Red Black Tree

A Red Black Tree is a category of the self-balancing binary search tree. It was created in 1972 by Rudolf Bayer who termed them **"symmetric binary B-trees**."

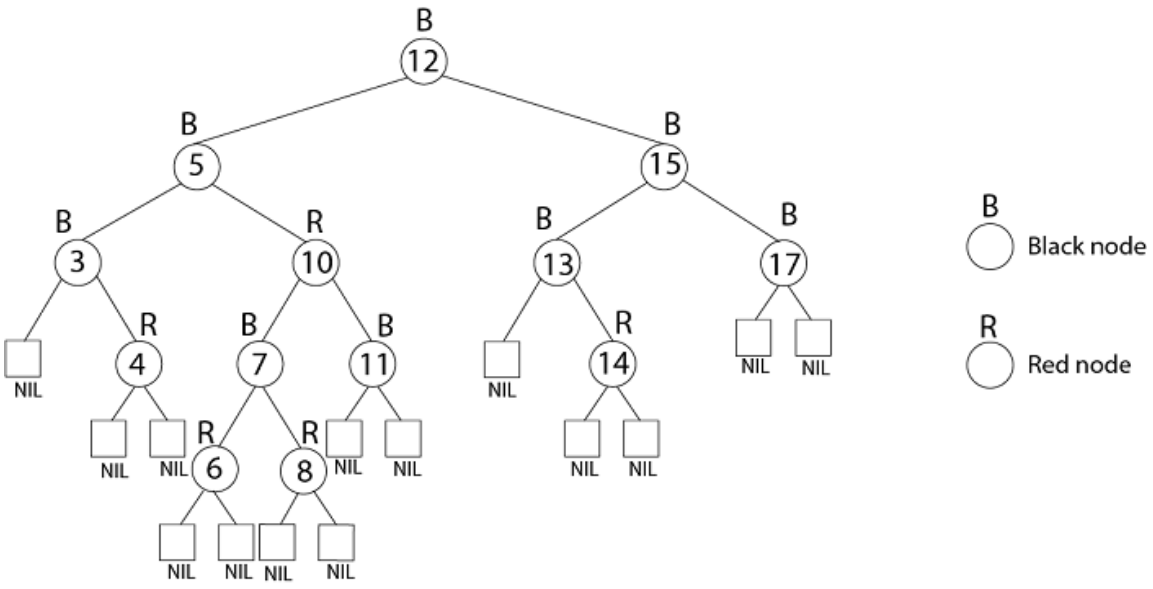
A red-black tree is a Binary tree where a particular node has color as an extra attribute, either red or black. By check the node colors on any simple path from the root to a leaf, red-black trees secure that no such path is higher than twice as long as any other so that the tree is generally balanced.

Properties of Red-Black Trees

A red-black tree must satisfy these properties:

1. The root is always black.
2. A nil is recognized to be black. This factor that every non-NIL node has two children.
3. **Black Children Rule:** The children of any red node are black.
4. **Black Height Rule:** For particular node v, there exists an integer bh (v) such that specific downward path from v to a nil has correctly bh (v) black real (i.e. non-nil) nodes. Call this portion the black height of v. We determine the black height of an RB tree to be the black height of its root.

A tree T is an almost red-black tree (ARB tree) if the root is red, but other conditions above hold.

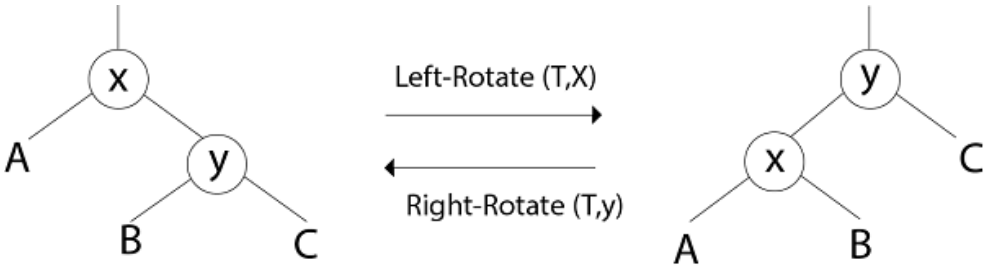


Operations on RB Trees:

The search-tree operations TREE-INSERT and TREE-DELETE, when runs on a red-black tree with n keys, take O (log n) time. Because they customize the tree, the conclusion may violate the red-black properties. To restore these properties, we must change the color of some of the nodes in the tree and also change the pointer structure.

1. Rotation:

Restructuring operations on red-black trees can generally be expressed more clearly in details of the rotation operation.



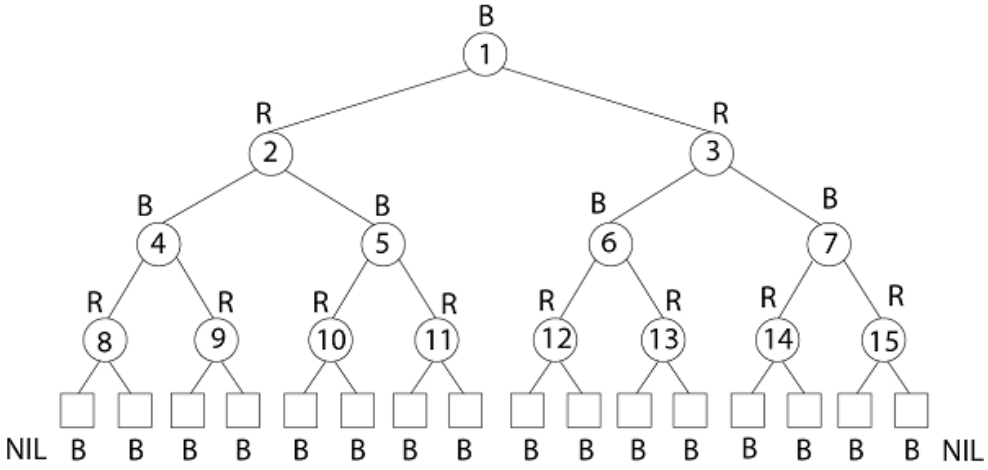
Clearly, the order (Ax By C) is preserved by the rotation operation. Therefore, if we start with a BST and only restructure using rotation, then we will still have a BST i.e. rotation do not break the BST-Property.

LEFT ROTATE (T, x)

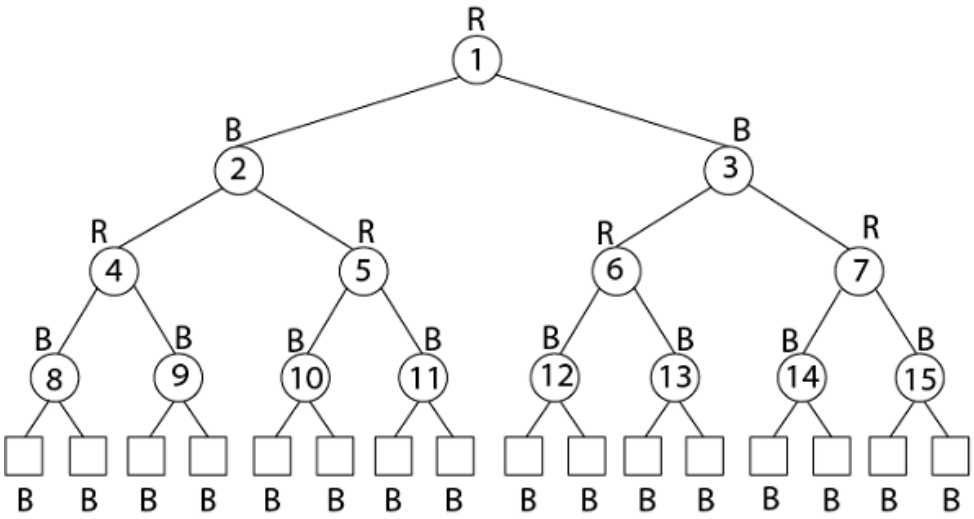
```
1. y ← right [x]
1. y ← right [x]
2. right [x] ← left [y]
3. p [left[y]] ← x
4. p[y] ← p[x]
5. If p[x] = nil [T]
  then root [T] ← y
   else if x = left [p[x]]
     then left [p[x]] ← y
   else right [p[x]] ← y
6. left [y] ← x.
7. p [x] ← y.
```

Example: Draw the complete binary tree of height 3 on the keys {1, 2, 3... 15}. Add the NIL leaves and color the nodes in three different ways such that the black heights of the resulting trees are: 2, 3 and 4.

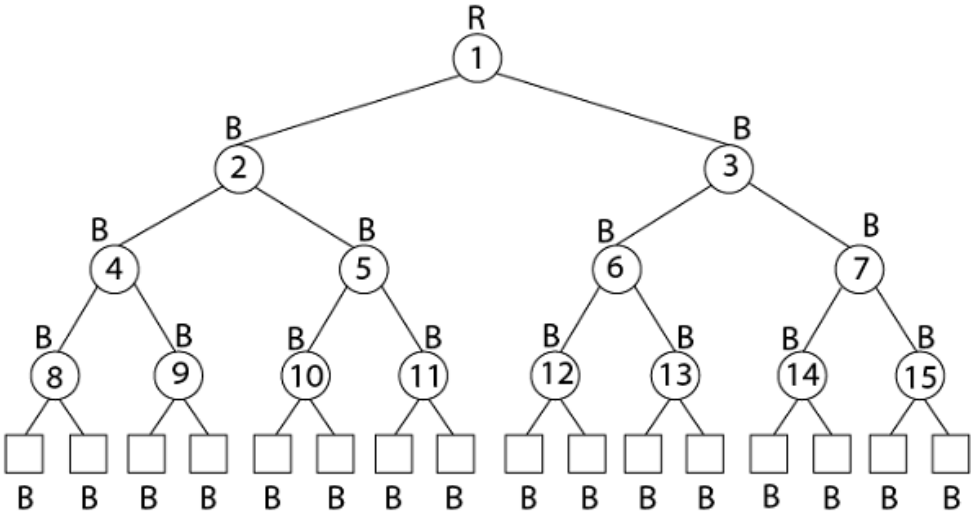
Solution:



Tree with black-height-2



Tree with black-height-3



Tree with black-height-4

2. Insertion:

- Insert the new node the way it is done in Binary Search Trees.
- Color the node red
- If an inconsistency arises for the red-black tree, fix the tree according to the type of discrepancy.

A discrepancy can decision from a parent and a child both having a red color. This type of discrepancy is determined by the location of the node concerning grandparent, and the color of the sibling of the parent.

RB-INSERT (T, z)

```
1. y ← nil [T]
2. x ← root [T]
3. while x ≠ NIL [T]
4. do y ← x
5. if key [z] < key [x]
6. then x  ← left [x]
7. else x ←  right [x]
8. p [z] ← y
9. if y = nil [T]
10. then root [T] ← z
11. else if key [z] < key [y]
12. then left [y] ← z
13. else right [y] ← z
14. left [z] ← nil [T]
15. right [z] ← nil [T]
16. color [z] ← RED
17. RB-INSERT-FIXUP (T, z)
```

After the insert new node, Coloring this new node into black may violate the black-height conditions and coloring this new node into red may violate coloring conditions i.e. root is black and red node has no red children. We know the black-height violations are hard. So we color the node red. After this, if there is any color violation, then we have to correct them by an RB-INSERT-FIXUP procedure.

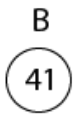
RB-INSERT-FIXUP (T, z)

```
1. while color [p[z]] = RED
2. do if p [z] = left [p[p[z]]]
3. then y ← right [p[p[z]]]
4. If color [y] = RED
5. then color [p[z]] ← BLACK    //Case 1
6. color [y] ← BLACK            //Case 1
7. color [p[z]] ← RED           //Case 1
8. z  ← p[p[z]]                 //Case 1
9. else if z= right [p[z]]
10. then z ← p [z]              //Case 2
11. LEFT-ROTATE (T, z)          //Case 2
12. color [p[z]] ← BLACK        //Case 3
13. color [p [p[z]]] ← RED      //Case 3
14. RIGHT-ROTATE  (T,p [p[z]])  //Case 3
15. else (same as then clause)
     With "right" and "left" exchanged
16. color [root[T]] ← BLACK
```

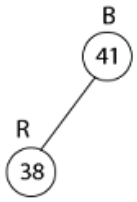
Example: Show the red-black trees that result after successively inserting the keys 41,38,31,12,19,8 into an initially empty red-black tree.

Solution:

Insert 41

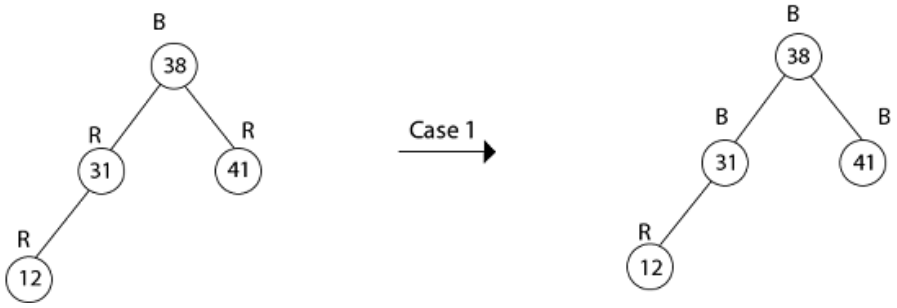


Insert 38

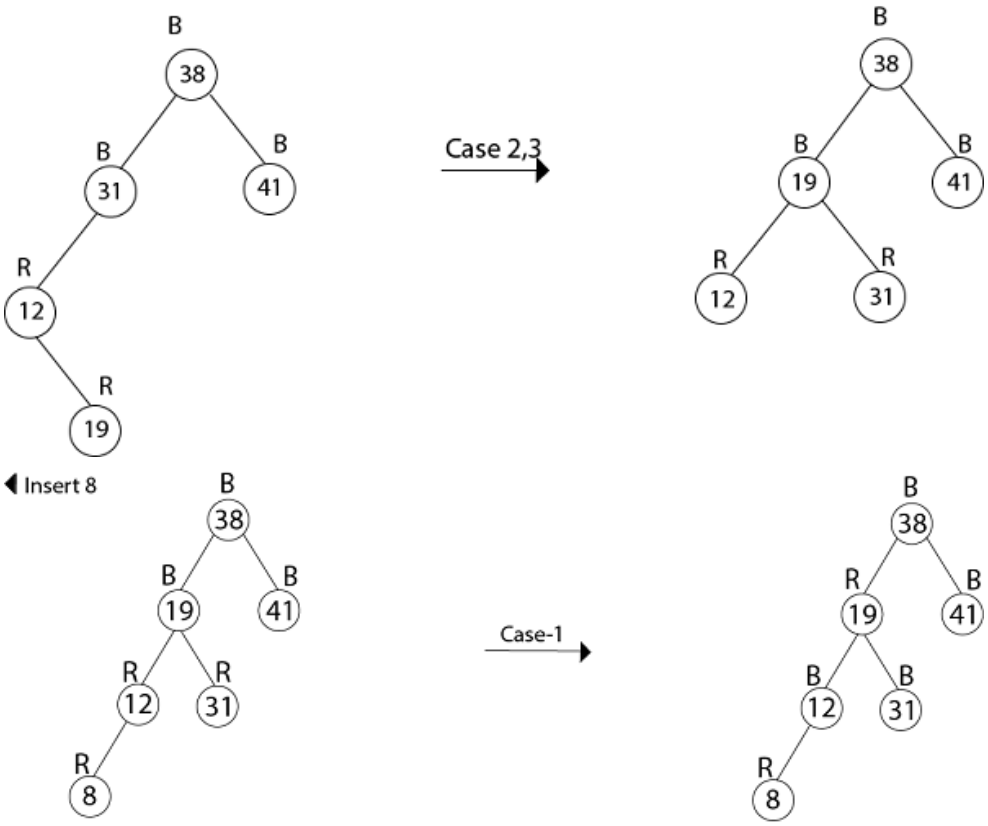


- Insert 31

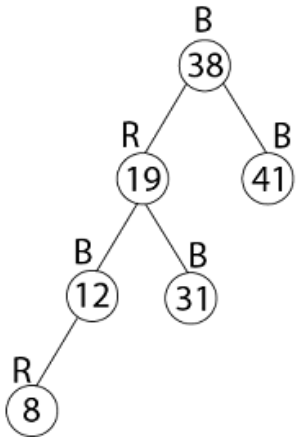
- Insert 12



Insert 19



Thus the final tree is



3. Deletion:

First, search for an element to be deleted

- If the element to be deleted is in a node with only left child, swap this node with one containing the largest element in the left subtree. (This node has no right child).
- If the element to be deleted is in a node with only right child, swap this node with the one containing the smallest element in the right subtree (This node has no left child).
- If the element to be deleted is in a node with both a left child and a right child, then swap in any of the above two ways. While swapping, swap only the keys but not the colors.
- The item to be deleted is now having only a left child or only a right child. Replace this node with its sole child. This may violate red constraints or black constraint. Violation of red constraints can be easily fixed.
- If the deleted node is black, the black constraint is violated. The elimination of a black node y causes any path that contained y to have one fewer black node.

- Two cases arise:
  - The replacing node is red, in which case we merely color it black to make up for the loss of one black node.
  - The replacing node is black.

The strategy RB-DELETE is a minor change of the TREE-DELETE procedure. After splicing out a node, it calls an auxiliary procedure RB-DELETE-FIXUP that changes colors and performs rotation to restore the red-black properties.

RB-DELETE (T, z)

```
1. if left [z] = nil [T] or right [z] = nil [T]
2. then y ← z
3. else y ← TREE-SUCCESSOR (z)
4. if left [y] ≠ nil [T]
5. then x ← left [y]
6. else x ← right [y]
7. p [x] ←  p [y]
8. if p[y] = nil [T]
9. then root [T]  ← x
10. else if y = left [p[y]]
11. then left [p[y]] ← x
12. else right [p[y]] ← x
13. if y≠ z
14. then key [z] ← key [y]
15. copy y's satellite data into z
16. if color [y] = BLACK
17. then RB-delete-FIXUP (T, x)
18. return y
```

RB-DELETE-FIXUP (T, x)

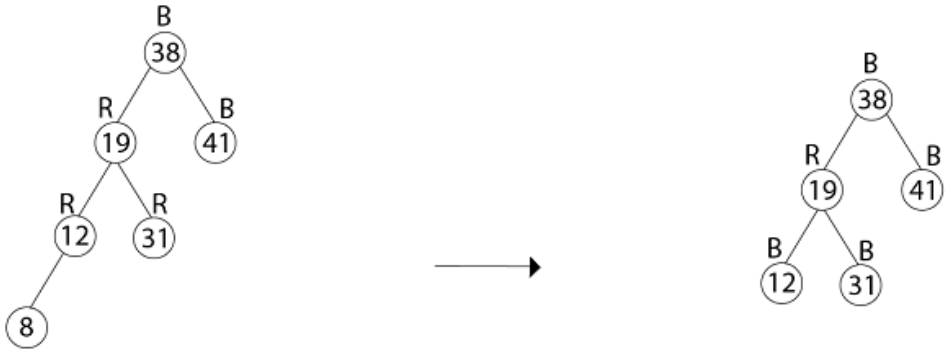
```
1. while x ≠ root [T] and color [x] = BLACK
2. do if x = left [p[x]]
3. then w ← right [p[x]]
4. if color [w] = RED
5. then color [w] ← BLACK        //Case 1
```

```
6. color [p[x]] ← RED            //Case 1
7. LEFT-ROTATE (T, p [x])        //Case 1
8. w ← right [p[x]]              //Case 1
9. If color [left [w]] = BLACK and color [right[w]] = BLACK
10. then color [w] ← RED         //Case 2
11. x ← p[x]                     //Case 2
12. else if color [right [w]] = BLACK
13. then color [left[w]] ← BLACK //Case 3
14. color [w] ← RED              //Case 3
15. RIGHT-ROTATE (T, w)          //Case 3
16. w ← right [p[x]]             //Case 3
17. color [w] ← color [p[x]]     //Case 4
18. color p[x] ← BLACK           //Case 4
19. color [right [w]] ← BLACK    //Case 4
20. LEFT-ROTATE (T, p [x])       //Case 4
21. x ← root [T]                 //Case 4
22. else (same as then clause with "right" and "left" exchanged)
23. color [x] ← BLACK
```

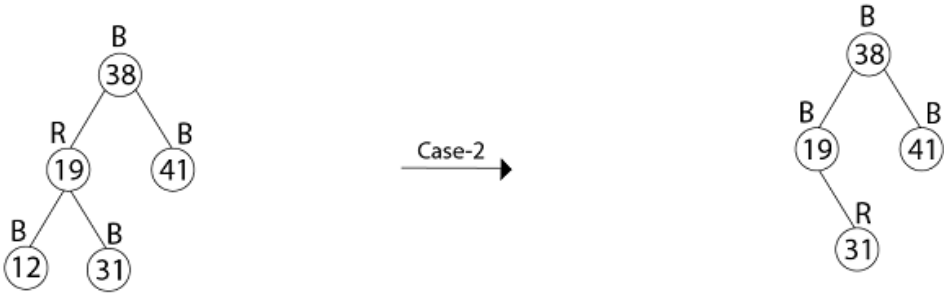
Example: In a previous example, we found that the red-black tree that results from successively inserting the keys 41,38,31,12,19,8 into an initially empty tree. Now show the red-black trees that result from the successful deletion of the keys in the order 8, 12, 19,31,38,41.

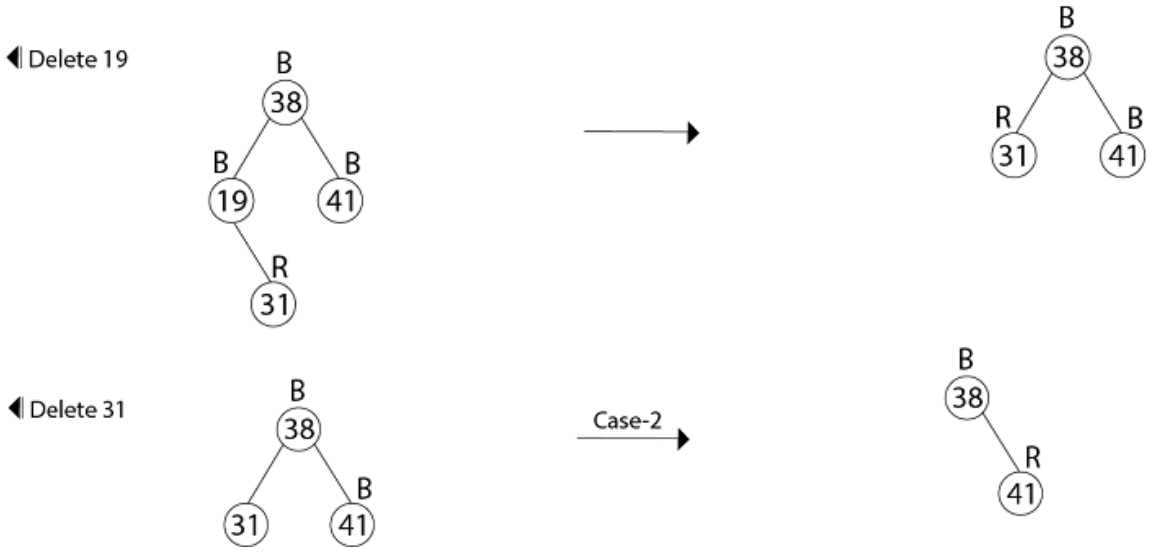
Solution:

Delete 8

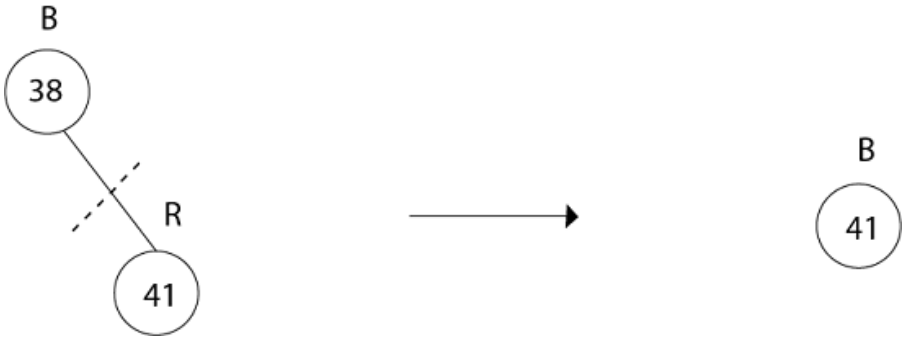


Delete 12





Delete 38



Delete 41

No Tree.

← Prev Next →

Aptitude

Logical Reasoning
Reasoning

Verbal Ability
Verbal Ability

Interview Questions
Interview Questions

Company Interview Questions
Company Questions

Trending Technologies

Artificial Intelligence
Artificial Intelligence

AWS Tutorial
AWS

Selenium tutorial
Selenium

Cloud Computing
Cloud Computing

Hadoop tutorial
Hadoop

ReactJS Tutorial
ReactJS

Data Science Tutorial
Data Science

Angular 7 Tutorial
Angular 7

Blockchain Tutorial
Blockchain

Git Tutorial
Git

Machine Learning Tutorial
Machine Learning

DevOps Tutorial
DevOps

B.Tech / MCA

DBMS tutorial
DBMS

Data Structures tutorial
Data Structures

DAA tutorial
DAA

Operating System
Operating System

Computer Network tutorial
Computer Network

Compiler Design tutorial
Compiler Design

Computer Organization and Architecture
Computer Organization

Discrete Mathematics Tutorial
Discrete Mathematics

Ethical Hacking
Ethical Hacking

Computer Graphics Tutorial
Computer Graphics

Software Engineering
Software Engineering

html tutorial
Web Technology

Cyber Security tutorial
Cyber Security

Automata Tutorial
Automata

C Language tutorial
C Programming

C++ tutorial
C++

Java tutorial
Java

.Net Framework tutorial
.Net

Python tutorial
Python

List of Programs
Programs