippets are parts of below C program. This below program would be working basic program for binary tree.

```
#include<stdlib.h>
#include<stdio.h>

struct bin_tree {
int data;
struct bin_tree * right, * left;
};
typedef struct bin_tree node;

void insert(node ** tree, int val)
{
    node *temp = NULL;
    if(!(*tree))
    {
        temp = (node *)malloc(sizeof(node));
        temp->left = temp->right = NULL;
        temp->data = val;
        *tree = temp;
        return;
    }

    if(val < (*tree)->data)
    {
        insert(&(*tree)->left, val);
    }
    else if(val > (*tree)->data)
    {
        insert(&(*tree)->right, val);
    }

}

void print_preorder(node * tree)
{
    if (tree)
    {
        printf("%d\n",tree->data);
        print_preorder(tree->left);
        print_preorder(tree->right);
    }

}

void print_inorder(node * tree)
{
    if (tree)
    {
        print_inorder(tree->left);
```

```
        printf("%d\n",tree->data);
        print_inorder(tree->right);
    }
}

void print_postorder(node * tree)
{
    if (tree)
    {
        print_postorder(tree->left);
        print_postorder(tree->right);
        printf("%d\n",tree->data);
    }
}

void deltree(node * tree)
{
    if (tree)
    {
        deltree(tree->left);
        deltree(tree->right);
        free(tree);
    }
}

node* search(node ** tree, int val)
{
    if(!(*tree))
    {
        return NULL;
    }

    if(val < (*tree)->data)
    {
        search(&((*tree)->left), val);
    }
    else if(val > (*tree)->data)
    {
        search(&((*tree)->right), val);
    }
    else if(val == (*tree)->data)
    {
        return *tree;
    }
}
```

Searching

Linear Search

Linear search is a very basic and simple search algorithm. In Linear search, we search an element or value in a given array by traversing the array from the starting, till the desired element or value is found.

Binary Search

Binary Search is used with sorted array or list. In binary search, we follow the following steps:

- We start by comparing the element to be searched with the element in the middle of the list/array.
- If we get a match, we return the index of the middle element.
- If we do not get a match, we check whether the element to be searched is less or greater than in value than the middle element.
- If the element/number to be searched is greater in value than the middle number, then we pick the elements on the right side of the middle element(as the list/array is sorted, hence on the right, we will have all the numbers greater than the middle number), and start again from the step 1.
- If the element/number to be searched is lesser in value than the middle number, then we pick the elements on the left side of the middle element, and start again from the step 1.
- Binary Search is useful when there are large number of elements in an array and they are sorted.
- So a necessary condition for Binary search to work is that the list/array should be sorted.

Algorithm	Best case	Expected	Worst case
Selection sort	$O(N^2)$	$O(N^2)$	$O(N^2)$
Merge sort	O(N log N)	O(N log N)	O(N log N)
Linear search	O(1)	O(N)	O(N)
Binary search	O(1)	O(log N)	O(log N)

Algorithm	Space complexity
Selection sort	O(1)
Merge sort	O(N)
Linear search	O(1)
Binary search	O(1)

SORTING ALGORITHMS

In order to have a good comparison between different algorithms we can compare based on the resources it uses: how much time it needs to complete, how much memory it uses to solve a problem or how many operations it must do in order to solve the problem:

Time efficiency: a measure of the amount of time an algorithm takes to solve a problem.

Space efficiency: a measure of the amount of memory an algorithm needs to solve a problem.

Complexity theory: a study of algorithm performance based on cost functions of statement counts.

Bubble Sort

Bubble sort algorithm starts by comparing the first two elements of an array and swapping if necessary

```
void bubbleSort(int ar[])
{
   for (int i = (ar.length - 1); i >= 0; i--)
   {
      for (int j = 1; j ≤ i; j++)
      {
         if (ar[j-1] > ar[j])
         {
              int temp = ar[j-1];
              ar[j-1] = ar[j];
              ar[j] = temp;
   } } } }
```

Example: Here is one step of the algorithm. The largest element - 7 - is bubbled to the top:

7, 5, 2, 4, 3, 9
5, **7, 2**, 4, 3, 9
5, 2, **7, 4**, 3, 9
5, 2, 4, **7, 3**, 9
5, 2, 4, 3, **7, 9**
5, 2, 4, 3, 7, 9

Selection Sort

The algorithm works by selecting the smallest unsorted item and then swapping it with the item in the next position to be filled.

The selection sort works as follows: you look through the entire array for the smallest element, once you find it you swap it (the smallest element) with the first element of the array. Then you look for the smallest element in the remaining array (an array without the first element) and swap it with the second element. Then you look for the smallest element in the remaining array (an array without first and second elements) and swap it with the third element, and so on. Here is an example,

```
void selectionSort(int[] ar){
   for (int i = 0; i < ar.length-1; i++)
   {
      int min = i;
      for (int j = i+1; j < ar.length; j++)
            if (ar[j] < ar[min]) min = j;
      int temp = ar[i];
      ar[i] = ar[min];
      ar[min] = temp;
} }
```

Example.

29, 64, 73, 34, **20**,
20, **64**, 73, 34, **29**,
20, 29, **73**, **34**, 64
20, 29, 34, **73**, **64**
20, 29, 34, 64, 73

Insertion Sort

To sort unordered list of elements, we remove its entries one at a time and then insert each of them into a sorted part (initially empty):

```
void insertionSort(int[] ar)
{
   for (int i=1; i < ar.length; i++)
   {
      int index = ar[i]; int j = i;
      while (j > 0 && ar[j-1] > index)
      {
           ar[j] = ar[j-1];
           j--;
```

```
        }
        ar[j] = index;
} }
```

Example. We color a sorted part in green, and an unsorted part in black. Here is an insertion sort step by step. We take an element from unsorted part and compare it with elements in sorted part, moving form right to left.

29, 20, 73, 34, 64
29, 20, 73, 34, 64
20, 29, 73, 34, 64
20, 29, 73, 34, 64
20, 29, 34, 73, 64
20, 29, 34, 64, 73

Mergesort

Merge-sort is based on the divide-and-conquer paradigm. It involves the following three steps:

- Divide the array into two (or more) subarrays
- Sort each subarray (Conquer)
- Merge them into one (in a smart way!)

Example. Consider the following array of numbers

27 10 12 25 34 16 15 31

divide it into two parts

27 10 12 25 34 16 15 31

divide each part into two parts

27 10 12 25 34 16 15 31

divide each part into two parts

27 10 12 25 34 16 15 31

merge (cleverly-!) parts

10 27 12 25 16 34 15 31

merge parts

10 12 25 27 15 16 31 34

merge parts into one

10 12 15 16 25 27 31 34

Quick Sort Algorithm

Quick Sort is also based on the concept of Divide and Conquer, just like merge sort. But in quick sort all the heavy lifting(major work) is done while dividing the array into subarrays, while in case of merge sort, all the real work happens during merging the subarrays. In case of quick sort, the combine step does absolutely nothing.

It is also called partition-exchange sort. This algorithm divides the list into three main parts:

1. Elements less than the Pivot element
2. Pivot element(Central element)
3. Elements greater than the pivot element

Pivot element can be any element from the array, it can be the first element, the last element or any random element. In this tutorial, we will take the rightmost element or the last element as pivot.

How Quick Sorting Works?

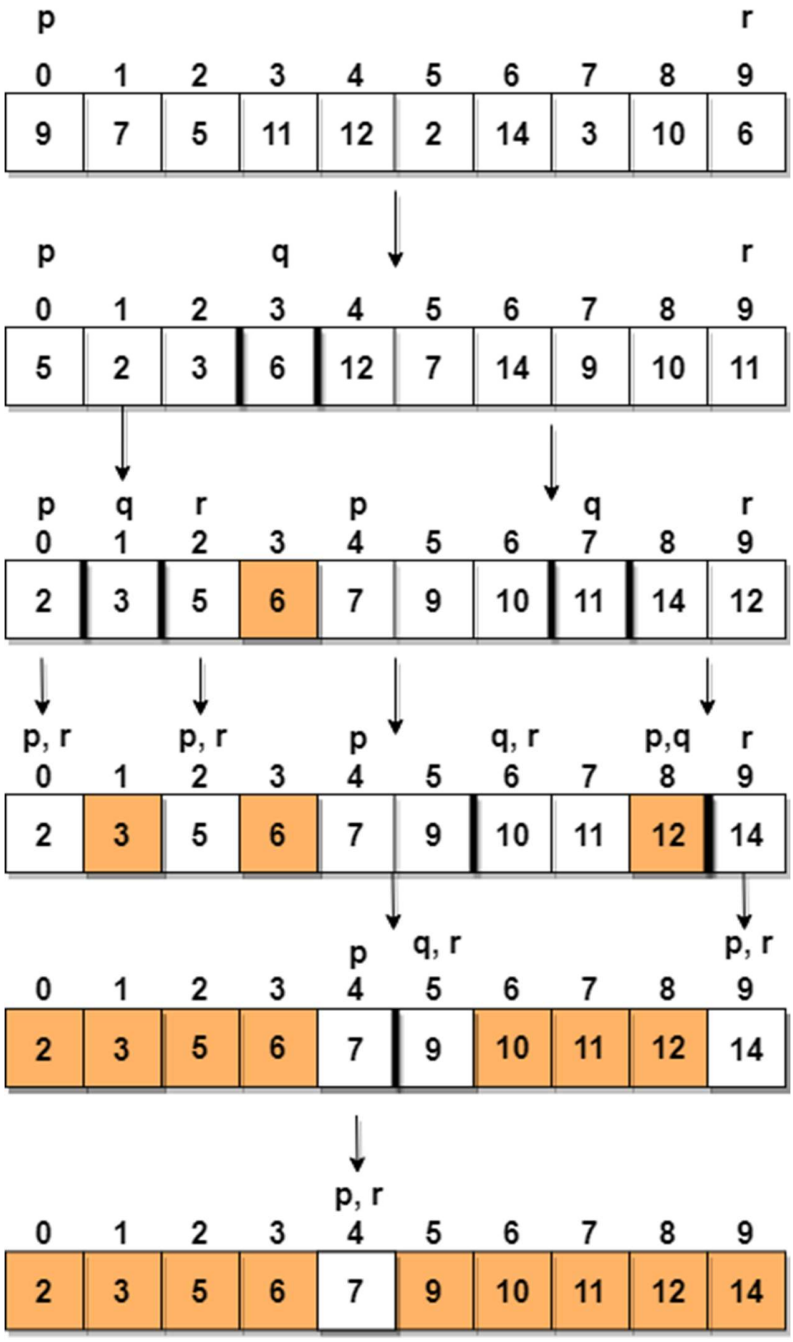
Following are the steps involved in quick sort algorithm:

1. After selecting an element as pivot, which is the last index of the array in our case, we divide the array for the first time.
2. In quick sort, we call this partitioning. It is not simple breaking down of array into 2 subarrays, but in case of partitioning, the array elements are so positioned that all the elements smaller than the pivot will be on the left side of the pivot and all the elements greater than the pivot will be on the right side of it.
3. And the pivot element will be at its final sorted position.
4. The elements to the left and right, may not be sorted.
5. Then we pick subarrays, elements on the left of pivot and elements on the right of pivot, and we perform partitioning on them by choosing a pivot in the subarrays.

Let's consider an array with values {9, 7, 5, 11, 12, 2, 14, 3, 10, 6}

Below, we have a pictorial representation of how quick sort will sort the given array.

https://www.studytonight.com/data-structures/heap-sort



In step 1, we select the last element as the pivot, which is 6 in this case, and call for partitioning, hence re-arranging the array in such a way that 6 will be placed in its final position and to its left will be all the elements less than it and to its right, we will have all the elements greater than it.

Then we pick the subarray on the left and the subarray on the right and select a pivot for them, in the above diagram, we chose 3 as pivot for the left subarray and 11 as pivot for the right subarray.

And we again call for partitioning.

Implementing Quick Sort Algorithm
Below we have a simple C program implementing the Quick sort algorithm:

```
// simple C program for Quick Sort
# include <stdio.h>

// to swap two numbers
void swap(int* a, int* b)
{
    int t = *a;
    *a = *b;
    *b = t;
}

/*
    a[] is the array, p is starting index, that is 0,
    and r is the last index of array.
*/
void quicksort(int a[], int p, int r)
{
    if(p < r)
    {
        int q;
        q = partition(a, p, r);
        quicksort(a, p, q);
        quicksort(a, q+1, r);
    }
}

int partition (int a[], int low, int high)
{
    int pivot = arr[high];  // selecting last element as pivot
    int i = (low - 1);  // index of smaller element

    for (int j = low; j <= high- 1; j++)
    {
        // If current element is smaller than or equal to pivot
        if (arr[j] <= pivot)
        {
            i++;    // increment index of smaller element
            swap(&arr[i], &arr[j]);
        }
    }
    swap(&arr[i + 1], &arr[high]);
    return (i + 1);
}

// function to print the array
void printArray(int a[], int size)
```

```
{
    int i;
    for (i=0; i < size; i++)
    {
        printf("%d ", a[i]);
    }
    printf("\n");
}

int main()
{
    int arr[] = {9, 7, 5, 11, 12, 2, 14, 3, 10, 6};
    int n = sizeof(arr)/sizeof(arr[0]);

    // call quickSort function
    quickSort(arr, 0, n-1);

    printf("Sorted array: n");
    printArray(arr, n);
    return 0;
}
```

Hash table

Hash Table is a data structure which stores data in an associative manner. In a hash table, data is stored in an array format, where each data value has its own unique index value. Access of data becomes very fast if we know the index of the desired data.

Thus, it becomes a data structure in which insertion and search operations are very fast irrespective of the size of the data. Hash Table uses an array as a storage medium and uses hash technique to generate an index where an element is to be inserted or is to be located from.

Hashing

Hashing is a technique to convert a range of key values into a range of indexes of an array. We're going to use modulo operator to get a range of key values. Consider an example of hash table of size 20, and the following items are to be stored. Item are in the (key,value) format.

```
struct DataItem {
   int data;
   int key;
};
```

```
int hashCode(int key){
   return key % SIZE;
}
```

```
struct DataItem *search(int key) {
   //get the hash
   int hashIndex = hashCode(key);

   //move in array until an empty
   while(hashArray[hashIndex] != NULL) {

      if(hashArray[hashIndex]->key == key)
         return hashArray[hashIndex];

      //go to next cell
      ++hashIndex;

      //wrap around the table
      hashIndex %= SIZE;
   }
```

```
   return NULL;
}
```

```
void insert(int key,int data) {
   struct DataItem *item = (struct DataItem*) malloc(sizeof(struct
DataItem));
   item->data = data;
   item->key = key;

   //get the hash
   int hashIndex = hashCode(key);

   //move in array until an empty or deleted cell
   while(hashArray[hashIndex] != NULL && hashArray[hashIndex]->key != -1) {
      //go to next cell
      ++hashIndex;

      //wrap around the table
      hashIndex %= SIZE;
   }

   hashArray[hashIndex] = item;
}
```

```
struct DataItem* delete(struct DataItem* item) {
   int key = item->key;

   //get the hash
   int hashIndex = hashCode(key);

   //move in array until an empty
   while(hashArray[hashIndex] !=NULL) {

      if(hashArray[hashIndex]->key == key) {
         struct DataItem* temp = hashArray[hashIndex];

         //assign a dummy item at deleted position
         hashArray[hashIndex] = dummyItem;
         return temp;
      }

      //go to next cell
      ++hashIndex;

      //wrap around the table
```

```
        hashIndex %= SIZE;
    }

    return NULL;
}
```

Graph

Operating systems

Networking