Huffman Coding | Greedy Algo-3

Huffman coding is a lossless data compression algorithm. The idea is to assign variable-length codes to input characters, lengths of the assigned codes are based on the frequencies of corresponding characters.
The variable-length codes assigned to input characters are Prefix Codes, means the codes (bit sequences) are assigned in such a way that the code assigned to one character is not the prefix of code assigned to any other character. This is how Huffman Coding makes sure that there is no ambiguity when decoding the generated bitstream.
Let us understand prefix codes with a counter example. Let there be four characters a, b, c and d, and their corresponding variable length codes be 00, 01, 0 and 1. This coding leads to ambiguity because code assigned to c is the prefix of codes assigned to a and b. If the compressed bit stream is 0001, the de-compressed output may be “cccd” or “ccb” or “acd” or “ab”.
See this for applications of Huffman Coding.
There are mainly two major parts in Huffman Coding

1. Build a Huffman Tree from input characters.
2. Traverse the Huffman Tree and assign codes to characters.

Algorithm:

The method which is used to construct optimal prefix code is called **Huffman coding**.

This algorithm builds a tree in bottom up manner. We can denote this tree by **T**

|c| -1 are number of operations required to merge the nodes. Q be the priority queue which can be used while constructing binary heap.

```
Algorithm Huffman (c)
{
   n= |c|

   Q = c
   for i<-1 to n-1

   do
   {

       temp <- get node ()

      left (temp] Get_min (Q) right [temp] Get Min (Q)

      a = left [templ b = right [temp]

      F [temp]<- f[a] + [b]

      insert (Q, temp)

    }
return Get_min (0)
}
```

Steps to build Huffman Tree

Input is an array of unique characters along with their frequency of occurrences and output is Huffman Tree.

1. Create a leaf node for each unique character and build a min heap of all leaf nodes (Min Heap is used as a priority queue. The value of frequency field is used to compare two nodes in min heap. Initially, the least frequent character is at root)
2. Extract two nodes with the minimum frequency from the min heap.
3. Create a new internal node with a frequency equal to the sum of the two nodes frequencies. Make the first extracted node as its left child and the other extracted node as its right child. Add this node to the min heap.
4. Repeat steps#2 and #3 until the heap contains only one node. The remaining node is the root node and the tree is complete.
   Let us understand the algorithm with an example:

```
character   Frequency
    a            5
    b           9
    c           12
    d           13
    e           16
    f           45
```

Step 1. Build a min heap that contains 6 nodes where each node represents root of a tree with single node.

Step 2 Extract two minimum frequency nodes from min heap. Add a new internal node with frequency 5 + 9 = 14.

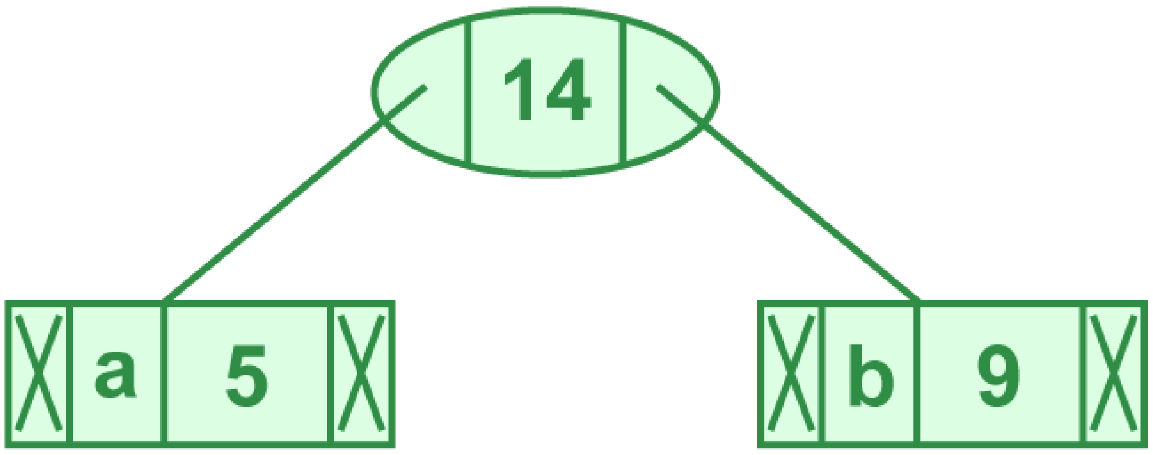


Illustration of step 2

Now min heap contains 5 nodes where 4 nodes are roots of trees with single element each, and one heap node is root of tree with 3 elements

```
character           Frequency
       c               12
       d               13
 Internal Node         14
       e               16
       f                45
```

Step 3: Extract two minimum frequency nodes from heap. Add a new internal node with frequency 12 + 13 = 25

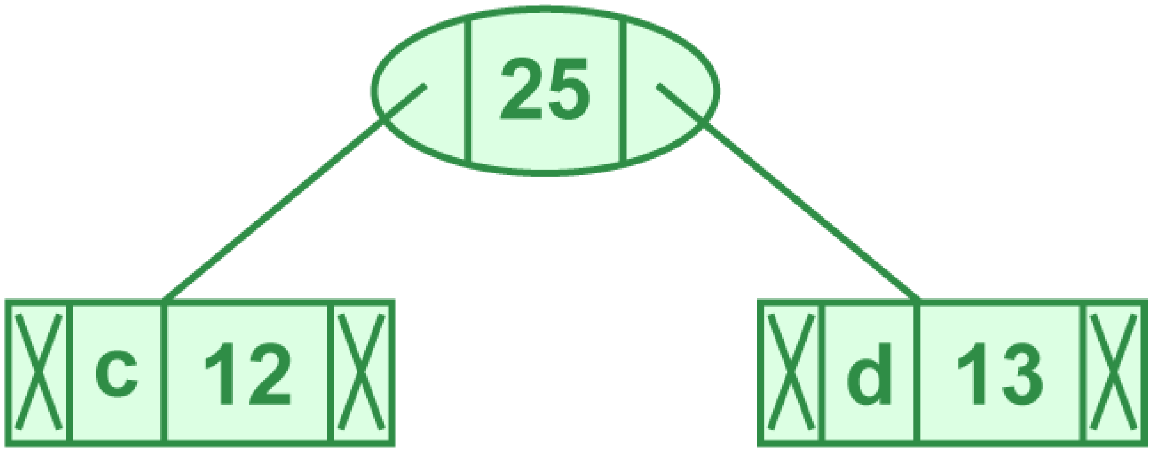


Illustration of step 3

Now min heap contains 4 nodes where 2 nodes are roots of trees with single element each, and two heap nodes are root of tree with more than one nodes

```
character           Frequency
Internal Node          14
       e               16
Internal Node          25
       f               45
```

Step 4: Extract two minimum frequency nodes. Add a new internal node with frequency 14 + 16 = 30

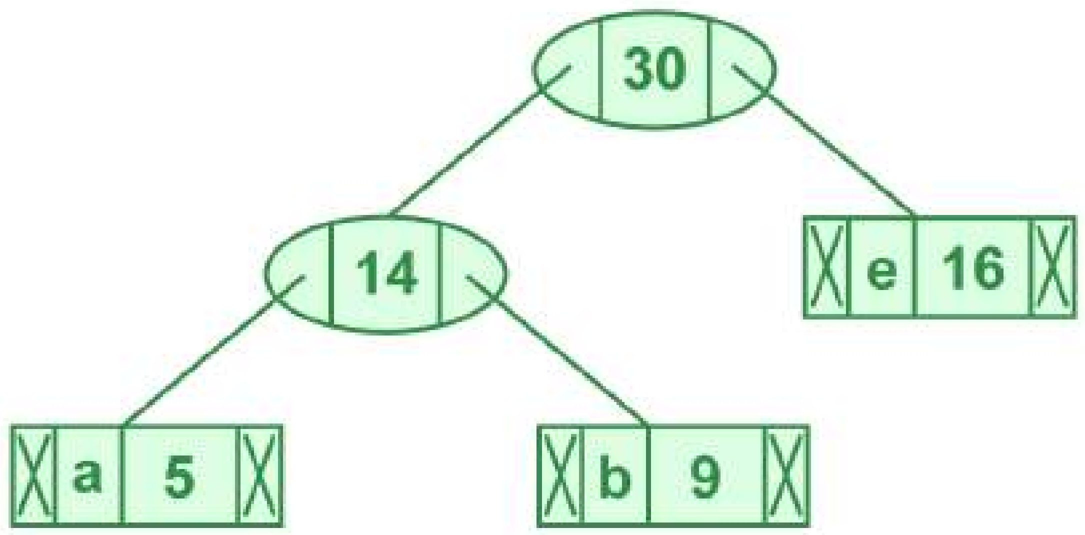


Illustration of step 4

Now min heap contains 3 nodes.

character	Frequency
Internal Node	25
Internal Node	30
f	45

Step 5: Extract two minimum frequency nodes. Add a new internal node with frequency 25 + 30 = 55

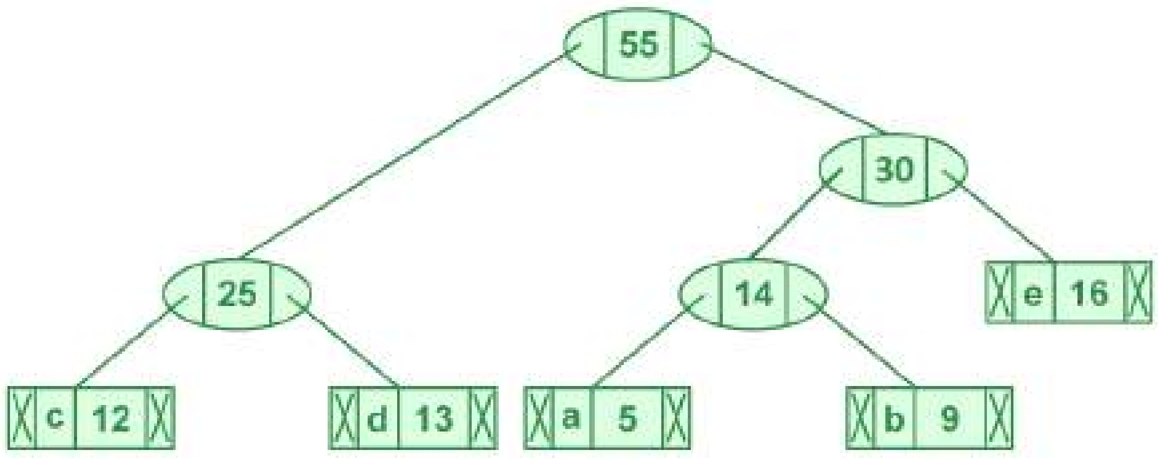


Illustration of step 5

Now min heap contains 2 nodes.

```
character      Frequency
       f          45
Internal Node     55
```

Step 6: Extract two minimum frequency nodes. Add a new internal node with frequency 45 + 55 = 100

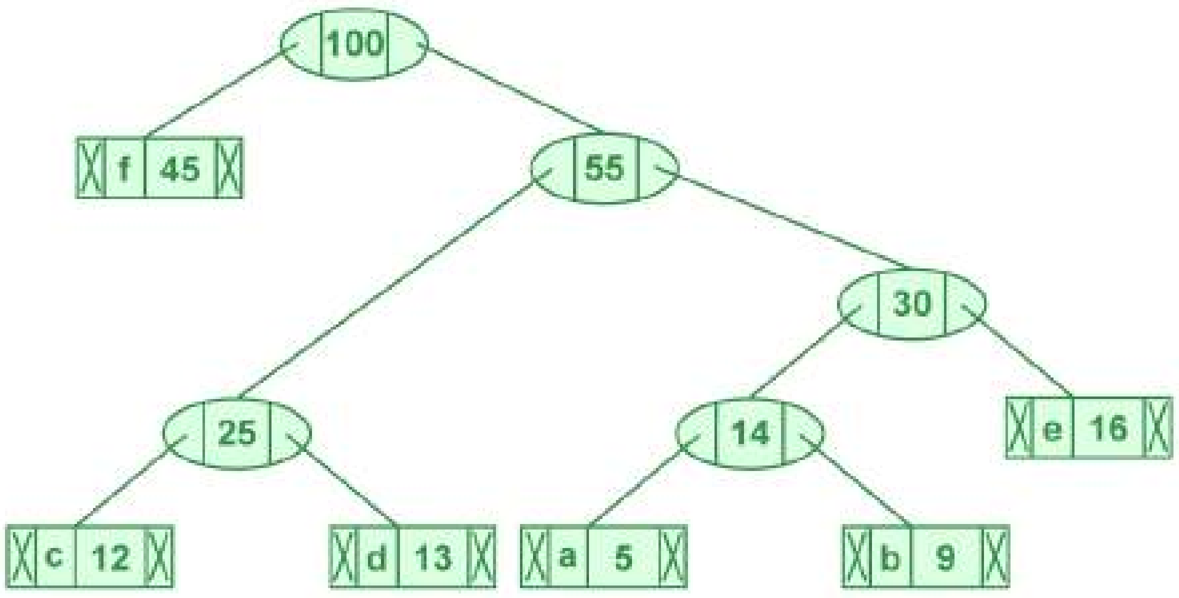


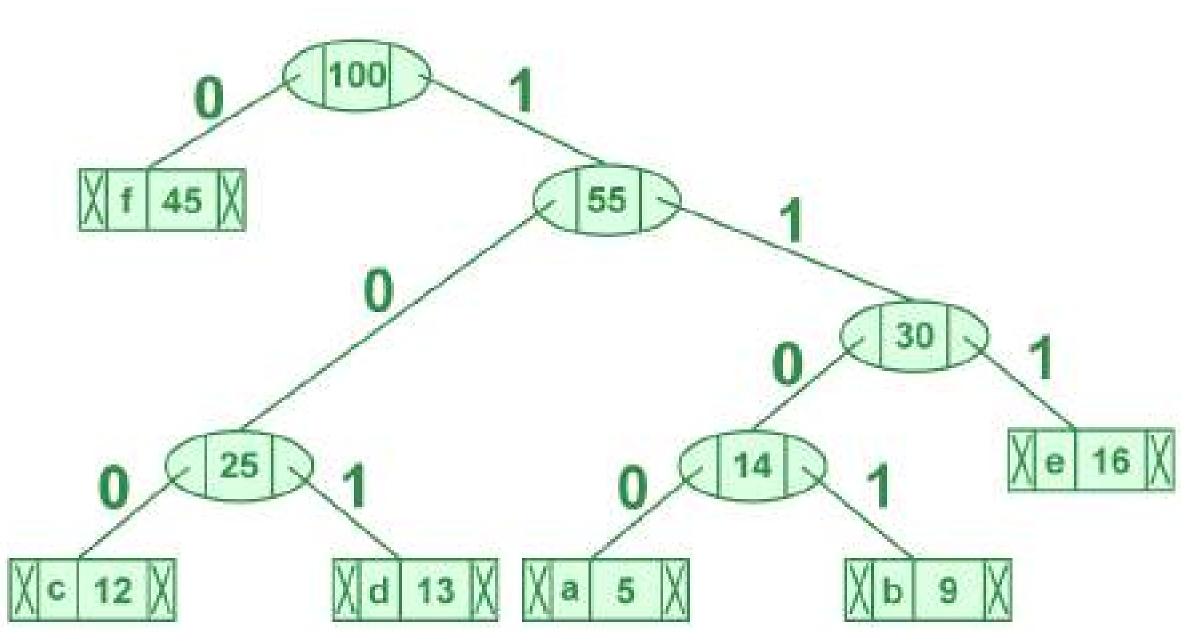
Illustration of step 6

Now min heap contains only one node.

```
character      Frequency
Internal Node    100
```

Since the heap contains only one node, the algorithm stops here.

Steps to print codes from Huffman Tree:
Traverse the tree formed starting from the root. Maintain an auxiliary array. While moving to the left child, write 0 to the array. While moving to the right child, write 1 to the array. Print the array when a leaf node is encountered.



Steps to print code from HuffmanTree

The codes are as follows:

```
character   code-word
    f          0
    c          100
    d          101
    a          1100
    b          1101
    e          111
```

Heap priority-queue +2 more Morgan Stanley Amazon +3 more Submission count: 32.1K

Below is the implementation of above approach:

C

```
// C program for Huffman Coding
#include <stdio.h>
#include <stdlib.h>

// This constant can be avoided by explicitly
// calculating height of Huffman Tree
#define MAX_TREE_HT 100

// A Huffman tree node
struct MinHeapNode {
```

```
    unsigned freq;

    // Left and right child of this node
    struct MinHeapNode *left, *right;
};

// A Min Heap:  Collection of
// min-heap (or Huffman tree) nodes
struct MinHeap {

    // Current size of min heap
    unsigned size;

    // capacity of min heap
    unsigned capacity;

    // Array of minheap node pointers
    struct MinHeapNode** array;
};

// A utility function allocate a new
// min heap node with given character
// and frequency of the character
```

```
        sizeof(struct MinHeapNode));

    temp->left = temp->right = NULL;
    temp->data = data;
    temp->freq = freq;

    return temp;
}

// A utility function to create
// a min heap of given capacity
struct MinHeap* createMinHeap(unsigned capacity)

{

    struct MinHeap* minHeap
        = (struct MinHeap*)malloc(sizeof(struct MinHeap));

    // current size is 0
    minHeap->size = 0;

    minHeap->capacity = capacity;

    minHeap->array = (struct MinHeapNode**)malloc(
        minHeap->capacity * sizeof(struct MinHeapNode*));
    return minHeap;
}

// A utility function to
// swap two min heap nodes
void swapMinHeapNode(struct MinHeapNode** a,
                     struct MinHeapNode** b)

{

    struct MinHeapNode* t = *a;
    *a = *b;
    *b = t;
}

// The standard minHeapify function.
void minHeapify(struct MinHeap* minHeap, int idx)

{

    int smallest = idx;
    int left = 2 * idx + 1;
    if (left < minHeap->size
        && minHeap->array[left]->freq
               < minHeap->array[smallest]->freq)
        smallest = left;

    if (right < minHeap->size
        && minHeap->array[right]->freq
               < minHeap->array[smallest]->freq)
        smallest = right;

    if (smallest != idx) {
        swapMinHeapNode(&minHeap->array[smallest],
                        &minHeap->array[idx]);
        minHeapify(minHeap, smallest);
    }
}

// A utility function to check
// if size of heap is 1 or not
int isSizeOne(struct MinHeap* minHeap)
{

    return (minHeap->size == 1);
}

// A standard function to extract
// minimum value node from heap
struct MinHeapNode* extractMin(struct MinHeap* minHeap)

{

    struct MinHeapNode* temp = minHeap->array[0];
    minHeap->array[0] = minHeap->array[minHeap->size - 1];

    --minHeap->size;
    minHeapify(minHeap, 0);

    return temp;
}

// A utility function to insert
// a new node to Min Heap
void insertMinHeap(struct MinHeap* minHeap,
                   struct MinHeapNode* minHeapNode)

{
    while (i
           && minHeapNode->freq
                  < minHeap->array[(i - 1) / 2]->freq) {

        minHeap->array[i] = minHeap->array[(i - 1) / 2];
        i = (i - 1) / 2;
    }

    minHeap->array[i] = minHeapNode;
}

// A standard function to build min heap
void buildMinHeap(struct MinHeap* minHeap)

{

    int n = minHeap->size - 1;
    int i;

    for (i = (n - 1) / 2; i >= 0; --i)
        minHeapify(minHeap, i);
}

// A utility function to print an array of size n
void printArr(int arr[], int n)
{
    int i;
    for (i = 0; i < n; ++i)
        printf("%d", arr[i]);

    printf("\n");
}

// Utility function to check if this node is leaf
int isLeaf(struct MinHeapNode* root)

{

    return !(root->left) && !(root->right);
}

// Creates a min heap of capacity
// equal to size and inserts all character of
// data[] in min heap. Initially size of
// min heap is equal to capacity
struct MinHeap* createAndBuildMinHeap(char data[],
{

    struct MinHeap* minHeap = createMinHeap(size);

    for (int i = 0; i < size; ++i)
        minHeap->array[i] = newNode(data[i], freq[i]);

    minHeap->size = size;
    buildMinHeap(minHeap);

    return minHeap;
}

// The main function that builds Huffman tree
struct MinHeapNode* buildHuffmanTree(char data[],
                                     int freq[], int size)

{
    struct MinHeapNode *left, *right, *top;

    // Step 1: Create a min heap of capacity
    // equal to size.  Initially, there are
    // modes equal to size.
    struct MinHeap* minHeap
        = createAndBuildMinHeap(data, freq, size);

    // Iterate while size of heap doesn't become 1
    while (!isSizeOne(minHeap)) {

        // Step 2: Extract the two minimum
        // freq items from min heap
        left = extractMin(minHeap);
        right = extractMin(minHeap);

        // Step 3:  Create a new internal
        // node with frequency equal to the
        // sum of the two nodes frequencies.
        // Make the two extracted node as
        // left and right children of this new node.
        // Add this node to the min heap
        // '$' is a special value for internal nodes, not
        // used
        top = newNode('$', left->freq + right->freq);

        top->left = left;
        top->right = right;
    // Step 4: The remaining node is the
    // root node and the tree is complete.
    return extractMin(minHeap);
}

// Prints huffman codes from the root of Huffman Tree.
// It uses arr[] to store codes
void printCodes(struct MinHeapNode* root, int arr[],
                int top)

{

    // Assign 0 to left edge and recur
    if (root->left) {

        arr[top] = 0;
        printCodes(root->left, arr, top + 1);
    }

    // Assign 1 to right edge and recur
    if (root->right) {

        arr[top] = 1;
        printCodes(root->right, arr, top + 1);
    }

    // If this is a leaf node, then
    // it contains one of the input
    // characters, print the character
    // and its code from arr[]
    if (isLeaf(root)) {

        printf("%c: ", root->data);
        printArr(arr, top);
    }
}

// The main function that builds a
// Huffman Tree and print codes by traversing
// the built Huffman Tree
void HuffmanCodes(char data[], int freq[], int size)

{
    // Construct Huffman Tree
    struct MinHeapNode* root
        = buildHuffmanTree(data, freq, size);
    // the Huffman tree built above
    int arr[MAX_TREE_HT], top = 0;

    printCodes(root, arr, top);
}

// Driver code
int main()
{

    char arr[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
    int freq[] = { 5, 9, 12, 13, 16, 45 };

    int size = sizeof(arr) / sizeof(arr[0]);

    HuffmanCodes(arr, freq, size);

    return 0;
}
```

C++

```
// C++ program for Huffman Coding
#include <cstdlib>
#include <iostream>
using namespace std;

// This constant can be avoided by explicitly
// calculating height of Huffman Tree
#define MAX_TREE_HT 100

// A Huffman tree node
struct MinHeapNode {

    // One of the input characters
    char data;

    // Frequency of the character
    unsigned freq;

    // Left and right child of this node
    struct MinHeapNode *left, *right;
};

// A Min Heap: Collection of
```

```
    // Current size of min heap
    unsigned size;

    // capacity of min heap
    unsigned capacity;

    // Array of minheap node pointers
    struct MinHeapNode** array;
};

// A utility function allocate a new
// min heap node with given character
// and frequency of the character
struct MinHeapNode* newNode(char data, unsigned freq)
{
    struct MinHeapNode* temp = (struct MinHeapNode*)malloc(
        sizeof(struct MinHeapNode));

    temp->left = temp->right = NULL;
    temp->data = data;
    temp->freq = freq;

    return temp;
}

// A utility function to create
// a min heap of given capacity
struct MinHeap* createMinHeap(unsigned capacity)

{

    struct MinHeap* minHeap
        = (struct MinHeap*)malloc(sizeof(struct MinHeap));

    // current size is 0
    minHeap->size = 0;

    minHeap->capacity = capacity;

    minHeap->array = (struct MinHeapNode**)malloc(
        minHeap->capacity * sizeof(struct MinHeapNode*));
    return minHeap;
}

// A utility function to
// swap two min heap nodes
void swapMinHeapNode(struct MinHeapNode** a,
{

    struct MinHeapNode* t = *a;
    *a = *b;
    *b = t;
}

// The standard minHeapify function.
void minHeapify(struct MinHeap* minHeap, int idx)

{

    int smallest = idx;
    int left = 2 * idx + 1;
    int right = 2 * idx + 2;

    if (left < minHeap->size
        && minHeap->array[left]->freq
               < minHeap->array[smallest]->freq)
        smallest = left;

    if (right < minHeap->size
        && minHeap->array[right]->freq
               < minHeap->array[smallest]->freq)
        smallest = right;

    if (smallest != idx) {
        swapMinHeapNode(&minHeap->array[smallest],
                        &minHeap->array[idx]);
        minHeapify(minHeap, smallest);
    }
}

// A utility function to check
// if size of heap is 1 or not
int isSizeOne(struct MinHeap* minHeap)
{

    return (minHeap->size == 1);
}

// A standard function to extract
// minimum value node from heap
struct MinHeapNode* extractMin(struct MinHeap* minHeap)

{
    --minHeap->size;
    minHeapify(minHeap, 0);

    return temp;
}

// A utility function to insert
// a new node to Min Heap
void insertMinHeap(struct MinHeap* minHeap,
                   struct MinHeapNode* minHeapNode)

{

    ++minHeap->size;
    int i = minHeap->size - 1;

    while (i
           && minHeapNode->freq
                  < minHeap->array[(i - 1) / 2]->freq) {

        minHeap->array[i] = minHeap->array[(i - 1) / 2];
        i = (i - 1) / 2;
    }

    minHeap->array[i] = minHeapNode;
}

// A standard function to build min heap
void buildMinHeap(struct MinHeap* minHeap)

{

    int n = minHeap->size - 1;
    int i;

    for (i = (n - 1) / 2; i >= 0; --i)
        minHeapify(minHeap, i);
}

// A utility function to print an array of size n
void printArr(int arr[], int n)
{
    int i;
    for (i = 0; i < n; ++i)
        cout << arr[i];
```

```
// Utility function to check if this node is leaf
int isLeaf(struct MinHeapNode* root)

{

    return !(root->left) && !(root->right);
}

// Creates a min heap of capacity
// equal to size and inserts all character of
// data[] in min heap. Initially size of
// min heap is equal to capacity
struct MinHeap* createAndBuildMinHeap(char data[],
                                      int freq[], int size)

{

    struct MinHeap* minHeap = createMinHeap(size);

    for (int i = 0; i < size; ++i)
        minHeap->array[i] = newNode(data[i], freq[i]);

    minHeap->size = size;
    buildMinHeap(minHeap);

    return minHeap;
}

// The main function that builds Huffman tree
struct MinHeapNode* buildHuffmanTree(char data[],
                                     int freq[], int size)

{
    struct MinHeapNode *left, *right, *top;

    // Step 1: Create a min heap of capacity
    // equal to size. Initially, there are
    // modes equal to size.
    struct MinHeap* minHeap
        = createAndBuildMinHeap(data, freq, size);

    // Iterate while size of heap doesn't become 1
    while (!isSizeOne(minHeap)) {

        // Step 2: Extract the two minimum
        // freq items from min heap
        // Step 3: Create a new internal
        // node with frequency equal to the
        // sum of the two nodes frequencies.
        // Make the two extracted node as
        // left and right children of this new node.
        // Add this node to the min heap
        // '$' is a special value for internal nodes, not
        // used
        top = newNode('$', left->freq + right->freq);

        top->left = left;
        top->right = right;

        insertMinHeap(minHeap, top);
    }

    // Step 4: The remaining node is the
    // root node and the tree is complete.
    return extractMin(minHeap);
}

// Prints huffman codes from the root of Huffman Tree.
// It uses arr[] to store codes
void printCodes(struct MinHeapNode* root, int arr[],
                int top)

{

    // Assign 0 to left edge and recur
    if (root->left) {

        arr[top] = 0;
        printCodes(root->left, arr, top + 1);
    }

    // Assign 1 to right edge and recur
    if (root->right) {

        arr[top] = 1;
        printCodes(root->right, arr, top + 1);
    }

    // If this is a leaf node, then
    // it contains one of the input
    // characters, print the character
    // and its code from arr[]
```

```
        cout << root->data << ": ";
        printArr(arr, top);
    }
}

// The main function that builds a
// Huffman Tree and print codes by traversing
// the built Huffman Tree
void HuffmanCodes(char data[], int freq[], int size)

{
    // Construct Huffman Tree
    struct MinHeapNode* root
        = buildHuffmanTree(data, freq, size);

    // Print Huffman codes using
    // the Huffman tree built above
    int arr[MAX_TREE_HT], top = 0;

    printCodes(root, arr, top);
}

// Driver code
int main()
{

    char arr[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
    int freq[] = { 5, 9, 12, 13, 16, 45 };

    int size = sizeof(arr) / sizeof(arr[0]);

    HuffmanCodes(arr, freq, size);

    return 0;
}
```

C++

```
// C++(STL) program for Huffman Coding with STL
#include <bits/stdc++.h>
using namespace std;

// A Huffman tree node
struct MinHeapNode {
    // Frequency of the character
    unsigned freq;

    // Left and right child
    MinHeapNode *left, *right;

    MinHeapNode(char data, unsigned freq)

    {

        left = right = NULL;
        this->data = data;
        this->freq = freq;
    }
};

// For comparison of
// two heap nodes (needed in min heap)
struct compare {

    bool operator()(MinHeapNode* l, MinHeapNode* r)

    {
        return (l->freq > r->freq);
    }
};

// Prints huffman codes from
// the root of Huffman Tree.
void printCodes(struct MinHeapNode* root, string str)
{

    if (!root)
        return;

    if (root->data != '$')
        cout << root->data << ": " << str << "\n";

    printCodes(root->left, str + "0");
    printCodes(root->right, str + "1");
}

// The main function that builds a Huffman Tree and
// print codes by traversing the built Huffman Tree
void HuffmanCodes(char data[], int freq[], int size)
{
    struct MinHeapNode *left, *right, *top;
    priority_queue<MinHeapNode*, vector<MinHeapNode*>,
                   compare>
        minHeap;

    for (int i = 0; i < size; ++i)
        minHeap.push(new MinHeapNode(data[i], freq[i]));

    // Iterate while size of heap doesn't become 1
    while (minHeap.size() != 1) {

        // Extract the two minimum
        // freq items from min heap
        left = minHeap.top();
        minHeap.pop();

        right = minHeap.top();
        minHeap.pop();

        // Create a new internal node with
        // frequency equal to the sum of the
        // two nodes frequencies. Make the
        // two extracted node as left and right children
        // of this new node. Add this node
        // to the min heap '$' is a special value
        // for internal nodes, not used
        top = new MinHeapNode('$',
                              left->freq + right->freq);

        top->left = left;
        top->right = right;

        minHeap.push(top);
    }

    // Print Huffman codes using
    // the Huffman tree built above
    printCodes(minHeap.top(), "");
}

// Driver Code
int main()
{

    char arr[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
    int freq[] = { 5, 9, 12, 13, 16, 45 };

    int size = sizeof(arr) / sizeof(arr[0]);
```

```
        return 0;
    }

    // This code is contributed by Aditya Goel
```

Java

```
import java.util.Comparator;
import java.util.PriorityQueue;
import java.util.Scanner;

class Huffman {

    // recursive function to print the
    // huffman-code through the tree traversal.
    // Here s is the huffman - code generated.
    public static void printCode(HuffmanNode root, String s)
    {

        // base case; if the left and right are null
        // then its a leaf node and we print
        // the code s generated by traversing the tree.
        if (root.left == null && root.right == null
            && Character.isLetter(root.c)) {

            // c is the character in the node
            System.out.println(root.c + ":" + s);

            return;
        }

        // if we go to left then add "0" to the code.
        // if we go to the right add"1" to the code.

        // recursive calls for left and
        // right sub-tree of the generated tree.
        printCode(root.left, s + "0");
        printCode(root.right, s + "1");
    }

    // main function
    public static void main(String[] args)
    {
        int n = 6;
        char[] charArray = { 'a', 'b', 'c', 'd', 'e', 'f' };
        int[] charfreq = { 5, 9, 12, 13, 16, 45 };

        // creating a priority queue q.
        // makes a min-priority queue(min-heap).
        PriorityQueue<HuffmanNode> q
            = new PriorityQueue<HuffmanNode>(
                n, new MyComparator());

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

            // creating a Huffman node object
            // and add it to the priority queue.
            HuffmanNode hn = new HuffmanNode();

            hn.c = charArray[i];
            hn.data = charfreq[i];

            hn.left = null;
            hn.right = null;

            // add functions adds
            // the huffman node to the queue.
            q.add(hn);
        }

        // create a root node
        HuffmanNode root = null;

        // Here we will extract the two minimum value
        // from the heap each time until
        // its size reduces to 1, extract until
        // all the nodes are extracted.
        while (q.size() > 1) {

            // first min extract.
            HuffmanNode x = q.peek();
            q.poll();

            // second min extract.
            HuffmanNode y = q.peek();
            q.poll();

            // new node f which is equal
            HuffmanNode f = new HuffmanNode();
            f.data = x.data + y.data;
            f.c = '-';

            // first extracted node as left child.
            f.left = x;

            // second extracted node as the right child.
            f.right = y;

            // marking the f node as the root node.
            root = f;

            // add this node to the priority-queue.
            q.add(f);
        }

        // print the codes by traversing the tree
        printCode(root, "");
    }
}

// node class is the basic structure
// of each node present in the Huffman - tree.
class HuffmanNode {

    int data;
    char c;

    HuffmanNode left;
    HuffmanNode right;
}

// comparator class helps to compare the node
// on the basis of one of its attribute.
// Here we will be compared
// on the basis of data values of the nodes.
class MyComparator implements Comparator<HuffmanNode> {
    public int compare(HuffmanNode x, HuffmanNode y)
    {

        return x.data - y.data;
    }
}

// This code is contributed by Kunwar Desh Deepak Singh
```

```
# A Huffman Tree Node
import heapq


class node:
    def __init__(self, freq, symbol, left=None, right=None):
        # frequency of symbol
        self.freq = freq

        # symbol name (character)
        self.symbol = symbol

        # node left of current node
        self.left = left

        # node right of current node
        self.right = right

        # tree direction (0/1)
        self.huff = ''

    def __lt__(self, nxt):
        return self.freq < nxt.freq


# utility function to print huffman
# codes for all symbols in the newly
# created Huffman tree
def printNodes(node, val=''):

    # huffman code for current node
    newVal = val + str(node.huff)

    # if node is not an edge node
    # then traverse inside it
    if(node.left):
        printNodes(node.left, newVal)
    if(node.right):
        printNodes(node.right, newVal)

        # if node is edge node then
        # display its huffman code
    if(not node.left and not node.right):
        print(f"{node.symbol} -> {newVal}")
```

```
# frequency of characters
freq = [5, 9, 12, 13, 16, 45]

# list containing unused nodes
nodes = []

# converting characters and frequencies
# into huffman tree nodes
for x in range(len(chars)):
    heapq.heappush(nodes, node(freq[x], chars[x]))

while len(nodes) > 1:

    # sort all the nodes in ascending order
    # based on their frequency
    left = heapq.heappop(nodes)
    right = heapq.heappop(nodes)

    # assign directional value to these nodes
    left.huff = 0
    right.huff = 1

    # combine the 2 smallest nodes to create
    # new node as their parent
    newNode = node(left.freq+right.freq, left.symbol+right.symbol, left, right)

    heapq.heappush(nodes, newNode)

# Huffman Tree is ready!
printNodes(nodes[0])
```

Javascript

```
// node class is the basic structure
// of each node present in the Huffman - tree.
class HuffmanNode
{
    constructor()
    {
        this.data = 0;
        this.c = '';
        this.left = this.right = null;
// recursive function to print the
    // huffman-code through the tree traversal.
    // Here s is the huffman - code generated.
    function printCode(root,s)
    {
        // base case; if the left and right are null
        // then its a leaf node and we print
        // the code s generated by traversing the tree.
        if (root.left == null
            && root.right == null
            && (root.c).toLowerCase() != (root.c).toUpperCase()) {

            // c is the character in the node
            document.write(root.c + ":" + s+"<br>");

            return;
        }

        // if we go to left then add "0" to the code.
        // if we go to the right add"1" to the code.

        // recursive calls for left and
        // right sub-tree of the generated tree.
        printCode(root.left, s + "0");
        printCode(root.right, s + "1");
    }

 // main function
// number of characters.
        let n = 6;
        let charArray = [ 'a', 'b', 'c', 'd', 'e', 'f' ];
        let charfreq = [ 5, 9, 12, 13, 16, 45 ];

        // creating a priority queue q.
        // makes a min-priority queue(min-heap).
        let q = [];

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

            // creating a Huffman node object
            // and add it to the priority queue.
            let hn = new HuffmanNode();

            hn.c = charArray[i];
            hn.data = charfreq[i];

            hn.left = null;
            // add functions adds
            // the huffman node to the queue.
            q.push(hn);
        }

        // create a root node
        let root = null;
          q.sort(function(a,b){return a.data-b.data;});

        // Here we will extract the two minimum value
        // from the heap each time until
        // its size reduces to 1, extract until
        // all the nodes are extracted.
        while (q.length > 1) {

            // first min extract.
            let x = q[0];
            q.shift();

            // second min extract.
            let y = q[0];
            q.shift();

            // new node f which is equal
            let f = new HuffmanNode();

            // to the sum of the frequency of the two nodes
            // assigning values to the f node.
            f.data = x.data + y.data;
            f.c = '-';

            // first extracted node as left child.
            f.left = x;

            // second extracted node as the right child.
            f.right = y;

            // marking the f node as the root node.
            root = f;

            // add this node to the priority-queue.
            q.push(f);
            q.sort(function(a,b){return a.data-b.data;});
        }

        // print the codes by traversing the tree
        printCode(root, "");
```

C#

```
// C# program for the above approach

using System;
using System.Collections.Generic;

// A Huffman tree node
public class MinHeapNode
{
    // One of the input characters
    public char data;

    // Frequency of the character
    public uint freq;

    // Left and right child
    public MinHeapNode left, right;

    public MinHeapNode(char data, uint freq)
    {
        left = right = null;
        this.data = data;
        this.freq = freq;
    }
}

// For comparison of two heap nodes (needed in min heap)
public class CompareMinHeapNode : IComparer<MinHeapNode>
{
    public int Compare(MinHeapNode x, MinHeapNode y)
    {
        return x.freq.CompareTo(y.freq);
    }
}

class Program
{
    // Prints huffman codes from the root of Huffman Tree.
    static void printCodes(MinHeapNode root, string str)
    {
        if (root == null)
            return;

        if (root.data != '$')
```

```
            printCodes(root.right, str + "1");
        }

        // The main function that builds a Huffman Tree and
        // print codes by traversing the built Huffman Tree
        static void HuffmanCodes(char[] data, uint[] freq, int size)
        {
            MinHeapNode left, right, top;

            // Create a min heap & inserts all characters of data[]
            var minHeap = new SortedSet<MinHeapNode>(new CompareMinHeapNode());

            for (int i = 0; i < size; ++i)
                minHeap.Add(new MinHeapNode(data[i], freq[i]));

            // Iterate while size of heap doesn't become 1
            while (minHeap.Count != 1)
            {
                // Extract the two minimum freq items from min heap
                left = minHeap.Min;
                minHeap.Remove(left);

                right = minHeap.Min;
                minHeap.Remove(right);

                // Create a new internal node with frequency equal to the sum of the t
                // Make the two extracted node as left and right children of this new
                // Add this node to the min heap '$' is a special value for internal r
                top = new MinHeapNode('$', left.freq + right.freq);

                top.left = left;
                top.right = right;

                minHeap.Add(top);
            }

            // Print Huffman codes using the Huffman tree built above
            printCodes(minHeap.Min, "");
        }

        // Driver Code
        static void Main()
        {
            char[] arr = { 'a', 'b', 'c', 'd', 'e', 'f' };
            uint[] freq = { 5, 9, 12, 13, 16, 45 };

            int size = arr.Length;
```

```
    }
}

// This code is contributed by sdeadityasharma
```

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Output

```
f: 0
c: 100
d: 101
a: 1100
b: 1101
e: 111
```

Time complexity: O(nlogn) where n is the number of unique characters. If there are n nodes, extractMin() is called 2*(n – 1) times. extractMin() takes O(logn) time as it calls minHeapify(). So, the overall complexity is O(nlogn).
If the input array is sorted, there exists a linear time algorithm. We will soon be discussing this in our next post.

Space complexity :- O(N)

Applications of Huffman Coding:

1. They are used for transmitting fax and text.
2. They are used by conventional compression formats like PKZIP, GZIP, etc.
3. Multimedia codecs like JPEG, PNG, and MP3 use Huffman encoding(to be more precise the prefix codes).

It is useful in cases where there is a series of frequently occurring characters.

Reference:
http://en.wikipedia.org/wiki/Huffman_coding
This article is compiled by Aashish Barnwal and reviewed by GeeksforGeeks team. Please write comments if you find anything incorrect, or you want to share more information about the topic discussed above.

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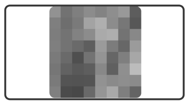
-  Image Compression using Huffman Coding
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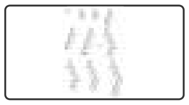
-  Adaptive Huffman Coding And Decoding
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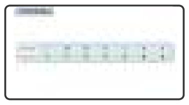
-  Text File Compression And Decompression Using Huffman Coding
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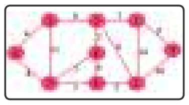
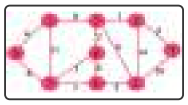
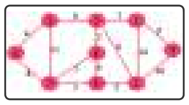
-  Dijkstra’s Algorithm for Adjacency List Representation | Greedy…
-  Boruvka's algorithm | Greedy Algo-9
-  Prim’s MST for Adjacency List Representation | Greedy Algo-6

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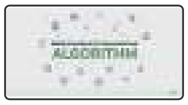
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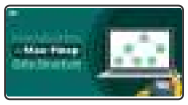
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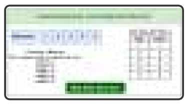
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